TRANSPORTATION SERVICE PROCUREMENT USING

COMBINATORIAL AUCTIONS

by

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B.S., Civil Engineering
TsingHua University, 1993

Submitted to the Engineering Systems Division
In Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

Auction is a mechanism of selling distinct assets that can be both physical objects and virtual objects. Examples of virtual objects are the rights to use assets like airport time slots and FCC spectrum, or to service truckload delivery routes in a transportation network. Under some situations bidding on combinations of objects can render lower total price compare with bidding the objects one at a time, and the auction that allows bidders to bid on combinations of different assets are called combinatorial auctions. With shipper being the auctioneer and carriers being the bidders, combinatorial auction has become increasingly important in the transportation service procurement domain, due to its mechanism to align shipper's procurement interest with carrier's transportation service cost structure, which in turn lowers shipper's total procurement cost.

The thesis provides a comprehensive review of the use of conditional bidding within a transportation combinatorial auction framework. The thesis first describes the general forms of the transportation services available, and discusses the economics of motor carriers that provide LTL and TL services. It then illustrates the basic optimization technique of conditional bidding for TL service procurement and discusses the information technologies that enable the optimization-based procurement and the actual application of the method in the real world.

Thesis Supervisor: Masters, James M
Title: Executive Director, MLOG Program

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1. Introduction

This chapter describes the general classification of transportation systems. The section explains the direct and consolidated operation, gives background in the motor carrier industry, and discusses the economics of TL and LTL services. The chapter serves as the fundamental knowledge base of the thesis discussion of the TL service procurement best practice.

1.1 The Classification of Transportation Systems

Transportation Systems can first be classified by carrier transportation mode. Generally speaking there are following transportation modes: Rail, Motor, Ocean, Air, Parcel, Pipeline, Barge. The operation of each type of transportation mode, especially for Rail, Motor, Ocean, Air, and Parcel types of services that are most commonly used, can be further classified by the type and degree of consolidation. Consolidation is the process of combining different items or shipments into loads on a single vehicle. The extent of consolidation performed is a prime determinant of how the system makes trade-offs between levels of service and cost [1].

Three types of consolidation have been most commonly observed: time consolidation, vehicle consolidation and terminal consolidation:

- **Time consolidation:** is where a shipper (or carrier) holds items at a location until a sufficient volume is accumulated before arranging for movement. The items do not necessarily need to have the same destination. A typical example would be an office arranging for a single pickup of mail at the close of each business day.

- **Vehicle consolidation:** is where a single vehicle makes multiple stops to pickup (or deliver) shipments from shippers that have the same destination (or origin). The multiple shipments are combined into a single load in the vehicle. A typical example would be the postal service and mail carriers (FedEx, UPS, etc.) that perform regularly scheduled pickup and delivery runs.

- **Terminal consolidation:** is where shipments from multiple origins are sent to a common facility where they are unloaded, sorted, and reloaded into vehicles heading to common destinations. A shipment may be routed through multiple terminals in its path to its final destination. A typical example would be the Hub and Spoke system used in the passenger airline operations.

A transportation system could use one type of consolidation, or use combination of consolidation types, depending on the trade-offs involved with consolidation decisions between unit costs and delivery time. All three types of consolidation lowers unit cost though the spread out of the fixed cost of the shipment movement, but Time consolidation increases the transit time by delaying the departure for a portion of the items; Vehicle consolidation involves additional travel time due to circuitous routing; and Terminal consolidation results in additional time and cost involved in handling, sorting, and circuitous travel to route items through terminals, and requires substantial investment in facilities that can only be justified by sufficiently high volumes.

The degree of consolidation, in the other hand, depends on the critical factors like shipment size and level of service. The smaller the size of the shipment is, the more consolidation is required to achieve lane density justifiable to the cost of movement. Higher level of service requirement like tighter transit time would restrict consolidation opportunities and can lead to direct shipment operation. In the next section, we illustrate the difference between the direct and consolidated operations.

1.2 The Direct versus Consolidated Transportation Operations

A classic example of consolidated and direct operation is buses/subways and taxis. Busses/subways is a consolidated transportation system, operate according to a schedule over predefined and regular routes that rely upon all three types of consolidation: Passengers must wait at the stops until a scheduled pickup has arrived (time consolidation). Busses/subways performs vehicle consolidation along the predefined routes for picking and drop off of passengers. Busses/subways transport passengers to terminals where passengers sort themselves to exit the system or get on other vehicles that head for different locations. In a consolidated system, items spend more time in the system in exchange of the lower unit cost.

On the other hand, taxis provides in time and flexible service for the passengers. The taxi goes to a person's destination directly, and no vehicle or terminal consolidation is involved between the origin and destination. The passenger pays higher cost in exchange of faster transit time or possibly better service in reliability and access.

With similar principle, in the Rail transportation mode, distinction is made between CL (Car Load) and LCL (Less than Car Load). In the Motor carrier transportation mode, distinction is made between TL (Truck Load) and LTL (Less than Truck Load). The following figure illustrates the transportation system modal alternatives distinguished between direct and consolidated shipment operation:

	Operation	
	Direct	Consolidated
Rail	CL (Car Load)	LCL (Less than Car Load)
Motor	TL (Truck Load)	LTL (Less than Truck Load)
Ocean	Charter	Scheduled
Air	Charter	Scheduled
Parcel	Courier	UPS/FDX

Figure 1.2. Direct versus Consolidated Transportation Operation

1.3 The Motor Carrier Industry --- TL and LTL

The thesis focuses on the procurement of TL services of Motor carrier transportation mode. The next sections provide background of the Motor carrier industry, the distinction between TL and LTL services, and the economies of each operation.

