Auction Algorithms for Achieving Efficiencies in Logistics Marketplaces

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Abstract— **Logistics is an important business process in a supply chain. A logistics marketplace is the virtual marketplace that bridges the procurement gap between shippers and carriers. Shippers are buyers who pay to the carriers for carrying their load. Current logistics marketplaces are not efficient to its end due to the improper negotiation models. In this paper we identify the need for innovative negotiation models for logistics marketplaces and propose four auction algorithms that suit the requirements of logistics marketplaces. Two negotiation models based on Dutch Auctions are proposed for rail/air/water and road transportation. A sequential-combinatorial auction and discriminatory call market are proposed, respectively for intermodal transportation and logistics hubs.**

Keywords— **Logistics marketplaces, Reverse auction, Dutch auction, Sequential-Combinatorial auctions, Call Markets**

I. Introduction

Logistics refers to the transportation of product from one location to another as it makes its way from the beginning of a supply chain to the customer. Logistics is an important business process in any supply chain because products are rarely produced and consumed in the same location, and it incurs significant cost. With the growth in e-commerce and the associated home delivery of products, transportation costs have become more significant in retailing [8]. Effective transportation is a key to the success of any on-line business, because these businesses often attract customers from distant locations, and the product must be transported from the seller to the customer. For example, Amazon [1] has centralized warehouses in US but accepts orders worldwide and relies on package carriers and postal system to deliver orders. Thus any supply chain's success is closely linked to its logistics network.

A logistics marketplace is the virtual B2B marketplace that bridges the procurement gap between shippers and carriers. Shippers are buyers who pay to the carriers for carrying their load. Markets have three main functions [5]: matching buyers to sellers; facilitating exchange of information, goods, services, and payments associated with a market transaction; and providing an institutional infrastructure, such as a legal and regulatory framework that enables efficient functioning of the market. Internet-based E-markets leverage information technology to perform these functions with increased effectiveness and reduced transaction costs, leading to more efficient, friction-free markets. Currently reverse auction is the predominant negotiation process in the logistics marketplaces. The marketplaces are mainly used for transfer of information. The shippers post their requirements and carriers post their extra capacities. The trade and negotiation are done generally offline. There are not many matching and automated negotiation mechanisms used currently in logistics marketplaces. This is one of the significant reasons for the decrease in the number of logistics marketplaces in 2001. The logistics processes vary significantly with the type of goods and the mode of transport. No single negotiation model can suit all logistics marketplaces.

The paper is organized as follows. Section II briefly surveys the negotiation models currently deployed in logistics marketplaces. Distinctive characteristics of the logistics marketplaces are presented in Section III. In Section IV we propose auction algorithms that are relevant for the logistics marketplaces. Conclusions are drawn in Section V.

II. Current Scenario

The following are the different business models currently used in the logistics marketplaces.

A. Reverse Auction

In reverse auction or procurement auction, there will be a single buyer and the sellers bid to sell their object to the buyer. The seller with the lowest bid trades with the buyer for the price he has quoted. ShippingFinder [2] uses reverse auction to match shippers with carriers. Shippers post their shipping requests on the site stating the maximum price they are prepared to pay for their shipping requirement as a starting point for the reverse auction, and carriers bid against each other. The carrier with the lowest bid wins the shipper's business. ShippingFinder is currently planning to change the site from a reverse auction venue to a Request For Quote (RFQ) venue. In the RFQ venue, shippers will be able to post their shipping needs on the site without stating any pricing expectations and shipping companies will present their offers. The shipper will then have the ability to select whichever carrier he or she desires (not necessarily the lowest price) and the system will automatically match the shipper with the desired carrier.

B. Transportation Quote Request

Transportation Quote Request (TQR) is the same as an RFQ. In FreightMarket [3], shippers register a TQR that has certain mandatory fields relating to the goods, the routing and the timing of the shipment. The TQR can be an *open request* or a *closed tender*. An open request is a TQR

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[1] http://www.amazon.com

[2] http://www.shippingfinder.com, www.shipping-auction.com

[3] http://www.freightmarket.com

posted by a shipper which can be viewed by all carriers visiting FreightMarket. A closed tender is a TQR which the shipper chooses to send to a selected list of carriers. Similar to TQR is the *Carriers' Notice Board* for the carriers. The Carriers' Noticeboard is used by the carriers to post information for shippers and is divided into two sections: General and Last Minute Space. As its name implies, General is for messages of a general nature such as employment offers, change of office details, announcements of new services available, etc. Last Minute Space refers to late space availability offers posted by carriers looking to fill any remaining space left on their planes, trucks or ships before their scheduled departure. These offers can only be on the noticeboard for a maximum of 2 weeks.

