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Reputation-Based Winner Determination Problem in Centralized Combinatorial Auctions for the Procurement of Transportation Services

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ABSTRACT

This paper considers a centralized procurement auction in which shippers simultaneously submit their transportation requests to a set of carriers. The latter compete by submitting combinatorial bids on shippers' requests. Winning bids are determined based not only on ask prices, but also on carriers' reputation that may differ from one shipper to another. Three approaches are proposed to solve the problem. Our results show that considering carriers' reputation in centralized auctions leads to considerable savings in total costs. Also, choosing the appropriate approach closely depends on the shippers' past experience with the participating carriers, their weight in the auction and their perception of centralization.

Keywords: Winner determination problem, truckload transportation services, centralized procurement, combinatorial auctions, carriers' reputation.

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1. Introduction

Traditionally, a shipper that decides to outsource all or a part of its transport operations runs its own procurement auction and invites a set of preselected carriers to participate into it. These auctions are one-sided meaning that they involve a single shipper (or its representative) which acts as the auctioneer and several carriers which are the only bidders. Given the synergy characterizing transportation operations, it is now well established that combinatorial auctions are very efficient for Full TruckLoad (FTL) transportation services procurement (Caplice and Sheffi, 2006). Combinatorial bidding enables a carrier to express its interest for a combination of contracts. After receiving all carriers' bids, the auctioneer determines winning bids by solving the so-called Winner Determination Problem (WDP). The objective of a WDP is generally to minimize the shipper's total transportation costs.

Recently, Ben Othmane et al. (2019a) studied the impacts of what they call centralized auctions on carriers. A centralized auction is defined as a combinatorial auction in which several shippers simultaneously present their transportation requests to a set of participating carriers. The latter submit package bids that may cover contracts belonging to different shippers. Then, a unique centralized WDP is solved for all the shippers at the same time where the objective is to minimize the total ask-prices of the winning bids. Ben Othmane et al. (2019a) reported that centralized auctions enable carriers to increase their potential profits when compared to decentralized mechanisms where each shipper runs its own auction separately.

In Ben Othmane et al. (2019a), the focus was on carriers' benefits. The authors implicitly assumed that shippers' contracts present a high level of synergy so that interesting bids with relatively low ask-prices are submitted. Consequently, centralization is expected to yield monetary savings in bid ask prices for the shippers globally. However, several studies showed the importance of considering attributes other than the price when determining winning carriers. These attributes are related to the quality of services offered by carriers during operations (e.g., on-time delivery). Rekik and Mellouli (2012) reported that considerable additional costs may be incurred by the shipper during operations due to unreliable carriers in case only price attributes are considered in the WDP. Their paper addresses a decentralized combinatorial procurement auction run by a single shipper.

Our paper extends the work of Rekik and Mellouli (2012) to handle both centralized procurement auctions and reputation-based WDP. Unlike decentralized mechanisms, a centralized auction offers each carrier the possibility to put in the same package bid contracts belonging to different shippers. This may result in interesting bid prices for the shippers globally but at the expense of the services quality delivered, as individually perceived by each shipper. Indeed, a carrier 's reputation is likely to be evaluated differently by shippers depending on their own experience with the carrier. To the best of our knowledge, our paper is the first to address a WDP in a centralized procurement auction taking into account carriers' reputation.

We propose three approaches to model the problem. They differ with regard to the weight attributed to each shipper's valuation of carriers' reputation. A centralized auction is then simulated in different contexts to measure the impact of centralization on total costs and services quality. Our results prove that for all the proposed approaches, shippers always gain, in total, by considering carriers' reputation when determining winning bids. Our results also show that choosing the appropriate approach to model a reputation-based WDP in a centralized auction closely depends on the shippers' past experience, their weight in the auction and their perception of centralization.

The remainder of the paper is organized as follows. Next section is a literature review on WDPs and carriers' reputation in FTL transportation procurement auctions. Section 3 formally defines the problem addressed and describes the three approaches proposed to solve it. Section 4 is our experimental study. Section 5 concludes the paper and opens on future research avenues.

2. Literature review

Different approaches have been proposed in the literature to tackle the WDP in combinatorial auctions for the procurement of FTL transportation services.

