Carrier Bidding Strategies for Iterative Auctions for Transportation Services

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Abstract

Transportation service procurement auctions are typically characterized by limited number of rounds and low profit margin. In this paper we address the bid determination problem for single-lane and combinatorial bids in the successive rounds of an auction, which maximizes the profit and also ensures winning. A profit factor (PF) is computed at each round using the industry average price for this lane from the historical figures and the winning bids for the past round of this auction.

1 Introduction

Procurement of transportation services is one of the most important operations of manufacturing firms interested in moving goods in bulk shipments. Creating and maintaining a fleet of vehicles for transporting goods can become a financial overhead and a management burden for firms having very different core competencies. Procurement of shipment services often results in considerable cost saving if implemented correctly.

The market model in a transportation service procurement process involve shippers and carriers. Shippers want to transport shipments from a set of sources to a set of destinations. A lane is a single transportation path from a source to a destination. Carriers provide transportation services over these lanes. We assume here that each lane is defined such that it is indivisible, i.e. a single carrier has to haul the shipment from the source to the destination. Shippers buy transportation services from carriers through auctions and other processes.

Historically firms interested in shipping goods used to advertise in local or national media for request of quotations (RFQ’s). From the quotations received, a winner was selected based on cost and other criteria e.g. reliability, past experience with the carrier etc. This was repeated for each shipment. This process is nothing but a first price sealed bid auction, and is still in use by many small and mid-size firms. This RFQ based method was often complemented with offline negotiation for shipment bundles (i.e. a group of shipments).
With the advent of new technologies, carriers and shippers have made substantial improvements in the way they conduct their operations. New manufacturing philosophies like Quick Response Manufacturing (QRM), Just-In-Time (JIT) manufacturing etc. place much importance on quick and frequent shipments among other things. On the other hand, carriers are using technologies like Geographical Information System (GIS), Intelligent Transportation System (ITS) etc. to get a better visibility on the real-time positions of carriages.

Though our work discusses transportation service procurement auction in general, the most relevant among all the transportation modes is the trucking service. According to the survey figure released by the Bureau of Transportation Statistics (BTS, 2005), trucks moved more than $6.2 trillion and 7.8 billion tons of manufactured goods and raw materials in 2002, which is around 74.3% of the value shipped and 67.2% of the weight (figure 1). Thus, the focus of our research is procuring trucking services.

<table>
<thead>
<tr>
<th>Category</th>
<th>For-hire truck</th>
<th>Private truck</th>
<th>Total Freight Truck</th>
<th>% of total freight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value (million of $)</td>
<td>3,757,114</td>
<td>2,445,288</td>
<td>6,235,001</td>
<td>74.3</td>
</tr>
<tr>
<td>Tons (thousands)</td>
<td>3,657,333</td>
<td>4,149,658</td>
<td>7,842,836</td>
<td>67.2</td>
</tr>
<tr>
<td>Ton-miles (million)</td>
<td>959,610</td>
<td>291,114</td>
<td>1,255,908</td>
<td>40.0</td>
</tr>
</tbody>
</table>

Figure 1: U.S. Freight Shipments by Trucks: 2002

Use of combinatorial auctions (de Vries and Vohra, 2003; Xia, Koehler and Whinston, 2004; Nisan, 2000) in transportation and other procurement processes are increasingly becoming common practice. Holmer et al. (2003) mention monetary benefit to Mars Inc., a privately owned business, from the use of combinatorial auctions in procurement from its suppliers. Ledyard et al. (2002) describe their use of combined-value auction for procuring transportation services for Sears Logistics Services, which reduced their cost by $165 million per year. Elmaghraby and Keskinocak (2003) discuss some trends in procurement auction, and a successful implementation for transportation services procurement at The Home Depot. The authors also mention similar auctions at Wal Mart Stores, Compaq Computer Co., Staples Inc., The Limited Inc. etc. Various software solution providers like Logistics.com Inc., Manugistics Inc., CAPS Logistics, i2 Inc., Schneider Logistics etc. have developed independent software modules for this purpose. Sheffi (2004) surveys the use of combinatorial auctions in procurement of transportation services in a recent article.