The commonality of these techiniques is that shippers/carriers just post their requirements so that the parties interested can contact them with their deals. The marketplace just enables transfer of information and there exists no mechanism for automated matching or negotiation. Similar on these lines is Tranzlink [4], which allows members to interact between each other using automatic searching and posting. FreightMatrix [5] selects the cheapest transportation option that complies with the shipment requirements of a shipper. It also provides the shippers with a list of potential carriers from which the shipper can select the desired carrier. Other marketplaces that provide information transfer include TruckLoad Freight [6], LoadSource [7] (leverages Internet and wireless technology for information updates), LoadMatch [8] and Load Dock [9].

C. Proprietary Models

National Transport Exchange (NTE), an online marketplace for ground transportation, uses proprietary matching logic that matches carriers with shippers [10]. Shipment orders are collected, market price is computed for each shipment, and shipment orders are matched to truck routes provided by carriers. NTE combines the public market with private online services through what it calls as alternate placement services [3]. A shipper offering a load sets criteria for the services it requires of carriers. If no carrier meets those criteria in the open market, the shipper's offered load is bumped to a contract that NTE already has negotiated and that meets the shipper's requirements. This combination service clears 100% of the shippers' requirements in contrast with the open market that was clearing only 30%.

III. Characteristics of Logistics Marketplaces

No single business model can suit all logistics marketplaces. The marketplace requirements vary with the mode of transport, number of modes and the types of goods being carried.

[4]http://www.tranzlink.com
[5]http://www.freightmatrix.com
[6]http://www.truckloadfreight.com
[7]http://www.loadsource.com
[8]http://www.loadmatch.com
[9]http://www.loaddock.com
[10]http://www.nte.com

A. Mode of Transport

Mode of transport can be ground (road/rail), air or water. Among the above, road transport is flexible and allows alterations for the carriers in the schedule and route. To illustrate this let us consider the case of two carriers Metzger & Sons Trucking Caompany, Silver Lake, Indiana, and May Trucking Company, Brooks [12]. Metzger has little difficulty in lining up full outbound loads of recycled waste containers as well as feed grain from the central Midwest to points in the eastern two-thirds of the country. However, truckload backhauls have to be found to avoid costly deadhead runs back home. May Trucking Company have customers with committed lanes and/or committed volumes, but occasionally they need to locate truckload shipments for the in-between segments. Both companies find solutions using NTE by searching for the shipment requirements around the geographical area of their truck routes and choose the one that fits within their revenue criteria after the alterations in routes. Thus given a set of shippers with varying requirments in terms of load and route, a carrier has the flexibility to choose the one that gives more revenue. Such is not the case with rail, air or ocean transportation. Here the carriers have fixed routes and pick up points with some available capacity. The shippers have a choice of choosing the carriers who will fit their requirements in terms of load, route and cost.

B. Number of Modes

When more than one mode of transport is required for shipping a load from source to destination we have intermodal logistics. The different modes of transport may not be provided by a single carrier. A shipper requiring intermodal transportation therefore requires negotiation with different carriers simultaneously and the final trade should be consistent with the timings and the routes of the all the carriers involved. For intermodal logistics, currently practised reverse auction or catalog exchanges will not be of much use to the shippers.

C. Types of Goods

Depending on the types of goods, carrier requirement varies. Refrigerated goods like dairy products require refrigerated vans. Dry goods can be packaged in cargoes of standard sizes but some heavy or awkward shaped goods require open top containers. In such cases both dimensions and weight are issues of negotiations.

The above discussion shows that the logistics marketplaces require different negotiation models depending on the individual requirements.

IV. Auction algorithms for Logistics Marketplaces

An auction is a bidding mechanism, described by a set of auction rules that specify how the winner is determined and how much the winner has to pay. In addition, auction rules may restrict participation and feasible bids and impose certain rules of behaviour [18]. Auctions and bidding have long been used as methods for allocating and procuring goods and services. An excellent survey of auction and bidding models can be found in [18] and [9] gives a good textbook introduction to design and analysis of various of auction algorithms. In this section we propose auction algorithms for different logistics marketplaces.