Caplice and Sheffi (2003) presented two models for the WDP. The first model takes into account transported volumes and the second model incorporate the so-called conditional bids. Guo et al. (2006) considered a WDP where a number of shipper's business considerations had to be respected (restrictions on the number of carriers, favouring incumbents carriers, etc.).
In the same context, van Norden et al. (2006) reported that although the objective of WDP is to minimize the total transportation cost, the shipper may consider additional constraints such as limiting the total number of winning carriers, the number of winning carriers per load location or per country of destination, etc.
Chen et al. (2009) developed an implicit approach for truckload procurement auctions in which the solution of the bid-generating problem is integrated in the WDP. Their results show that their implicit WDP is more tractable than a standard WDP.
Ma et al. (2010) considered uncertainty on shipment volumes when solving the WDP. They consider a two-stage stochastic programming approach with recourse to solve it. Remli and Rekik (2013) addressed the same problem as in Ma et al. (2010). They modeled the WDP with a two-stage robust formulation and solved it using a constraint generation algorithm. Recently, Remli et al. (2019) extended the two-stage robust formulation of Remli and Rekik

(2013) to deal with uncertainty on both shippers demands and a carriers' capacity.

Most of the studies dealing with the WDP focused on minimizing the total procurement cost. However, a number of papers addressing carriers' selection (not necessarily using auction mechanisms) reported the importance of considering attributes other than the price to select carriers. Danielis et al. (2005), for example, identified four transportation attributes that are important for shippers to commit with a carrier: transportation cost, travel times, risk of delay, and risk of loss and damage.

Sheffi (2004) proposed to integrate services quality attributes in the WDP by adding penalties and rewards to bids ask prices. Buer and Pankratz (2010a) and Buer and Pankratz (2010b) modelled the WDP as a bi-objective optimization problem. The first objective minimizes the total cost and the second objective maximizes the service quality. Rekik and Mellouli (2012) proposed to translate carriers' reputation into unexpected hidden costs. The latter represent the possible additional costs that the shipper may incur if some problems such as delays, damages, or cancellations occur.

Our literature review shows that little works have been conducted to deal with the reputations of carriers in transportation procurement auctions. Moreover, all the published papers on WDPs only considered decentralized auctions run by single shippers separately. To the best of our knowledge, our paper is the first to integrate carriers' reputation to solve the WDP in centralized auctions for the procurement of FTL transportation services.

3. Problem definition and formulation

3.1. Auction context

We consider a transportation market where a number of shippers centralize their transportation requests in a unique single-round first-price one-sided reverse combinatorial auction. One-sided reverse auctions include a buyer which acts as the auctioneer, and multiple sellers which are the only bidders. In our case, the auctioneer is an entity, a third-party-logistics provider (3PL) for example, that acts as shippers' representative and bidders are the carriers. First-price auctions imply that if a carrier's bid is won, then the carrier must be allocated a price equal to the price asked in its winning bid. It is also assumed that transportation requests are on Full Truckload (FTL) operations. For FTL operations, shipments must be driven directly from pick-up to delivery locations without any intermediate stop.

In the following, we denote by $K(s)$ the set of contracts requested by a shipper s and by K the set of all contracts to be auctioned ($K = \cup_s K(s)$). Each contract $k \in K$ is defined by a pick-up location, a delivery location, a number of shipments, and an estimated volume that is assumed the same for all the shipments of contract k. Each carrier a is assumed to submit a set of combinatorial bids $B(a)$. A bid $b \in B(a)$ is defined by a pair $(K(b); BP_b)$, where $K(b)$ denotes the set of contracts carrier a offers to serve in bid b and BP_b is the price asked for serving all these contracts. As already mentioned, the set of contracts $K(b)$ covered by a bid b may include contracts belonging to different shippers. We denote by $K(s, b)$ the set of contracts in $K(b)$ belonging to a shipper s.

3.2. Reputation modeling

Our paper addresses a reputation-based WDP for centralized auctions where the objective is to minimize the total cost to be paid by the shippers while taking into account the carriers' reputation. As in Rekik and Mellouli (2012), a carrier's reputation is modeled by what the authors call "hidden costs". Hidden costs represent the potential cost that must be possibly paid by the shipper if the quality of services offered by the winning carriers during operations is not as agreed. As in Rekik and Mellouli (2012), we consider a set of service attributes, denoted by Ω, to evaluate carriers' reputation. An attribute could be for example the delay in shipments delivery.