This paper considers the transportation procurement auction from the carrier perspective. Plummer (2003) gives a description of the bidding process by the carriers which can be summarized into an outline. The bidding process starts with carriers responding to Request for Quotations (RFQ) or Request for Proposal (RFP). Typically a carrier select which RFQ’s to respond depending on the fleet size and current load in the network.
Once the carrier responds to a RFQ, she has to quote a price on lanes and lane bundles by within a specific timeframe. Depending on the nature of the auction (single round or multi-round), the carrier might have to review price quotes in the next round of the auction.

Carriers typically answer the following three questions while participating in an auction.

1. **Participation and Valuation Determination**: Whether to participate in an auction? What are the valuation of lanes/bundles that are auctioned off when (a) there are no existing commitments, and (b) there are existing commitments? An, Elmaghraby and Keskinocak (2004) discuss a synergy model to find out the valuation of a bundle. Song and Regan (2003a) discuss some variation of set covering formulations with respect to preexisting commitments from the carrier.

2. **Bundling Strategy**: How to select bundles for bidding? In a simulation based study, Song and Regan (2002) show that combinatorial bids are beneficial to carriers compared to singleton bids in terms of revenue. An, Elmaghraby and Keskinocak (2004) discuss two strategies for prioritizing bundles for bidding, which they mention as internal-based strategy (INT) and competition-based strategy (COMP).

3. **Pricing or Bid Determination Strategy**: What is the best bid price on these bundles, that maximizes the profit of the winner? How does the pricing strategy change if the auction is single or multi-round? These questions, also raised in part by Song and Regan (2002), are the focus of this paper. Though there exists literature on pricing auctions (see Xia, Koehler and Whinston (2004) for a survey), neither do they suggest a way of determining best bid at each round, nor are they tailored towards the transportation sector. An, Elmaghraby and Keskinocak (2004) mention that carriers mostly price their bundles using fixed profit margin, but do not mention how to vary the profit margin for multi-round auctions. Song and Regan (2003b), Figliozzi, Mahmassani and Jaillet (2003) discuss bidding strategies for sequential auctions for transportation services market, which are quite different from the market we are discussing.

We discuss a novel approach in this paper to determine the best bid at each round of a multi-round transportation service procurement auction. Our approach can be used for both singleton and combinatorial bids. Singleton bids are still prevalent in transportation procurement auctions for various reasons.

The remaining paper is arranged in the following way. In section 2 we discuss about the Profit Factor based approach for determining singleton bids for each round of the auction. This section also acts as background for section 3, where we discuss how to extend this approach to combinatorial bids. We conclude in section 4.
2 Model for Single Lane Bids

2.1 Profit Factor Based Approach

We consider a descending-price auction for truckload cases (TL) with non-reloadable (dedicated, i.e. serving only this shipper and this lane) price per mile per load for each lane. Let there be \( N \) carriers competing for \( L \) lanes. Let \( c_{il} \) be the cost for providing service for lane \( l \in L \) by carrier \( i \in N \). Let \( C_l \) represent the second lowest cost for lane \( l \) among the participants. The historical average winning price for a lane can be a good starting estimate for \( C_l \). This depends upon the implicit assumption that, the winning bid of an ideal first-price reverse auction is the second lowest cost among the bidders reduced by an infinitesimal amount. We also note here that \( c_{il} \) will most likely be the true cost of carrier \( i \) padded with a minimum profit margin.

For our model, we assume that the bidding function is a multiplier to the true cost of the carrier for each lane. We call this multiplier the Profit Factor (PF). When the cost is multiplied to the PF, we get the bid for a round.

The model assumes a minimum number of rounds for the auction specified by the shipper, denoted by \( R_{min} \) and a maximum number of rounds, denoted by \( R_{max} \). This model can be extended to other cases like auctions with no specified \( R_{max} \), or when \( R_{min} = R_{max} \). This model also requires the carrier to specify their risk behavior by specifying a minimum and maximum winning probability in the auction. Denote these probabilities by \( p_{i}^{min} \) and \( p_{i}^{max} \) for the \( i^{th} \) carrier.

2.2 Outline of the Algorithm

Here we outline the algorithm which we use to find out the best PF for a package in a particular round.