1.3.1 Motor Carrier Industry Market Overview

By 1998, with some $344 billion in 1998 revenues, the motor carrier business claimed 79% of the U.S. commercial freight transportation market. This total was divided between two sectors: private carriage and for hire. The following table breaks down the segment by operations:

Transportation	Billion $	% of Total
Private, Interstate	$115	21.3%
Private, Local	$85	15.7%
Truckload (TL)	$65	12.0%
Local For-Hire	$40	7.4%
LTL, National	$9	1.7%
LTL, Regional	$11	2.0%
Package/Express (ground)	$19	3.5%
Trucking, Total	**$344**	**63.6%**
Railroad	$36	6.7%
Pipeline (oil and gas)	$26	4.8%
Air Freight, Package Domestic	$17	3.1%
Air Freight, Heavy Domestic	$6	1.1%
Water (Great Lakes/rivers)	$7	1.3%
Transportation Total*	**$436**	**80.6%**
Logistics Administration	$35	6.5%
Distribution Total	**$105**	**19.4%**
Total*	**$541**	**100.0%**

**Excluding $ 5 billion in international cargo.*
Sources: Standard & Poor's, Data Resources, Inc., and Cass Information Systems.

Figure 1.3.1. Commercial Freight Distribution in 1998

It is estimated that the total Motor carrier activity exceeds $450 billion annually in the United States in following years [2]. There are approximately 83,000 truck fleets in the country. These fleets represent private fleets and those available for hire. About $260 B is accounted for private fleets, with the rest of the $190 B account for the for-hire carriers regulated by the Department of Transportation. A for-hire carrier is a company whose primary business is the transportation of goods for other companies for a fee. These regulated carrier number over 60,000. The top 100 carriers control about 50% of this sector. Market segment of the for-hire motor carrier industry are generally identified by the following types of service:

- **Small package services**: This is the smallest segment of the trucking industry and is dominated by United Parcel Service and Federal Express. By 1997, the segment stands for about $38 B revenues led by Airborne Express, Federal Express, UPS and US Postal Service [2].

- **Less-than-truckload, general freight (LTL):** LTL carriers consolidate and haul multiple shipments in one vehicle and operate a regular route system connecting local, breakbulk, and relay terminals. This segment generally involves shipments of less than 10,000 pounds. At least 75% of LTL revenues are obtained from interstate traffic.

- **Truckload (TL):** The truckload segment hauls full loads of general or specialized commodities over irregular routes from shipper's dock to consignee's location typically without passing through carrier terminals to consolidate or sort freight. Truckload shipments include a variety of general bulk freight, household goods, automobile transport, and chemical tanks. Less than 75% of TL traffic is derived from interstate commerce. The overall market size is estimated at well over $60 billion (about 200 carriers). TL segment is comprised of

General Freight and Specialized Service. With General Freight stands for about one third of the TL revenue.

The LTL and TL segments are extremely fragmented. The largest players in these markets are national in scope and have a presence in several market niches. There are thousands of regional trucking companies, many of which serve specialized niches. The major distinctions between the LTL and TL are average output, average load size, shipment size, and length of haul. TL carriers have lower average output, but higher average loads, shipment size, and average length of haul than LTL services.

1.3.2 The Economics of TL and LTL Carriers

In this thesis, we focus on the transportation services provided by the for-hire carriers, specifically, the TL service. To do that, we first need to examine the economics of shipper and carrier as a buyer-vendor relationship. For a shipper to procure transportation service from a carrier, the shipper tries to reduce freight rates through best matching of carrier's cost structure. The cost function for carrier can be represented by $C(X_1, X_2, \ldots X_i)$, where X_i is the number of shipments on lane i. Consider the following simple example with two lanes:

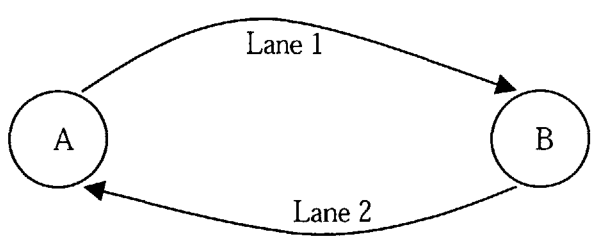

Figure 1.3.2. Example Transportation Network

- **Economies of Scale:** Economies of Scale are present if the unit costs for serving over a network decrease if the volume on all of the lanes increases in the same proportion. Using λ as the scale parameter, in the example network, if there is economy of scale, we would have:

  $$C(\lambda X_1, \lambda X_2) < \lambda C(X_1, X_2)$$

  Assume the monthly flow on the network is 100 shipments for lane 1, 10 shipments for lane 2. One TL carrier is assigned 50% on each lane --- 50 shipments for lane 1, and 5 shipments for lane 2. If economy of scale exists for TL, it would mean assigning 100% of the traffic instead of 50% would lower the unit transportation cost for the carrier. However, since TL carriers have very low fixed costs, and are more sensitive to the balance of loads, they tend to have slight diseconomies of scale if the network is very imbalanced. We will explain why TL carriers are more sensitive to balance of loads in the next section.

- **Economies of Scope:** Economies of Scope are present if the total cost of a single carrier serving a set of lanes is lower than the cost would be if multiple carriers served these lanes. Using the example network, if there is economy of scope, it can be represented by the following formula:

  $$C_A(X_1, X_2) < C_A(X_1, 0) + C_B(0, X_2)$$

  For the two carriers A and B, if economy of scope exists, it means using one carrier for both lanes is more cost effective than using one carrier for each lane. TL carriers exhibit significant economies of scope, because the cost of serving an origin-destination pair is heavily affected by the probability of finding a follow-on load out of that destination location.