Rekik and Mellouli (2012) consider a decentralized combinatorial auction where the auctioneer is a single shipper. To determine the hidden costs, the authors define a unit cost for each attribute $\omega \in \Omega$ and each auctioned contract k, they denoted by $C_{k,\omega}$. Then, for each carrier a, they propose to compute the value of the attribute $\omega \in \Omega$, they denoted by $\Gamma_{a,\omega}$, based on the shipper's past experience with a. Afterwards, if carrier a wins a contract k (a contract that is covered by its winning bid), then the hidden cost that could be paid by the shipper, denoted by $HC_{a,k}$, is computed as:

$$HC_{a,k} = \sum_{\omega \in \Omega} C_{k,\omega} \Gamma_{a,\omega}.$$

Similarly, if carrier a wins a bid $b = (K(b); BP_b)$, then the hidden cost that could be paid by the shipper if bid b wins is:

$$HC_{a,b} = \sum_{k \in K(b)} HC_{a,k}.$$

We propose to model a carrier's reputation for centralized auctions by using the same concepts of hidden costs and service quality attributes. However, as already mentioned, a centralized auction includes multiple shippers which may have different valuations of the participating carriers' reputation. For example, a carrier a that has good service attributes values for a shipper s_1 based on shipper s_1 historical data may have a very bad reputation for another shipper s_2. How to model then the hidden cost associated with a bid b of carrier a if b covers at the same time contracts from s_1 and s_2?

We propose three approaches to answer this question. These approaches differ by the way a carrier's reputation is computed with regard to the shippers' individual valuations of each bid. We first summarize the notation that will be used throughout the paper. Section 3.3 formally describes the three proposed approaches.

S	set of shippers
A	set of carriers
K	set of auctioned contracts
B	set of bids submitted by carriers
B^v	set of fictive bids to ensure WDP feasibility
R_k	the reserve price of contract k
Ω	set of service quality attributes
$K(s)$	set of contracts requested by shipper s
$B(a)$	set of bids submitted by carrier a
BP_b	ask-pice of bid b
$K(b)$	set of contracts covered by bid b
$K(s,b)$	set of contracts of shipper s covered by bid b
$S(b)$	set of shippers having a contract covered by bid b
$C_{k,\omega}$	unit cost for attribute ω and contract $k \in K(s), s \in S$
$\Gamma_{a,\omega,s}$	value of attribute ω for carrier a and shipper s
$HC_{a,k,s}$	hidden cost associated with carrier a, contract k and shipper s
$HC_{a,b,s}$	hidden cost associated with carrier a, bid b and shipper s
$PE(s,a)$	number of shipments assigned in the past by shipper s to carrier a

As in Rekik and Mellouli (2012), the hidden cost associated with a bid b of a carrier a as evaluated by shipper s is computed as:

$$HC_{a,b,s} = \sum_{k \in K(s,b)} HC_{a,k,s}, \tag{1}$$

where $HC_{a,k,s} = \sum_{\omega \in \Omega} C_{k,\omega} \Gamma_{a,\omega,s}$.
$HC_{a,b,s}$ translates the reputation of carrier a with respect to its bids b as perceived by shipper s based on its own knowledge of carrier a.

3.3. Reputation-based WDP

The reputation-based WDP is formulated with an integer programming model in which a binary variables x_b is defined for each bid $b \in B$. Variable

$x_b = 1$ if bid b is won and $x_b = 0$; otherwise. A binary constant parameter $\delta_{k,b}$ is also defined for each bid $b \in B$ and each contract $k \in K$ to indicate whether contract k is covered by bid b or not. That is, $\delta_{k,b} = 1$ if and only if $k \in K(b)$.