**Round 0:**  
(i) From historical data, find out the mean (\( \hat{\mu}_l \)) and standard deviation (\( \hat{\sigma}_l \)) of the winning price for the lane \( l \).
(ii) The carrier has to find out her cost for providing service \( (c_{il}) \), and \( f_{il} \). This cost can be treated as the valuation of the lane.
(iii) Set the first bid at \( f_{il} c_{il} \). After all the carriers submit their bids, shipper (or his agent) announces tentative winning bid for each lane.

**Round \( k < R_{min} \):** After the \( i^{th} \) carrier gets back the spreadsheet with the winning bids, two cases might arise. If she has won this round, she doesn’t change her bid, as there is a possibility that the other carriers have already reached their cost and stopped bidding. If she hasn’t won this round, either she reduces her bid by the minimum bid decrement, or retains her bid if she has already reached her cost.

**Round \( k = R_{min} \):** In this round, a carrier bids irrespective of whether she has won the last round. This is because after this round, the auction can stop at any round. Exception to this rule is if the carrier has won the last two or more rounds, which ascertains her as
the winner for this lane. The substeps are as follows.

(i) Find a suitable mean \( \mu_l \) using \( \hat{\mu}_l \) and the bids from round 1 to \((R_{min} - 1)\). This step is further illustrated in subsection 2.3. Set the target winning probability \( p \) at \( p_{i\min}^l \).

(ii) Find a suitable \( f_{ilk} \leq f_{ilk}^{max} \). Set the bid \( b_{ilk} = f_{ilk}c_{il} \). This step is further illustrated in section 2.4. The value of \( f_{ilk}^{max} \) can be calculated using \( f_{ilk,k-1} \) and the minimum bid decrement.

**Round** \( R_{min} < k < R_{max} \): In these rounds, the carrier would retain her bid if she is the winner of the last round. Otherwise the substeps are as follows.

(i) Update mean \( \mu_l \) using \( \hat{\mu}_l \) and the bids from round 1 to \((k-1)\), as illustrated in subsection 2.3. Decrease standard deviation \( \sigma_l \) so that it linearly decreases from \( \hat{\sigma}_l \) to some small value \((\geq 2)\). The intuition behind this is that as more and more auction rounds are conducted, the updated mean becomes more near to the actual value of the second lowest cost for the lane \( l \) among the participants. The carrier also updates the target winning probability \( p \) so that it linearly increases from \( p_{i\min}^l \) to \( p_{i\max}^l \) in \((R_{max} - R_{min})\) steps. We reason this as the increment in bidding aggressiveness as auction rounds progress.

(ii) Again find a suitable \( f_{ilk} \leq f_{ilk}^{max} \) as discussed in section 2.4. Set the bid \( b_{ilk} = f_{ilk}c_{il} \).

**Round** \( k = R_{max} \): In this round, the carriers’ behavior resembles that of a first-price sealed-bid auction. With the exception of winning the last two rounds or reaching the lowest possible cost, all carriers bid at this round. We update \( \mu_l \) and \( \sigma_l \) as stated for the last round, and set the target winning probability \( p = p_{i\max}^l \). The PF \( f_{ilk} \) is calculated as before and the bid set accordingly.

From the algorithm, the following lemma can be readily stated.

**Lemma 1** Since the price adjustment process described in the algorithm is non-increasing, the auction terminates after finite number of rounds.

### 2.3 Updating Mean

**Maximum Likelihood Method for Curve Estimation** Maximum Likelihood Estimation (MLE) is a common technique used in data mining applications or machine learning, for estimating parameters of an unknown function given observed data. Since the successive winning bids for a particular lane are monotonically decreasing, we can fit these bids to a suitable function (e.g. a straight line with negative slope, a negative exponential curve or a quadratic equation) and using that equation, find out the winning bid as predicted by this curve after sufficient number of rounds. Here we assume that, if the process of submitting minimum bids continue ad infinitum, the auction will converge to the second lowest price for a lane (also known as the Vickrey \((\text{Vickrey, 1961})\) price). The standard assumption of residual errors distributed normally with zero mean implies that the least square technique will generate a maximum likelihood estimate of the parameters of the function.