- **Economies of Density:** In addition to economies of scale and scope, a carrier's cost can also be influenced by density of shipments. Economies of density are present if increasing either the customer density or the number of shipments per customer location, while holding the total number of shipments constant, results in the reduction of unit delivery costs. This means the consolidation of shipments would result in lower unit cost. This economy applies primarily to consolidated carriers (the LTL services), and little on the TL service.

In general, we conclude that TL carriers exhibit strong economies of scope, and LTL carriers exhibit significant economies of density. The procurement strategy with the goal of lowering delivery cost thus can arise from this important observation and will be illustrated in the next chapter.

2. Truckload Procurement

This chapter first illustrates the truckload operation at the line haul level. Through the breakdown of a line haul operation, the non-value added activities are exposed. The objective of optimizing the TL service procurement is about reducing/eliminating the non-value added activities, especially the cost of reposition activity. The chapter then discusses the common procurement model for the Truckload industry, with the purpose of identifying the necessity of a procurement bidding best practice. The chapter finally defines the scope of the thesis discussion.

2.1 Truckload Operation Activities

As mentioned previously, Truckload (TL) carriers operate like taxis, performing direct line-hauls from origin to destination. The following figure shows the chain of activities associated with the connection between two loads in a time-space diagram [1].

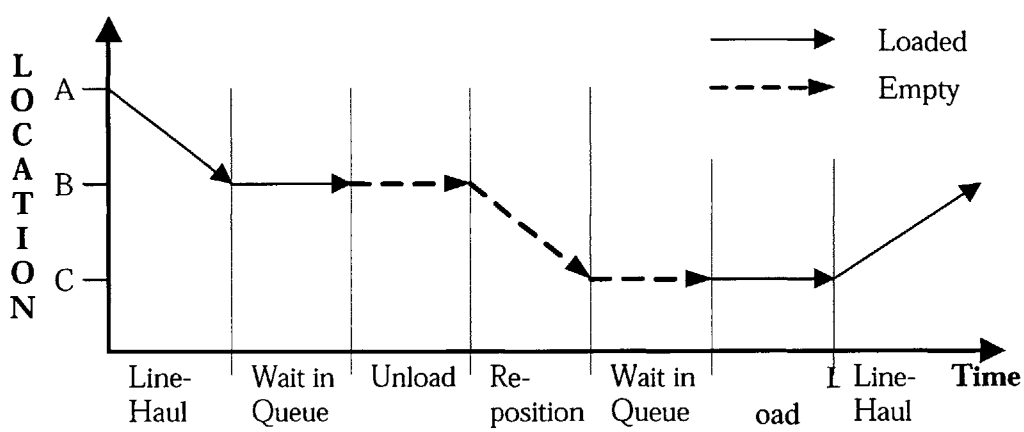

Figure 2.1. Connection activities between line-hauls

In the diagram, the vertical axis represents locations or nodes in the transportation network. We take an example of three locations: A, B and C. The horizontal axis is the time dimension, with each period of time marked with the corresponding activity. The solid arrow lines represent loaded movement that is usually paid activities. The dotted arrow lines represent deadhead, waits or other unpaid activities. Between two line-hauls, the unpaid (non-value added) activities that occupy equipment, resource and staff are usually unloading, reposition and Queue waiting. There are obvious reasons for the TL carriers to want to minimize or eliminate the unpaid activities. The same incentive goes to the Shipper: by corresponding better to the carrier's cost structure and reducing the uncertainty and waste for the carrier, the carrier can offer same service at lower rate. Among the three general unprofitable activities, the reduction of reposition activity is the one we focus on.

2.2 The General TL Procurement Process

In practice, most shippers follow a general five-step procedure to procure transportation services [1] in the sequence of strategic, tactical and operational procedures illustrated in Figure 3.

Step 1. Carrier Screening: The procurement process begins with the strategic decision of selecting the carrier base. Shipper usually uses some sort of screening process to reduce the number of potential carriers to a reasonable subset. The most common screening criteria are financial stability, geographic coverage, electronic data interchange (EDI) capability, and equipment availability. The purpose of carrier screening is to reduce the complexity and cost of the final selection process, by filtering the thousands of candidate carriers down to hundreds or dozens of quality guaranteed carriers.