The objective function minimizes a total direct cost and a weighted sum of shippers' individual hidden costs. The direct cost is the total cost to be paid by all shippers to winning carriers based on their bid ask price. It is formulated as:

$$\sum_{a \in A} \sum_{b \in B(a)} BP_b x_b. \tag{2}$$

The hidden cost quantitatively translates the winning carriers' reputations. It is formulated as:

$$\sum_{a \in A} \sum_{b \in B(a)} \sum_{s \in S_(b)} w_{s,b} HC_{a,b,s} x_b, \tag{3}$$

where $w_{s,b}$ is a parameter defined for each shipper s and each bid b. Parameter $w_{s,b}, s \in S, b \in B$ represents the weight assigned to a shipper s valuation of a carrier's reputation based on its own experience. The three proposed approaches differ by the method used to compute parameters $w_{s,b}, s \in S, b \in B$.

The first approach, refereed to in the following as the G-based approach, gives a larger weight to the shippers having globally more contracts in the auction relatively to the shippers that have contracts covered by the same bid. Formally,

$$w_{s,b} = w^G_{s,b} = \frac{|K(s)|}{\sum_{s \in S(b)} |K(s)|}, \quad \forall b \in B, s \in S(b)$$

The second approach, called the L-based approach, gives a larger weight to the shippers having more contracts locally in the bid. Formally, :

$$w_{s,b} = w^L_{s,b} = \frac{|K(s,b)|}{|K(b)|}, \quad \forall b \in B, s \in S(b)$$

Finally, the third approach, referred to as the H-based approach, assigns larger weights to the shippers that have more pas commitments (history) with the carrier. Formally,

$$w_{s,b} = w^H_{s,b} = \frac{PE(s,a)}{\sum_{s \in S(b)} PE(s,a)}. \quad \forall b \in B, s \in S(b)$$

Recall that $PE(s,a)$ represents the number of shipments shipper s has considered to evaluate the carrier a reputation. This may correspond to the number of shipments allocated in the past to carrier a and for which the different attributes values were available.

The generic reputation-based WDP in centralized auctions is then formulated as:

$$\min \quad \sum_{a \in A} \sum_{b \in B(a)} BP_b x_b + \sum_{a \in A} \sum_{b \in B(a)} \sum_{s \in S_(b)} w_{s,b} HC_{a,b,s} x_b, \tag{4}$$

subject to

$$\sum_{a \in A} \sum_{b \in B(a)} \delta_{kb} \geq 1, \quad \forall k \in K, \tag{5}$$

$$x_b \in \{0,1\}, \quad \forall b \in B. \tag{6}$$

Objective function (4) minimizes the total direct cost and a weighted sum of hidden costs. Constraints (5) ensure that each contract is served at least once. Constraints (6) are binary constraints on x variables.

Observe that model (4)-(6) may be infeasible in case there is no submitted bids that cover some contract $k \in K$. To circumvent this, and as suggested in Rekik and Mellouli (2012), we propose to add $|K|$ simple bids, one bid for each contract $k \in K$. Thees bids are not really submitted by carriers. They are added to the set of bids to ensure model feasibility. The set of fictive bids is denoted by B^v. A bid $b \in B^v$ covers only one contract k. Its ask price is equal to the maximum price that is accepted to be paid by the shipper requesting k, also known as the contract reserve price R_k (refer to Rekik and Mellouli (2012) for more details). Formally, $B^v = \{(\{k\}, R_k), k \in K\}$. Hence, replacing set B by set $B \cup B^v$ in (4)-(6) ensures the feasibility of the WDP. Observe that the hidden costs associated with bids in B^v are assumed null since they are not associated with any carrier.

4. Experimental study

Our experimental study analyses the merits/drawbacks of centralized auctions on shippers. We consider a competitive context assuming thus that the shippers' main goal through participating into the same auction is to realize gains in bid ask prices. Hence, the problem tests are generated so that the shippers total cost to be paid to winning carriers decreases when a centralized mechanism is used compared to a decentralized one. The main objective of our experimental study is to measure the impact of centralization on the quality of the services offered to shippers, based on their proper valuation of the carriers' reputations. In other words, is a gain in the total price to be paid by shippers yielded by centralization comes at the expense of the quality of services offered to them?

Since no real-life instances were available, we present in Section 4.1 our instances' generator. Section 4.2 evaluates the impact of considering carriers' reputations on shippers' total cost for the G-based, L-based and H-based approaches. To this end, we compare for each approach two scenarios: a scenario where only bid ask prices are considered to determine the winners and a scenario where winners are determined based on our proposed approaches. Section 4.3 compares the performance of the G-based, L-based and H-based approaches in terms of losses and cost savings. Finally, Section 4.4 measures, for each approach, the impacts of centralization on the quality of services offered to each shipper individually.