Depending on the nature of the curve chosen, either linear or non-linear least-square technique is used. This method minimizes the sum of squares of residuals. The general
method is as follows. Assume the bidding function to be estimated has the unknown parameter set \( P \), and is denoted by \( g(P; l, t) \), where \( l \) and \( t \) denote the lane and round respectively. We have the winning bids corresponding to rounds 1 through \((k - 1)\) at round \( k \) and lane \( l \), which are denoted by \( \hat{b}_{lk} \) as before. We define the residual \( r_{lt} \) as in equation (1).

\[
r_{lt} = \hat{b}_{lt} - g(P; l, t) \quad t = 1..(k - 1)
\]

Then we minimize the sum of square of residuals with respect to the unknown parameter set \( P \). The problem can be stated as shown in equation (2).

\[
\min \sum_{t=1}^{k-1} r_{lt}^2 = \sum_{t=1}^{k-1} (\hat{b}_{lt} - g(P; l, t))^2 \quad \forall l \in L
\]

The bid projection at \( t = 3k, t \geq 10 \), gives an estimate of the final price for lane \( l \). This can be directly used as the new mean for lane \( l \) (\( \mu_l \)), or a weighted average of this value and \( \hat{\mu}_l \) can be used.

### 2.4 Selection of Profit Factor

**Using Risk Profile**  Profit Factor can be obtained by using the minimum and maximum risk a carrier is willing to accept in terms of winning the auction. This method also requires less assumptions than the last method, though developing a representative risk profile can be a challenge. Let the risk factor for a round \( R_{min} \leq k \leq R_{max} \), as mentioned in section 2.2, is given by \( p_k \). Then we have the following equation (equation 3).

\[
\Pr(f_{ilk}c_{il} < C_l) = p_k
\]

If \( f_{ilk} \) obtained from equation 3 is less than 1.0, then the carrier finds \( p_k^* \) which satisfies equation (4). Then she finds a PF, which satisfies equation (5), giving slightly higher profit than minimum. The value of \( \delta \) is arbitrary, though 5% to 10% of \( p_k^* \) is reasonable.

\[
\begin{align*}
\Pr(c_{il} < C_l) & = p_k^* \\
\Pr(f_{ilk}c_{il} < C_l) & = p_k^* - \delta
\end{align*}
\]

The constraint \( f_{ilk} \leq f_{ilk}^{max} \) is enforced all the time.

### 3 Model for Combinatorial Bids

Combinatorial bids are used when bids for a set of lanes are put together. These lanes have synergistic values because of various reasons, e.g. either a set of lanes form a closed road circuit, or a set of lanes is a part of a road network. For these reasons, carriers offer a set of lanes like this at a price lower than the sum of the individual lane prices. The profit factor (PF) based approach presented for singleton bids can be extended to combinatorial bids. This requires the carriers to evaluate the bundle with one cost figure. Once this cost is found out, the bids can be submitted as suggested in section 2.2.
One important subproblem in this method is to compute the prices of bundles (singleton or sets of lanes) which have not won the auction and hence no price information is available. Our algorithm requires prices of all the bundles on which the carrier wants to update price. The following heuristic sets the price on all such bundles. Plummer (2003) mentions that, when carriers offer package discounts, those discounts tend to be around 5%. We use this in our heuristic as follows.

3.1 Price Adjustment Heuristic for Bundles

**Step 1:** For the edges contained in a winning bundle, set their prices according to the following equation. Let, \( B \) be a winning bundle, \( p \) be the price for each of the edges in \( B \), and \( p_B \) be the price of the bundle \( B \). Then \( p \) and \( p_B \) would satisfy equation \( 6 \)

\[
0.95|B|p = p_B
\]  \( 6 \)

If the prices for an edge obtained from the above equation is greater than the bid price of that edge for carrier \( i \), then she sets the price of the edge to her bid price.

**Step 2:** Given the prices of individual edges either known (for winning edges) or set by step 1, calculate prices of the bundles which don’t have prices set yet (bundles which are not won in the auction).

4 Conclusion

This paper suggests an innovative method for finding out the carrier bid for each round of a transportation procurement auction, which will maximize the profit of the winner. We suggest using an adaptive learning technique to guess the best opponent cost so as to maximize the bid. Further research is planned for implementing other adaptive learning techniques.

References