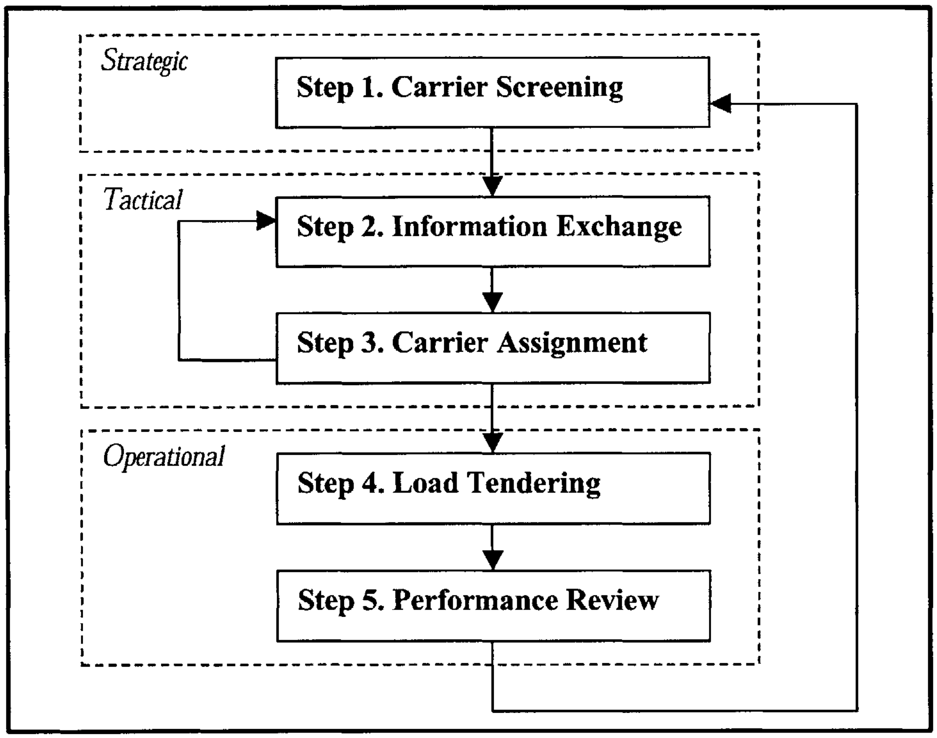

Figure 2.2. Transportation Procurement Model

Step 2. Information Exchange: After the set of potential carrier candidates has been selected, the shipper now provides shipment network details to the carriers, for example, the daily records of historical freight volume and movement. The carriers use this information to develop bids for the procurement services and volume commitments. The quality of the information and the format of the information that shippers communicate with the carriers are critical for the overall optimization of the procurement practice.

Step 3. Carrier Assignment: Once the shipper's transportation requirement has been shared with the carriers, depending on the bidding information the carriers submit, the shipper selects the final set of carriers that would best suit the procurement needs in terms of lowest cost. The shipper assigns carriers to the shipment network for each traffic lane. This is a lane-by-lane assignment that is performed either by a contract forming competitive bidding process or in the spot market. The contracts formed in this step are usually open agreements between shipper and carriers, as modification is usually allowed, and the load tendering carrier being picked for a lane at the time when the shipment is finally ready to be shipped. Step 2 and Step 3 are iterative and coupled as the tactical phase of the procurement process.

Step 4. Load Tendering: Although carriers have been assigned to each lane during the Carrier Assignment step, due to real time uncertainty, final choices need to be made for selecting exactly which carrier to use for each load as it becomes ready to ship. In other words, while the assignment process provides some guidelines as to which carrier to call for certain lanes, there is often need for real-time choices to be made between alternative carriers.

Step 5. Performance Review: The final step in the procurement process is review of each carrier performance by tracking important Key Performance Indicator like carrier refusal rates, on-time pickup/delivery rates, service standard, etc. This step provides feedback to the carrier screening procedure, and suggests corrective actions for the carrier screening decisions. Step 4 and

Step 5 are seen as the operational procedures. While important, they are outside the discussion of the thesis.

2.3 Thesis Scope

While many researches have been focused on the strategic phase of understanding of shipper's cost and service trade-off for identifying the criteria used for carrier selection, studies and major development have been done in the tactical transportation procurement phase during the last decade. This thesis focuses on the tactical steps of the procurement process: Information Exchange and Carrier Assignment. While important, the operational procedures are outside the scope of the thesis.

As mentioned before, the primary purpose for the Information Exchange and Carrier Assignment procedure is to find and allocate the right carriers serving the right lanes under service constraints with lowest possible cost. There are several ways that a shipper can perform the allocation:

- **Alternative one:** the shipper randomly assigns carriers to lanes or use a lottery;
- **Alternative two:** the shipper uses an administrative process where a traffic manager or transportation committee selects carriers based on direct negotiation;
- **Alternative three:** the shipper designs and conducts an auction to achieve efficient allocations. The outcome is to award lanes to those bidders that value them the most, in other words, assign traffic lanes to the carrier with the lowest cost structure for those lanes.

Studies have shown that alternative three, the auctioning method, used with a well designed approach, can generate much better results than the other two methods. Furthermore, using a conditional bidding process during an auction can be particularly beneficial to both shippers and carriers. This thesis thus discusses the conditional bidding practice that uses the optimization methodology for TL service procurement.

3. Combinatorial Auction in Transportation

As mentioned in the previous chapter, combinatorial auction framework can be used in the tactical procurement steps of Information Exchange and Carrier Assignment to optimize the service procurement cost. In this chapter, we discuss the mechanism of auction and the mathematical implementation of conditional bidding for TL transportation procurement. Here "shippers" are parties who have loads that need to be transported from origins to destinations and hence are the "auctioneers" in the auction framework. "Carriers" are service providers and "bidders". The items to bid are contracts to serve lanes with new loads, i.e. freight movement between an origin-destination pair. A bid is a set of lanes with a bidding price.

3.1 Auction Fundamental

An auction is a method of valuation and allocation. It is essentially a price discovery process that is most useful when the market value of an item is not established or is not suited for a single fixed price [1]. Items being auctioned can be physical goods like rare art, government and bank properties like houses, scare supplies like land, rights like spectrum licenses, etc. In transportation, the auctioning and bidding of TL services is primarily an allocation problem in which the shipper awards traffic lanes to carriers according to some mechanism.

An auction could be designed with different rules, and a slight change in rule could generate very different results in the winning bids in terms of allocation and item valuations. This section gives some basic explanations to the general forms of auctions that follow different rules.

3.1.1 Types of Auction

There are four commonly discussed types of auctions: 1. English or ascending price auction, 2. Dutch or descending price auction, 3. First-price sealed-bid auctions and 4. Second-price sealed-bid auctions. These types of auctions are known by different names, for example a Dutch auction is also known as a falling clock auction and a second-price sealed-bid auction is also known as a Vickrey auction.