4.1. Auction simulation

4.1.1. Problem tests

All the instances consider a centralized auction including two shippers s_1 and s_2, 10 carriers $a_1, \ldots, a_{10}$ ($|A| = 10$) and 1000 auctioned contracts ($|K| = 1000$). Instances are generated so that shippers s_1 and s_2 globally realize gains in direct costs when participating into the same centralized auction. In other words, if s_1 and s_2 have organized their auctions separately with the same set of carriers, the total price they would have paid to the winning carriers is larger than the total price they pay in a single centralized auction.

A total of 60 instances are considered. These instances are grouped into six instances sets as described in Table 1. An instance set is defined by an auction context and a shipper's profile. Three auction contexts are generated depending on how the 1000 auctioned contracts are dispatched among s_1 and s_2. Each context is represented by a pair $(|K(s_1)|, |K(s_2)|)$ in Table 1. For example, in the first context, $|K(s_1)| = 900$ and $|K(s_2)| = 100$ implying that shipper s_1 detains 90% of the contracts put in the auction. 10 instances are randomly generated for each context by varying contracts' origins and destinations among cities in Canada. Two shippers' profiles are considered depending on the volume of shipments that shippers s_1 and s_2 have committed in the past with the participating carriers. A profile is represented by a pair of intervals (I_1, I_2) where $I_i, i = 1, 2$ represents the interval within which the value of $PE(s_i, a)$ ranges for carrier a. For example, a profile $([100, 200], [1000, 1200])$ represents the case where shipper s_1 has less past commitments with the participating carriers than shipper s_2. Observe that varying the shippers profile is relevant and would yield different results only when the H-based approach is considered. For the G-based and L-based approaches, the results obtained for instances in sets 1, 2 and 3, respectively, are exactly the same as that obtained for instances in set 4, 5 and 6, respectively. This is because these approaches do not consider the $PE(s_1, a)$ and $PE(s_2, a)$ parameters when modeling the hidden costs in the objective function (4).

Instances set	Auction context $(\|K(s_1)\|, \|K(s_2)\|)$	Shippers' profile (I_1, I_2)
1	(900,100)	([100,200],[1000,1200])
2	(700,300)	([100,200],[1000,1200])
3	(500,500)	([100,200],[1000,1200])
4	(900,100)	([1000,1200], [100,200])
5	(700,300)	([1000,1200], [100,200])
6	(500,500)	([1000,1200], [100,200])

Table 1: Description of the instances sets

To simulate the centralized auction, a bid construction problem is solved for each carrier $a_1, \ldots, a_{10}$ using the heuristic algorithm proposed in Ben Othmane et al. (2019b). To this end, each carrier $a_i, i = 1, \ldots, 10$ is assumed to have an exiting transportation network with a pre-specified set of exiting contracts. Bids on new auctioned contracts are generated by each carrier to maximize its total profit while satisfying a number of operational constraints. We refer the reader to Ben Othmane et al. (2019b) for more details.

Contracts' reserve prices are generated based on the spot prices information provided by the web site **http://www.uship.com/shipping-calculator.aspx** in which we consider vehicles with a capacity of 40000 £.

4.1.2. Carriers' reputation

As in Rekik and Mellouli (2012), three attributes, reported in the literature as the most important for shippers, are considered to evaluate the reputation of each carrier: the delay, the damage, and the cancel attributes. The delay attribute, denoted by ω_1, represents the average delay (in days) per shipment recorded for the carrier. It is randomly generated for each shipper and each carrier within the interval $[0, 3.5]$. The damage attribute, denoted by ω_2, is generated for each shipper and each carrier within the interval $[0, 9\%]$ and represents the percentage of shipments with damages recorded for the carrier. Finally, the cancel attribute, denoted by ω_3, is generated within $[0, 10\%]$ for each shipper and each carrier and represents the percentage of canceled shipments recorded for the carrier.

