PRODUCTION AND OPERATIONS MANAGEMENT
POMS
Vol. 16, No. 4, July-August 2007, pp. 423–436
ISSN 1059-1478 | 07 | 1604 | 423$1.25

Electronic Markets for Truckload Transportation

Chris Caplice
MIT E40–365, 1 Amherst Street, Cambridge, Massachusetts 02139, USA
caplice@mit.edu

A wide variety of electronic marketplace formats are used in the Truckload (TL) transportation industry, including combinatorial auctions, private and public exchanges, and electronic catalogs. Combinatorial multi-attribute auctions are commonly used strategically to populate electronic catalogs, commonly called "routing guides," with pricing, assignments, and priority logic. Private and public exchanges are used to complement the electronic catalogs in cases where the catalog fails. This paper discusses the TL transportation market, places the procurement of services in the context of electronic marketplace formats, and illustrates how these are currently used.

Key words: freight transportation; auctions; electronic markets; electronic catalogs; transportation management
Submissions and Acceptance: Received March 2006; revision received June 2006; accepted July 2006.

1. Introduction

This paper provides an overview of the use of electronic markets for the procurement of truckload (TL) transportation services by the buyers of these services (shippers). Truckload transportation firms (carriers) generally handle shipments that are picked up at a location and driven directly to a single destination with no intermediate stops. This is contrasted with less-than-truckload (LTL) or parcel shipments where the individual shipment might be picked up and transported to an initial sorting hub on one vehicle and reloaded onto a separate vehicle for movement to another terminal before finally being loaded onto another vehicle for final delivery.

Currently, the use of a variety of different electronic market formats is widespread for TL services. The names used to describe these mechanisms, however, do not always match those used in the general electronic commerce literature. The three most common forms of electronic commerce trading models mentioned in the literature are auctions, catalogs, and exchanges (see, for example, Kaplan and Sawhney 2000 or Sculley and Woods 1999). So, although reverse auctions are the predominate mechanism used for strategic procurement of TL services, they are commonly referred to as either "bids" or "request for proposals" by shippers and carriers alike. Similarly, although all large shippers manage their TL operations through the use of electronic catalogs, they call the systems "routing guides" or "transportation management systems" (TMS). Finally, although some form of public or private exchange is used by most shippers for at least a portion of their TL business, the mechanism is referred to as the spot market. In fact, the words auction and exchange have negative connotations for both shippers and carriers alike in the TL industry. So, although the underlying mechanics of electronic markets are commonplace in TL procurement, the formal names are rarely mentioned.

There are several reasons why it is worthwhile to study the use of electronic markets for TL transportation services. First, the U.S. TL market is very large. In 2004, the domestic U.S. freight transportation market was $770 billion and accounted for 6.6% of the GDP (Standard & Poor's 2006). Trucking comprised $671 billion or 87% of the total market with the TL sector alone accounting for $312 billion.

Second, the TL market is very fragmented. As of 2002, there were over 45,000 TL carriers registered in the United States with 75% of them owning fewer than six power units (American Trucking Associations 2002). In 2003, there were only 500 TL firms with annual revenues in excess of $10 million and just 1,000 with revenues in excess of $2 million. The seven largest publicly traded TL firms combined represent less than 4% of the total TL market (Standard & Poor's 2006).

Third, in addition to being a large component of the overall economy, transportation is the largest logistics cost for most shippers, averaging over 60% of a firm's total logistics costs (Wilson 2005). Transportation has been estimated to average 3 to 4% of annual sales revenue for most firms (Ballou 2004; Enslow 2004). TL trucking is typically the largest component of a shipper's transportation budget (Wilson 2005). With the shift to more international inbound shipments from ports to distribution centers, the importance of longer haul TL services is only increasing.

Fourth, shippers use a variety of contractual arrangements for TL services, with the three most common being private fleets, for-hire contract carriers, and spot. Private fleets, valued at $294 billion in 2004, are composed of trucking operations run by firms whose primary business is not transportation. Contract relationships consist of a shipper and carrier who have entered into an annual (or longer) contract that stipulate rates for specific lanes (origin destination pairings, e.g., Chicago, IL, to Atlanta, GA). This is the most common form of relationship for for-hire carriers. In a spot market the carrier is selected on a load-by-load basis and the price is determined at the time of the physical shipment, rather than through a standing contract. It is difficult to estimate the exact size of the contract and spot TL markets because these statistics are not reported directly to government agencies or analyst firms. The common approximation in practice is that contract relationships cover 90 to 95% of the $312 billion for-hire TL market, whereas spot constitutes the remainder. Shippers will typically use a portfolio of all three types of relationships, to some degree, across their freight transportation network. In fact, firms with large private fleets, such as Wal-Mart Stores and Sysco Foods, are typically also large buyers of contracted and spot TL services.