In an English auction, bidders raise the price of a bid object until only one bidder is left. The object is then sold at that final price. In a Dutch auction the price of a bid object starts at a high level and is reduced by the auctioneer until one of the bidders declares that he is willing to pay that price. In a first-price sealed-bid auction bids are presented in confidence to the auctioneer and the winner is the highest bidder who then buys the bid object at his or her bid price. In a second-price sealed-bid auction, the winner buys the bid object at the price of the second highest bid price.

3.1.2 Individual versus Combinatorial Object Types

An auction can present the auctioning objects item by item, or combine items into packages each comprised of one or more items. Bidders submit bids against the individual objects, or the packaged objects that is "combinatorial". Many modern auctions are "combinatorial" in nature, meaning that a long list of items is offered for sale and bidders are free to submit bids on packages of items from the list. A particular item then can (and often does) add much to the price of one package, but little or nothing to the price of another. Combinatorial auctions are typically broken into a succession of "rounds," during each of which participants are free to bid on any unsold package, and at the end of which the auctioneer must either accept or reject each of the bids received. The process continues until a round occurs in which the auctioneer receives no acceptable bids. [5]

3.2 Combinatorial Auction for Truckload Procurement Problem

One auction practice that has been used widely in the TL procurement problem is lane-by-lane bidding and assignment, a sequential individual sealed-bid auction. During the Information Exchange stage, the shippers give aggregated volume estimated by lane, origin, region or system, based on historical record from previous year. Carriers then submit rates by lane in per mile or per move basis. After the information has been exchanged, Carrier Assignment is performed through Lane-by-lane analysis with low bid wins. Analysis is usually done using a spreadsheet, with no advanced optimization method involved. As illustrated in chapter 1, TL carriers exhibit strong economies of scope. The cost of serving a lane (an origin-destination pair) is heavily affected by the probability of finding a follow-on load out of that destination location. Thus the value of a lane cannot be truly discovered with a disconnected lane-by-lane auction practice.

Combinatorial auction in transportation, as the name implies, is the mechanism of combining multiple items, in this case, multiple lanes, as one or more packages for bidding purpose. Comparing to the lane-by-lane approach, optimum transportation procurement cost can be achieved using combinatorial auctioning since the carriers can provide better estimated cost based on the probability of follow-on loads provided in the bidding packages which usually is lower than the lane-by-lane bid price.

3.2.1 Conditional Bidding for Transportation Procurement

Within the combinatorial auction framework, one particular type of bid is conditional bids. A conditional bid includes multiple lanes that are awarded as an all-or-nothing package. The bid price is conditioned on the awarding of all of the lanes within the package, not just a portion of them. The term "conditional" is used to distinguish from the normal combinatorial auction terms like package bids, complex bids, or combination bids to emphasize the "all-or-nothing" criteria. It is important to notice that just combining lanes together into one or several groups does not mean it is a conditional bidding practice or combinatorial auctioning in transportation. For conditional bids, the lane involved need to be offered in at least two separate packages so the shipper cannot a priori determine to which package it should belong before the final optimized result is shown. If there is no conflict over how to combine the lanes, then the lanes should simply be grouped and treated as one lane using simple bids. A bid covering a lane is termed conditional since there are alternative ways in which the lane can be combined with other lanes.

3.2.2 The Integer Optimization Based Solution

The conditional bidding as discussed above is actually an integer optimization problem, as it is the decision about the shipper picking the carriers under the all-or-nothing constraint (and other applicable constraints like volume and demand, etc) that would minimize the total bidding price submitted by various carriers. A simple example is given in this section to illustrate the bid package construction and optimization resolution of the carrier assignment problem [18].

Consider a small network comprised of 3 locations: A, B, C, and 4 lanes (origin-destination pair): A to B, B to C, C to B, and C to A. Nine possible packages (#1 to #9) can be constructed with either one or more lanes for each package servable by a carrier. The network and packages are illustrated in Figure 3.1. Two carriers are bidding for the rights to serve the 4 lanes and submit bids for each of the packages a carrier is allowed to bid. In this simple case, assuming each of the two carriers is allowed to bid for all 9 packages. The bidding price for each package from each carrier is illustrated in Figure 3.2. Binary values "1" for each lane has been given corresponding to each package indicating whether the lane is included in the package.