As in Rekik and Mellouli (2012), the unit cost associated with each of these attributes for a contract k is computed based on contract k reserve price R_k. Formally,

$$\begin{aligned} C_{k,\omega_1} &= \gamma_1 R_k, \\ C_{k,\omega_2} &= \gamma_2 R_k, \\ C_{k,\omega_3} &= (1-\gamma_3) R_k, \end{aligned}$$

where γ_1, respectively, γ_2 and γ_3, are randomly generated within the interval $[0.3, 0.5]$, respectively, $[2, 2.5]$ and $[0.8, 0.9]$.

The mathematical models are coded in C++ and solved using the branch-and-cut of CPLEX 12.9.0. The instances are solved on an IBM server with 2 processors Xeon E5450 and 32 GO RAM.

4.2. Impact of reputation on total transportation costs

The objective of this section is to evaluate the impact of considering carriers' reputations on shippers' different cost by comparing the results obtained for two scenarios. In the first scenario, winning bids are determined based only on the direct cost. To do so, we solve a standard centralized WDP without considering carriers' reputations. That is, a model similar to (4)-(6) but in which the objective function (4) includes only the total ask-price as formulated in (2). In the second scenario, winning bids are determined taking into account both ask-prices and carriers' reputations. This is done by solving the reputation-based model (4)-(6).

For each scenario, once the winning bids are determined, the total hidden costs are estimated afterwards based on the shippers' own valuations (computed as in (1)). The total cost is then computed as the sum of the direct and hidden costs.

Table 2 reports the minimum, maximum and average relative gain/loss in direct (DC), hidden (HC) and total costs (TC) obtained with the second scenario compared to the first one. Results are presented for the G-based, L-based and H-based approaches. Minimum, maximum and average values are computed over the 10 instances of each instances set.

Instances set	G-based approach								
	Increase in DC (%)			Saving in *HC* (%)			Saving in TC (%)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
1	0.90	1.17	1.34	41.45	54.89	62.66	4.14	6.03	7.38
2	1.90	2.11	2.73	59.80	67.24	78.26	7.62	10.27	15.41
3	1.98	2.46	2.96	69.87	71.91	75.09	10.19	11.84	12.65
Instances set	L-based approach								
	Increase in DC (%)			Saving in *HC* (%)			Saving in TC (%)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
1	0.92	1.46	2.55	58.93	63.83	68.51	5.92	6.91	7.95
2	1.91	2.28	3.04	62.21	70.07	78.27	8.02	10.59	15.35
3	1.85	2.30	2.80	67.74	69.92	73.27	10.13	11.58	12.43
Instances set	H-based approach								
	Increase in DC (%)			Saving in *HC* (%)			Saving in TC (%)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
1	0.97	1.43	2.32	51.91	57.37	62.43	5.07	6.13	7.51
2	1.72	2.18	3.00	45.25	56.18	73.04	5.54	8.26	14.28
3	1.70	2.42	2.99	50.61	58.00	63.30	7.91	9.22	11.05
4	0.90	1.24	1.79	43.27	56.26	62.66	4.34	6.14	7.38
5	1.63	1.93	2.21	44.36	58.73	75.12	5.43	8.94	14.79
6	1.45	2.05	2.67	51.20	58.65	64.63	8.21	9.58	10.40

Table 2: Impact of considering carriers' reputation on direct, hidden and total costs

The results of Table 2 show that considering carriers reputation when determining the winning bids in centralized auctions always yielded important savings in total transportation costs for the three proposed approaches. This saving varies between 4.14% and 12.65% with an average of 9.38% for the G-based approach. It varies between 5.92% and 15.35% with an average of 9.70% for the L-based approach and between 5.07% and 14.28% with an average of 8.05% for the H-based approach.

Savings in total costs are explained by the important savings in total hidden costs that largely compensate the relatively small increase in direct costs. Indeed, savings in hidden costs are in average equal to 64.68%, 67.94% and 57.53% for the G-based, L-based and H-based approaches, respectively. On a counterpart, the increase in direct costs averages 1.92%, respectively, 2.01% and 1.88%, for the G-based, respectively, the L-based and the H-based, approach.