A. Dutch Auctions

The Dutch auction was developed in the 17th century in Amsterdam for the sale of fresh flowers and is different from conventional auctions in that the price of the goods on offer descends and all bids are immediately successful [11]. In a Dutch auction the auctioneer begins at a high price, the price then descends by steps until a bidder indicates intention to buy at the price level reached. The successful bidder then nominates all or part of the goods on offer. If any goods remain in the current lot, the auctioneer increases the offer price by a predetermined amount and then resumes the auction. The auction continues in this fashion until either the current lot is exhausted or its reserve price is reached. Central to the Dutch auction is a large electronic or mechanical clock which shows the current offer price. During the auction this clock shows the offer price descending and then kicking up when a bid is made and then descending again. The capacities traded in logistics marketplaces are like perishable goods, as unused capacity loses value once the shipment starts. Dutch auctions are generally preferred for perishable goods and here we present two kinds of dutch auctions, one for shippers and the other for carriers.

A.1 Dutch Auction for Carriers

Carriers post their available capacity with other information related to size, route and pickup points. The carrier can set the clock to reduce the bid value to a prespecified minimum allowable limit, with a time period that varies from hours to days depending on the requirements. If the carrier accepts groupage where loads from different shippers can be accommodated, group buying Dutch auctions can be conducted as explained above or the capacity can be considered as a single indivisible commodity that can be traded only with a single shipper. This is similar to the carrier notice board of FreightMarket with a principal difference: lowering of bid values. The following costs affect the shipper's decisions: transportation cost (cost paid to the carrier), inventory costs (cost of holding the inventory in the supply chain) and the service level costs (cost of not being able to meet delivery commitments). The lowering of bid values by carriers allows the shippers to reevaluate their cost in terms of shipping date and location and go for a cost effective carrier. This kind of auctions are suitable for air, rail or ocean transportation where carriers have no choice of changing their parameters except the price.

[11] http://www.cs.flinders.edu.au/research/CA/Inet/dutch.html

A.2 Dutch Auction for Shippers with an English Clock

The shippers identify their capacity requirements and conduct a Dutch auction with an English clock. In an English clock, the bid value posted by the shippers keeps increasing (in contrast to the traditional Dutch Auctions where price decreases). Carriers can stop the clock at a price which is found to be profitable. This auction is suitable for road transportation. The costs affecting carriers' decisions are: unutilized capacity cost (there may be excess capacity that is unutilized), route diversion cost (cost of chaning the route to accept a new shipment), and service level cost (failure to meet the delivery time of the agreed upon shipment due to the acceptance of the new shipment). However some of these costs may be zero. As the bid value of the shipment keeps raising, carriers can decide to accept the bid based on the evaluated cost and the bid price.

Dutch auction is strategically equivalent to the first-price sealed-bid auction [15]. Reverse auctions are same as the first-price sealed-bid auctions but the winner is one with lowest bid rather than the highest bid. Hence Dutch auctions are similar to the reverse auctions strategically. However, in a logistics marketplace, several auctions are conducted simultaneously. In reverse auctions, the bidders have to submit binding bids and cannot bid in more than one auction as there may not be enough capacity to ship the load if more than one bid is accepted. Therefore bidder has to bid only in single auction in which he may not win. This situation is avoided in Dutch auctions where the bidder can closely watch the auctions and can bid in a auction that turns out to be profitable.