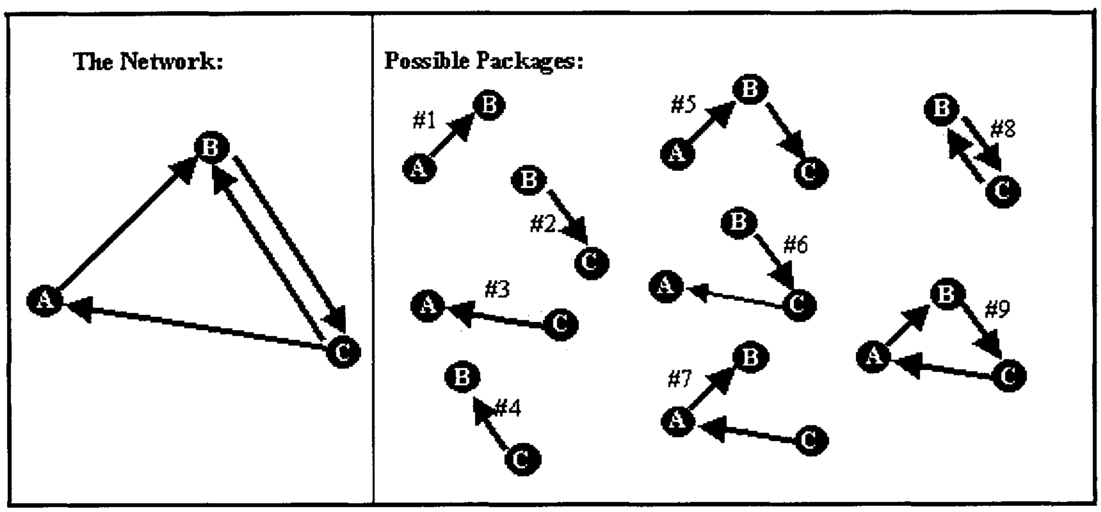

Figure 3.2.2.1 Network Example with Nine Bid Packages

The objective of the carrier assignment problem of this simple case thus can be defined as: Minimize total cost of the bid price through picking one or more carriers, while satisfying the constraint of one lane being served once and only once. Figure 3.2 shows an excel version of the optimization solution for the case using Excel Solver:

Package Bids																		
	Carrier 1 Bid Sets									Carrier 2 Bid Sets								
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#1	#2	#3	#4	#5	#6	#7	#8	#9
A→B	1				1		1		1	1				1		1		1
B→C		1			1	1		1	1		1			1	1		1	1
C→A			1			1	1		1			1			1	1		1
C→B				1				1					1				1	
Bid	$500	$525	$500	$475	$975	$950	$975	$900	$1,325	$525	$500	$525	$500	$1,000	$925	$925	$900	$1,375
Binary Variables:	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0

Constraints:

Const. for A→B:	1
Const. for B→C:	1
Const. for C→A:	1
Const. for C→B:	1
Objective Function:	$1,825

Figure 3.2.2.2. Bidding Packages and Bid Optimization Resolution

The decision variables are the Binary Variables of [0,1], indicating whether the bid of a package from a carrier is picked for service. The Constraints ensures that each origin-destination pair should only be included once when picking the carriers and packages. The Objective Function is to minimize the total bidding price for selected packages and carriers. The general formula for the optimization problem is illustrated as following:

Objective Function:

$$Min\sum_{p}\sum_{s} C_{p}^{s} X_{p}^{s}$$

Subject to:

$$1)\ \sum_{p}\sum_{s}\delta_l^{sp}X_p^s = 1 \qquad \forall l;\ p\in P; s\in S; l\in L$$

$$2)\ X_p^s \in [0,1] \qquad p\in P; s\in S$$

Where:

P : Bid package set; S : Carrier set; L : Lane set;

p : Bid package index (in the example, 1 to 9);

s : Carrier index (in the example, 1 to 2);

l : Lane index (in the example, 1 to 4);

δ_l^{sp} : Data input of binary indicator of [0,1], indicating whether lane l is included in package p bid by carrier s;

X_p^s : Binary decision variable indicating whether carrier s is selected for package p.

3.3 Implementation Factors for Combinatorial Auction

As simple as it seems in the above example, combinatorial auctioning is much more difficult to carry out in real life. One reason is because of the mathematical challenge of Integer Optimization for large-scale problem. Another reason is because of the implementation factors illustrated in this section.

3.3.1 Additional Constraints

On top of the integer and all-or-nothing constraints illustrated in the example, in real implementations of combinatorial auction for carrier assignment, usually the following additional constraints have to be included: demand for each lane, total number of carriers in the system, maximum number of carriers allowed for each location, etc. A general form of the optimization problem can thus be illustrated as following to embrace the additional constraints:

Objective Function:

$$Min\sum_{p}\sum_{s} C_p^s X_p^s$$

Subject to:

1) $\sum_{p}\sum_{s} \delta_l^{sp} X_p^s = 1 \qquad \forall l;\ p\in P; s\in S; l\in L$

2) $\sum_{p}\sum_{s} a_l^{sp} X_p^s \geq D_l \qquad \forall l;\ p\in P; s\in S; l\in L$

3) $\sum_{p}\sum_{s} X_p^s \leq K \qquad p\in P; s\in S$

4) $\sum_{p}\sum_{s} \vartheta_i^{sp} X_p^s \leq K_i \qquad \forall i;\ p\in P; s\in S; i\in I$

5) $X_p^s \in [0,1] \qquad p\in P; s\in S$

Where:

P : Bid package set; S : Carrier set; L : Lane set; I : Location set;

p : Bid package index (in the example, 1 to 9);

s : Carrier index (in the example, 1 to 2);

l : Lane index (in the example, 1 to 4);

i : Location index (in the example, 1 to 3);

X_p^s : Binary decision variable indicating whether carrier s is selected for package p.

δ_l^{sp} : Data input of binary indicator of $[0,1]$ indicating whether lane l is included in package p bid by carrier s;

ϑ_i^{sp} : Data input of binary indicator of $[0,1]$ indicating whether carrier s has a lane originating from location i to serve package p;

K : Total number of carriers allowed for the system;

K_i : Maximum number of carriers allowed for an originating location i;

3.3.2 Fixed Cost Considerations

The above formulation considers only the bidding price for each package by carriers, yet in real life fixed cost and other variable cost are usually encountered when adding a carrier to serve a certain location. If the situation is too important to be ignored, the additional cost should be included in the objective function. An example of the modified objective function is shown as below:

$$Min(\sum_p \sum_s C_p^s X_p^s + \sum_s \sum_i f_i^s y_i + \sum_s F^s)$$

where f_i^s is the fixed cost of adding carrier s to serve location i; y_i is the number of carriers serving location i; F^s is the fixed cost of adding carrier s to the system. Corresponding modifications should also be made for the constraints to include the additional variables and relationships.