4.3. Comparative results of the three approaches

Table 3 gives the number of instances for which the G-based, L-based and H-based approaches yielded the minimum direct cost (under column DC), the minimum hidden cost (under column HC) and the minimum total cost (under column TC). Hidden costs are computed based on each shipper's own valuation as in Section 4.2. Recall that each set includes 10 instances and that instances in sets 1, 2 and 3 are equivalent to that in sets 4,5 and for the G-based and H-based approaches.

Approach	Instances set	*DC*	*HC*	*TC*
G-based	1	1	0	0
	2	1	1	1
	3	0	9	10
L-based	1	1	9	10
	2	0	9	9
	3	0	1	0
H-based	1	3	1	0
	2	2	0	0
	3	2	0	0
	4	5	0	0
	5	7	0	0
	6	8	0	0

Table 3: Number of instance for which a proposed approach yielded the lowest cost

The results of Table 3 show that the H-based method yielded the minimum direct cost for the majority of the instances especially when shipper s_1 has more experience than s_2 with the participating carriers (instances sets 4,5 and 6). The L-based approach is the one that results in the minimum hidden and total costs for almost all the instances of sets 1,2, 4 and 5. Recall that for these contexts, shipper s_1 is an important player in the auction and detains more than 70% of the auctioned contracts. When auctioned contracts are equally distributed between shippers (instances sets 3 and 6), the G-based approach yielded the lowest hidden costs for almost all the instances.

Consequently, if shippers aim to reduce their direct costs, a H-based approach should be used, especially if the shipper that requests a relatively larger number of contracts is also the one that has the most experience with the bidding carriers. If the shippers aim to minimize the hidden costs, the L-based approach should be used if one shipper detains more than 70% of the auctioned contracts. If the two shippers have almost the same number of auctioned contracts, the G-based approach should be privileged to minimize hidden costs.

Recall that direct costs represent the effective cost to be paid to carriers. However, hidden costs are an estimation of the costs that could be incurred during operations due to a bad quality of services offered by the winning carriers. The results of Section 4.2 showed however that for all the proposed approaches, the relative increase in direct costs with regard to the optimal direct cost (the direct cost without reputation) does not exceed 3.04% for all the instances. Hence, the G-based and L-shaped approaches outperforms the H-based approach when considering globally hidden costs and total costs for the two shippers together. In the next section, we compare the three approaches with regard to each shipper individually.

4.4. Impact of centralized auctions on each shipper individually

The objective of this section is to measure, for each shipper, the difference between the hidden cost output by our proposed approaches and the hidden cost incurred in a centralized auction when only the shipper's valuation of the carriers' reputation is taken into account in the WDP. In other words, we want to measure the quality of the carriers selected by each of our approaches relatively to the best carriers that could be chosen for each shipper in a centralized auction.

To this end, for each shipper $s_i, i = 1, 2$, we solve a reputation-based WDP as described in Section 3.3 but in which the objective function minimizes the total direct cost and the hidden cost of shipper s_i. Formally, the WDP solved for shipper s_i, denoted by, $M(s_i)$, is formulated as:

$$\begin{aligned} \min \quad & \sum_{a \in A} \sum_{b \in B(a)} BP_b x_b + \sum_{a \in A} \sum_{b \in B(a)} HC_{a,b,s_i} x_b, \qquad (7) \\ \text{suject to} \quad & (5) - (6) \end{aligned}$$

If x^{*i} denotes the optimal solution of model $M(s_i), i = 1, 2$, then the hidden cost that could be paid by shipper s_i in a centralized auction where only its reputation valuation is considered is $HC^*_{s_i} = \sum_{a \in A} \sum_{b \in B(a)} HC_{a,b,s_i} x^{*i}_b$. Let HC_{s_i} denote the hidden cost associated with shipper $s_i, i = 1, 2$ and resulting from our reputation-based approaches as described in previous sections. Then, the gap between the two hidden costs for a shipper $s_i, i = 1, 2$ is:

$$Gap(s_i) = \frac{HC^*_{s_i} - HC_{s_i}}{HC^*_{s_i}}.$$

Table 4 summarizes the results obtained for the three approaches. It reports for each approach and each instances set, the minimum, the maximum and the averages values of $Gap(s_i)$ (in percentage) for each shipper $s_i, i = 1, 2$. These values are computed over the 10 instances of each set.