B. Sequential-Combinatorial Auctions for Intermodal Transportation

In intermodal logistics, a shipper requires several modes of transportation to accomplish the shipping. All modes of transportation, in general, need not belong to a single carrier. Hence the shipper has to negotiate with a set of carriers simultaneously or sequentially to make the deal. Let $X_1, X_2, ..., X_n$ be the set of alternatives for n modes of transport. An arbitrary combination of $(x_1, x_2, ..., x_n)$, where $x_i \in X_i$, need not be a feasible sequence of carriers that can ship the shipper's load. For example, the pick-up time of x_i may be prior to the delivery time of x_{i-1}. Hence there are constraints in the set of values the x_i can assume simultaneously. Thus we have a constraint satisfaction problem that finds out the set $\overline{X}$ of feasible carrier combinations. For each $\overline{x} \in \overline{X}$ there is a cost $C(\overline{x})$ which the shipper has to incur in shipping. The shipper's problem is to obtain a feasible deal $\overline{x}$ that minimizes the cost. Each $\overline{x}$ represents the complementarities existing between the x_i's and different $\overline{x}$ are the substitutables (if cost is not considered). If $X_1, X_2, ..., X_n$ are all in a single market we have a combinatorial auction [16], but if they are all different we have sequential auction problem where the objects auctioned exhibit complementarities [6]. The winner determination (determining the winning bids) in combinatorial auctions is computationally difficult to solve for large instances but if the bids impose certain structures then there are efficient algorithms to solve the problem [16]. In sequential auctions with complementarities, there is no combinatorial winner determination problem as there is no single seller. Given the set $\overline{X}$ and the cost function C over it, the bidders have to choose a $\overline{x} \in \overline{X}$ and bid sequentially in all the auctions. If the bidder cannot win the entire bundle then whatever he has acquired will be sunk costs. A dynamic programming based approach is proposed in [6] to help the bidders resolve the bidding decision problem.

C. Discriminatory Callmarket for Logistics Hubs

Logistics hubs are aggregation-distribution centers. Goods from different sources are aggregated and transported to another hub where it is distributed to different destinations. The hubs are source destination pairs that are subroutes to a set of routes. The modes of transport between hubs are generally water, air, and rail due to the large quantity and possibly the route involving international boundaries. For example, consider the intermodal transportation of containers from a set of sources S to a set of destinations D. The containers have to transported from a source $s \in S$ to a hub A using trucks. All the containers from S are aggregated in A and shipped to B through water. From B, the containers are distributed to the respective destinations $d \in D$. The containers are in standard dimensions and hence can be considered homogenous i.e. containers from different shippers can be shipped together (groupage market). There may be different carriers between any two hubs with some capacities and there are several shippers who want their loads to be shipped between these hubs. We propose a discriminatory call market for matching loads from shippers with the capacities of the carriers.

Call markets are periodic versions of continuous double auctions where bids from sellers and buyers are collected over a specified interval of time and the market is cleared at the expiration of the interval with a single market clearing price. All goods that gets traded are traded at the single price irrespective of the price quoted in the bids. However, the prices quoted in the bids determine the market clearing price. Call markets are used for trading homogeneous goods and have been used in many European Stock Exchanges, and for the daily opening on the New York, American and Tokyo Stock Exchanges [13]. We propose a call market with discriminatory pricing (no single market clearing price) for logistics hub marketplaces. The discriminatory call market for B2B procurement in [11] considers multiple attributes: quantity, price and delivery time. We consider here only price and quantity. In the following discussions, we will use *buying agent* to refer to a shipper and *selling agent* to refer to a carrier. The goods traded are capacities of carriers where we assume that the characteristics of the goods are fixed and known to all. For example, a unit good may be a capacity to hold a container of fixed dimension and has a maximum allowable weight. If a buyer m trades three goods with seller n then it means that carrier n will transport three containers of shipper m.

C.1 Bid Structure

Call market is a double auction and both buyers and sellers submit bids. The bid submitted by a buyer is referred as *bid* itself and that of seller is referred as *ask* or *offer*. The bid (offer) structure of the proposed market is as follows. A bid (offer) submitted by a buying (selling) agent is a *price-quantity* pair. The *price* is the unit price at which the agent wishes to trade the specified *quantity* of goods. The bid price is the buying agent's maximum *willingness-to-pay* (WTP) and the offer price is the selling agent's minimum *willingness-to-sell* (WTS). Hence any buying (selling) agent will trade at a price $\leq$WTP ($\geq$WTS). A buying agent can trade with a selling agent only if a *zone of agreement* exists i.e. WTP$\geq$WTS. The bids (offers) are "all-or-nothing" sealed bids (offers), i.e. the quantities are indivisible. The all-or-nothing criterion for a *quantity range*, given as [*Lower Limit, Upper Limit*], means that the agent is willing to trade any quantity within the given range and no quantity outside this range.