3.3.3 Additional Lanes versus All Lanes

Due to the economy of scope and density character of TL transportation procurement, the relationship between bid rates, lanes and volumes is usually not linear and is much more difficult to evaluate in real life. In addition, shippers sometimes just want to put out additional lanes to bid while a set of carriers serve the existing lanes. The carriers bidding for the new lanes might not have the right or opportunity to bid for the most cost effective package thus posing additional constraint to the optimization framework. Adjustment in this situation calls for better lane packaging and carrier selection in order to achieve effective allocation and value discovery.

3.3.4 Complexity of Auction Design

Despite the uncertainties in cost structure and business requirement, auction has its inherent complexity in implementation for both carriers and shippers, comparing to the traditional RFQ method. A traditional RFQ method is the way shippers acquire transportation service by sending out Request for Quote to the carriers, then negotiate with the carriers to establish contracts. A combinatorial auction approach, in particular, has five main complexities:

3.3.4.1 Bid Package Construction

The first complexity is the use of a large number of potential packages and the need for the carriers to be able to price each of the combinations. The shipper must solve the set partitioning problem during the auction design process to decide the bid package structure that fundamentally scopes the economics of the optimization problem. The bid package structure here refers to how the different lanes are grouped into packages. One rule of thumb for designing the bid package structure of TL bidding problem is to match inbound and outbound traffic lanes so the bid packages will generally, but not always, consist of adjacent lanes in a tour. The packages that represent closed tours (a combination of lanes together which begin and end at the same location), for example, will most likely not contain more than four or five lanes since it becomes unmanageable to control in real-time tendering. The process of designing the bid packages involves load requirement identification, network construction, lane matching, efficient aggregation of lanes and bid package design. Algorithms and methodologies for each of the procedures for this bid package design process can be found in the "Pre-Bid Network Analysis" section in Caplice's Ph.D thesis [1].

3.3.4.2 Carrier Pricing

Another complexity is the need for carrier to price the various (and usually numerous) packages and submit bids. In one hand, different bid package offerings can result in different prices for serving the lanes; on the other hand, it is usually difficult for the carriers to estimate the true reservation value of a package even when the packages are well presented. The reason for this difficulty lies in the lack of historical information, uncertainty of business process for reaching a contract, and low level of communication between shippers and carriers. Depending on how the auction is carried out, for example, single round or multiple round, simultaneous or sequential, negotiation after winner picking, competition information availability, etc., carriers for risk averse reasons and profit considerations can over estimate the biding price and hide the fair value even if they have the ability to estimate the real reservation value. In addition, the carriers might be required to submit prices multiple times for various packages in a short time period that may be difficult to achieve without sophisticated pricing technology.

3.3.4.3 Mathematical Formulation

As a complicated Integer Optimization problem, a concise and solvable mathematical model representation is critical in real life implementation. While numerous, in general three typical models have been proposed by previous studies: the WMG model, the carrier-set model and the bid-set model. We hereafter give some brief explanations to the three formulations.

The WMG model (a model published by Moore, Warmke, and Gorban in 1991) is a mixed integer program (MIP) model that minimizes freight costs (usually only single-move, flat rates) by assigning carriers to specific shipping locations and traffic lanes and allocating traffic volumes. The results of the MIP were then used in a simulation model of daily freight operations which took into account service problems with the fluctuating shipping requirements and other considerations.

The simulation is to make the final decisions on the number of carriers, core carrier selection, carrier assignment to shipping locations, fixed and variable commitments, expected shipping volumes and commitments, and estimated costs and savings. The WMG model, however, fails to capture economies of scope inherent in the TL procurement problem. A Carrier-Set formulation is presented by Caprice in 1996 that treats the entire allocation of lanes and traffic volume to a carrier as a single decision variable. The model considers a carrier's economics as a whole that allows the inclusion of various volume discount pricing strategies while maintaining a linear IP. The formulation is designed to be solved using column generation. A lane-based, bid-set model has also been proposed by Caprice that captures economies of scope.

3.4.4.4 Winner Selection

Combinatorial Auctions typically are administered in a multi-round auction format where pre-qualified carriers are allowed to compete with one another and refine their bid responses to target the portions of the shipper's network that they value the most. It also seems straightforward to select the winners by solving the Integer Program once formulated and data have been given. But usually the scale of the problem is very large in a real life scenario, so that some heuristic method is needed to solve the program in the time required regardless of how advanced the hardware and software is. Depending on the tactics of auction design and solution, the final winners coming out of the system may be different and may incur different economy.

3.4.4.5 Price Determination

The final auction price are based on the bidding prices that the carrier submitted, thus shippers are concerned about the carrier's reservation values that the submitted bids are based upon. The carrier's reservation value of a bid is defined as the lowest bid that the carrier is prepared to make to acquire that lane from a shipper, given the current information. As mentioned before, the reservation value depends on the network character, operational constraints, competitive forces among the carriers and shippers, information availability and the capability of determining the values accurately and timely.

On the other hand, bidding price is not the only cost that incurs to the procurement. Other costs like auction implementation cost and carrier shift cost also influences the actual price of the service procurement. In addition, even when the winning bids have been picked, depending on the auction rule of the first price or second price, single or multiple round, sealed or open, the final price settled for the contracts can be different. It is important to take account of the auction rules and cost factors other than the package bids to come to the fair final price for the winning carriers.

4. Applications of TL Combinatorial Auction

TL combinatorial auctioning has remained a theory until the advancement of software and hardware technology that has enabled the process and the benefits to be demonstrated. In this section, we give some discussion as to how the industries have been accommodating the advanced combinatorial auction process and what technology providers are available to facilitate the efforts.