The results of Table 4 show that for the majority of the instances, $Gap(s_1)$ and $Gap(s_2)$ take relatively large negative values. Hence, when centralizing their requests in a unique single auction, shippers are more likely to end up with carriers that considerably deviate from the best ones for them based on their own past experience.

Instances set	Shipper	G-based			L-based			H-based		
		Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
1	s_1	-3	-1	2	-5	0	9	-65	-41	-27
	s_2	-627	-393	-252	-247	-178	-122	-61	-34	-9
2	s_1	-15	-6	6	-19	-12	4	-258	-182	-93
	s_2	-211	-165	-114	-169	-125	-90	-45	-21	-12
3	s_1	-59	-34	-11	-59	-38	-14	-376	-263	-150
	s_2	-110	-81	-50	-128	-97	-72	-46	-20	-4
4	s_1	-3	-1	2	-5	0	9	-3	0	9
	s_2	-627	-393	-252	-247	-178	-122	-515	-370	-232
5	s_1	-15	-6	6	-19	-12	4	-9	0	6
	s_2	-211	-165	-114	-169	-125	-90	-429	-285	-183
6	s_1	-59	-34	-11	-59	-38	-14	-35	-5	14
	s_2	-110	-81	-50	-128	-97	-72	-291	-235	-172

Table 4: Gap (%) between the hidden cost obtained with a proposed approach and the optimal hidden cost for s_1 and s_2

When analyzing the results in details for each shipper and each approach separately, we observe that the more contracts a shipper s_i has in the auction, the smaller is the value of $Gap(s_i)$ for the G-based and the H-based approaches. This can be observed by gap variations through instances set 1, 2 and 3. Hence, the G-based and L-based approaches favour the shipper that has the more contracts in the auction to have its preferred carriers. For example, when shipper s_1 detains 90% of the auctioned contracts, the average deviation with regard to the preferred carriers is -1% for the G-based approach and 0% for the L-based one.

This was clearly not the case when the H-based approach is considered. When considering the same instances set 1, the average gap reaches -41% for s_1 and -34% for s_2. Moreover, for the H-based approach, the value of $Gap(s_i)$ is more impacted by the shipper 's degree of knowledge of the carriers than by the number of its auctioned contracts. This aligns with the approach principle that attributes larger weights to the shippers with more experience.

At first sight, the results of Table 4 show that centralization is not beneficial for some shippers that may be stuck with "bad" carriers either because they do not have enough weight on the auction in terms of numbers of auctioned contracts or because they do not have a large history with the bidding carriers. However, the “bad carrier” qualifier is only determined based on the shipper’s own experience whether it is representative or not of what the carrier’s actual reputation is. Hence centralization could be viewed as an opportunity to implicitly share and adjust knowledge about carriers between shippers. So our results interpretation mainly depends on the shippers’ perception. In other words, do shippers centralize their requests to benefit only from potential savings on ask-price and want their highest-rated carriers to win? Or do they want to take advantage from centralization to also adjust their knowledge and allow shippers that know better the bidding carriers to influence the auction outcome?

5. Conclusion

This paper considers a centralized procurement auction in which a set of shippers participate together in a unique combinatorial auction. Carriers compete by submitting package package bids on shippers’ contracts. A reputation-based WDP is addressed in which winning bids must be determined based on both ask-prices and carriers’ reputation. Such a problem is challenging since: (1) a same bid may include shipping contracts requested by different shippers and (2) a carrier’s reputation may differ from one shipper to another. Three approaches are proposed to model the problem. Our experimental results first show that considering carriers’ reputations when solving the WDP in centralized auctions generally leads to a little increase in direct costs. Important savings in hidden costs and in total costs are however obtained. Second, when comparing the three proposed approaches, we observed that choosing the appropriate one closely depends on the shippers profiles, their weight in the auction and their perception of centralization.

This paper focused on the carriers’ reputation attribute that was translated in hidden costs to be possibly paid by each shipper individually. Instances were generated so that shippers would gain globally in direct costs through centralization. Our paper does not address the so-called cost allocation problem to decide how the direct cost should be shared among the shippers. As a future work, we aim to conceive an integrated approach where both shipper's individual direct and hidden costs are determined. For example, a shipper that is allocated a non-preferred carrier could be compensated in its individual direct cost.

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