C.2 Discriminatory Pricing

Traditional call markets have a single market clearing price and all goods are traded at that price. Here we propose a discriminatory pricing scheme where buyers pay different prices to different sellers. Discriminatory or differential pricing is practiced by businesses in every segment of the economy [1], from auto dealers to airlines and is the dominant pricing mechanism in ECommerce. Some market segments could not be served without differential pricing and it is expected to increase economic efficiency [17]. In scenarios where both sellers' and buyers' prices are revealed, the midpoint of the *zone-of-agreement* (WTS-WTP) is a good trading price which gives equal surplus to both of them [14].

C.3 Trade Determination Problem

Given a set of bids and offers, the market has to perform the following functions:

- Accept/reject a bid (offer).
- Determine the amount of goods traded between a bid m and offer n i.e. determine the number of containers of shipper m that will be transported by carrier n.

The above trade determination problem is modeled as the following mathematical programming problem.

Notation

B	Set of bids, $\{1, 2, \ldots, m, \ldots, M\}$
S	Set of offers, $\{1, 2, \ldots, n, \ldots, N\}$
WTP_m	*Willingness-to-Pay* of bid m
WTS_n	*Willingness-to-Sell* of offer n
$[a'_m, a''_m]$	Quantity range of bid m
$[b'_n, b''_n]$	Quantity range of offer n
D	$\{(m,n) : WTP_m \quad WTS_n > 0\}$

y_{mn} Amount of goods traded between buying agent's bid m and selling agent's offer n

$$r_m \begin{cases} 1 & \text{if bid } m \text{ gets traded} \\ 0 & \text{otherwise} \end{cases}$$

$$s_n \begin{cases} 1 & \text{if offer } n \text{ gets traded} \\ 0 & \text{otherwise} \end{cases}$$

Formulation

$$\text{Maximize} \sum_{(m,n)\in D} y_{mn}(WTP_m \quad WTS_n) \tag{1}$$

subject to

$$\begin{aligned}
\sum_{\{n|(m,n)\in D\}} y_{mn} &\leq r_m a''_m \ \forall m \\
\sum_{\{n|(m,n)\in D\}} y_{mn} &\geq r_m a'_m \ \forall m \\
\sum_{\{m|(m,n)\in D\}} y_{mn} &\leq s_n b''_n \ \forall n \\
\sum_{\{m|(m,n)\in D\}} y_{mn} &\geq s_n b'_n \ \forall n \\
y_{mn} &\geq 0, \text{ integer } \forall (m,n) \in D \\
r_m &\in \{0,1\} \ \forall m \\
s_n &\in \{0,1\} \ \forall n
\end{aligned}$$

The objective function (1) maximizes the sum of the surplus (profits) of all the traders. The r_m and s_n are 0-1 variables that reject/select a bid or an offer. These binary variables are required for two reasons. One, accepting all bids and offers may not maximize the value of (1), due to the *more-for-less* paradox (commonly known as *transportation* paradox) [7]. The paradox says that it is possible to send more flow from supply to demand nodes at lower cost, even if all arc costs are positive. Second, the problem may be infeasible after accepting all bids and offers. For the above problem to be feasible, following inequalities need to be satisfied: [2]

$$\sum_m a''_m \geq \sum_n b'_n \tag{2}$$

$$\sum_n b''_n \geq \sum_m a'_m \tag{3}$$

Hence, 0-1 variables are required to judiciously select bids and offers such that the problem is feasible and (1) is maximized. The above integer programming problem is a semilinear problem. Once the 0-1 variables are fixed, the resulting problem is an interval transportation problem, which can be easily solved using network flow algorithms [4]. Semilinear problems can be solved using *Benders' decomposition* technique [10].

V. Conclusions

Logistics is an extremely important business process and is closely linked with the success of any supply chain. Logistics marketplaces are prevalent now in the B2B markets that increase the efficiency of transportation and inventory management. However the negotiation models used in the current marketplaces are not suitable for increasing the efficiency of the marketplaces. In this paper, we proposed auction algorithms depending on the requirements of the logistics marketplaces. Specifically we proposed Dutch auctions for carriers for air/rail/water transportation, Dutch auctions with English clock for shippers for road transportation, sequential-combinatorial auctions for intermodal transportation, and a discriminatory call market for transportation between logistics hubs.

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