4.1 Real Applications and Benefits

In the last several years, many large companies that have heavy needs for transportation procurement have been experimenting with sophisticated technology enabled combinatorial auctioning in replacement of the traditional manual simple bidding process or RFQ-negotiation process. Leading examples can be seen in Sears, Home Depot, W-Mart, etc. We hereby pick Home Depot and Sears as two pioneer example to illustrate the real life application of combinatorial auctioning.

Up until mid 90's, Home Depot's transportation bidding process was completely manual. Home Depot would provide the carriers with origin and destination zip codes for the locations in its network, and aggregate demand forecasts (expected number of annual moves) for each origin-destination pair (referred to as a lane). Carriers did not, however, have information on Home Depot's demand or growth patterns. Based on this sparse and aggregate information, carriers would bid on each origin-destination pair separately. In an effort to improve the efficiency of the bidding process, in 1996, Home Depot semi-computerized the bidding process by asking the carriers to submit bids on a standardized Excel spreadsheet on a diskette. Nevertheless, Home Depot continued to procure bids for lanes on an individual basis and limit the information that was provided to the carrier regarding the flow of orders on a lane. To achieve higher efficiency and effectiveness in transportation services, Home Depot partnered with i2 Technologies, Inc. to develop a flexible bidding mechanism for truckload shipments. The new bidding process provides detailed information to the carriers about Home Depot's network and demand, and allows carriers to bid for combinations of lanes, as well as for individual lanes. This helps carriers to better analyze the impact of certain bidding alternatives on their own network, and to achieve synergies, for example, by creating "continuous" moves which don't require empty travel between the lanes. Furthermore, the new bidding mechanism is Internet-based, which allows carriers to create and submit their bids electronically via a standard format. The first successful application of this new bidding process was completed in January 2000 [8].

Another example, Sears, Roebuck and Co. is one of the largest procurers of trucking services in the world through its wholly-owned subsidiary, Sears Logistics Services (SLS). SLS controls supply chain elements that originate at the vendor (manufacturer) through distribution centers to retail stores, and from vendor to distribution centers to cross dock facilities. In the early 90's, SLS sought to lower its truckload carrier costs by consolidating trucking service acquisition to allow truckload carriers to better deploy their assets and share the savings with SLS. SLS had contracted the consulting firm of Jos. Swanson & Co. (JS&Co) to advise how to implement the desired consolidation of trucking. JS&Co identified as promising the combined value trading technology being developed within the California Institute of Technology (Caltech) by the founders of Net Exchange (NEX). SLS, JS&Co, and NEX formed a team to implement the desired consolidation using combined value auctions. The initial auction involved 854 lanes with a service cost of approximately $190 million per year. The combined value sequential auction that was implemented reduced this cost to $165 million per year, a 13% savings. [9]

4.2 Technology Providers

While many technology providers have emerged (or vanished) during the last few years, Logistics.com and Schneider Logistics Inc. are two of the major technology providers in the transportation combinatorial auction arena that demonstrated sophistication and good customer service levels.

Logistics.com Inc. (acquired by Manhattan Associates in 2002) provides integrated logistics planning and execution solutions for shippers and carriers. The OptiBid (Version 3 by June, 2003) is the company's transportation e-procurement solution that allows trucking companies to bid on bundles of lanes. The company claims that approximately 35 Fortune 500 shippers and third-party logistics providers and 2000 carriers have used Logistics.com's OptiBid to enable the procurement of over $7 billion in annual recurring freight services, resulting in over $480 million in savings.

Schneider Logistics Inc. has just released a collaborative transportation procurement product, SUMIT CVA™, the combined value auction (CVA) process is intended to give shippers the ability to develop strategic transportation solutions that simultaneously lower costs and improve service levels by leveraging their carriers' existing capacity and networks. Through a multi-round auction format, SUMIT CVA enables pre-qualified carriers to view a shipper's transportation requirements and identify and bid on packages of lanes that best optimize their assets. Carriers are able to enter their rates, create packages and conditional bids, review specific service requirements of the freight, and analyze bid results in a Microsoft Excel-based bid workbook. Schneider Logistics integrated and customized the combinatorial trading framework from Net Exchange, which is a provider of optimization solutions that comprise contracts. Net Exchange is formed by the California Institute of Technology in May 1994, based on research in computational combinatorial trading.

5. Summary

Generally speaking, combinatorial auctions in transportation procurement can lead to higher economic efficiency. Being an important task, the procurement of transportation services poses great cost saving opportunities for shippers. The traditional way of procuring a commodity like TL services with service constraints involves shippers seeking transportation services from outside companies and typically putting out a request for quotes from a set of carriers. Contracts are then signed based on negotiated service charges. This process is similar to a simple sealed-bid auction in which each bidder submits a sealed bid for a single item. When shippers needed to procure transportation services for a set of distinctive delivery routes (called lanes) with different origins and destinations or delivery schedules, they would obtain quotes for each lane individually and repeat the simple auction process for each lane, or they might negotiate for bundles of lanes with one carrier at a time. In the last few years, software has been developed to allow shippers to make all lanes available for bidding simultaneously and to allow carriers to simultaneously bid upon combinations of individual lanes --- thus the application of the combinatorial auction, and the application has been reported to result in significant cost savings for both shippers and carriers [6].

On the other hand, the practical combinatorial auctions are hard to implement and sometimes may even have negative value due to the inherent complexity and technical difficulty in auction design and conditional bidding. The true value creation of using the conditional bidding scheme to secure transportation services thus needs to be carefully analyzed before making the decision.

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