Because the TL market is large, fragmented, important to buyers, and procured under many different relationships, it has been subjected to an exceptionally large number of first-generation procurement mechanisms over the past 25 years since it was deregulated in the United States. In 2000, for example, there were more than 50 Internet-based transportation exchanges in operation (Fontanella 2000). Very few of these were in existence just 5 years later. Optimization-based auctions for TL services were introduced in the late 1980s (Moore, Warmke, and Gorban 1991), with more complex combinatorial auctions in use as early as 1992 (Porter et al. 2002; Ledyard et al. 2000).

The three marketplace forms (auctions, catalogs, and exchanges) are intertwined. The objective of a shipper's strategic auction, for example, is to populate his own private electronic catalog for use in daily operations. When the catalog fails, that is, when the planned capacity and assignment is not sufficient, then the shipper relies on an exchange (public, private, or some combination) to find the needed capacity. Shippers utilize all three forms in the procurement and management of TL services.

The remainder of the paper is organized as follows. Section 2 provides an overview of TL transportation operations and networks. Section 3 discusses the use of auctions for the strategic procurement of TL services. Specifically, reverse combinatorial auctions will be discussed. Section 4 presents the operational side of TL services and shows how shippers use electronic catalogs and exchanges. Additionally, the automation of these exchange forms is illustrated. Finally, Section 6 summarizes the paper and recommends areas for future research.

2. Overview of Truckload Transportation

The physical process for truckload operations is straightforward and involves three parties: a shipper, a carrier, and a receiver. The shipper is a retailer, manufacturer, distributor, or some other firm that needs to move goods. The carrier is a trucking firm that owns transportation assets and whose primary business is the actual movement of freight. The receiver is the firm to which the shipment is being sent. The receiver can be the same firm as the shipper or a different one (e.g., a shipment to a customer).

2.1. Truckload Operations

The shipper's process for managing TL operations is as follows. Once it is determined that a load of freight is ready to move, the shipper selects a specific TL carrier and communicates the particulars of the shipment to the selected carrier. The carrier will then either accept or reject the shipment. If it is accepted, the carrier will coordinate with the shipper for scheduling the pick up. If the load is rejected, the shipper will select another TL carrier and repeat the process. Once a carrier has accepted the shipment, the carrier arrives at the shipper's location, loads the trailer, and transports it directly to the receiver's location, where it is unloaded. At that point, the carrier's truck is free to find its next load. In some cases, the shipper will pre-load a trailer and have it ready for the TL carrier to pick up. This is known as "drop and hook" and is used to reduce the waiting and loading time for the carrier at the origin or destination.

Three things are worth noting in the process. First, after the carrier delivers its shipment, it must drive to its next customer's location. This is referred to as an empty or "deadhead" move because the carrier is not paid by any shipper for driving this distance. Large sophisticated TL carriers can average between 6 and 12% empty miles, whereas private fleets average over 24%[1] (see, for example, Werner Enterprises 2006; USA Truck 2006; Corsi and Stowers 1991). The carrier's search and movement cost for finding and securing the follow-on load can be a relatively large component of the TL carrier's costs.

The need to relocate from the destination of one load to the origin of the subsequent load results in strong cost interdependencies or economies of scope for TL carriers. The cost of serving a lane is strongly affected by the probability of finding a follow-on load out of that destination. The by-product of one shipment (ending up at a certain location) can influence the cost of performing a subsequent shipment from some other location. Securing a balanced network reduces the uncertainty in connection costs and can lower the carrier's overall costs. Thus, a carrier may offer a lower price for hauling a given number of loads from A to B if it also hauls loads from B to A. Economies of scope explain why combinatorial auctions were first introduced in the TL industry. Combinatorial auctions allow the bidder (the carrier in this case) to submit a package bid on a specified collection or set of items (lanes). Package bids, it is thought, allow a carrier to capture the economies of scope of multiple lanes within a TL transportation network. Types of bids used in TL auctions are discussed in greater detail in Section 3.2. Economies of scope also explain why some carriers will provide a discount to a shipper if they can be offered a *continuous move* where the inbound delivery of a trailer to a facility is matched in real time with an outbound shipment for the same conveyance.

The second point to note is that TL carriers will often reject a load that is tendered to them. This is because, in many cases, a carrier will not have the exact equipment available in the exact location at the exact time that the shipper requests it. Cooke (2004) reported 5% of all loads offered to a TL carrier are rejected by the carrier and almost 10% of the time the equipment is not ready when requested. Harding and Caplice (2005) analyzed a data set of 400,000 shipments valued at $300 million crossing multiple shippers and involving 284 carriers and determined carrier acceptance ratios averaged 74%, with a median of 79%. Although many carriers have stellar accept ratios (maximum was 99.9%), roughly half are below 80%. The high level of rejection implies that shippers must have alternate carriers in place, along with appropriate mechanisms to access them.

[1] This high empty mile percentage is usually for shorter haul trips where the vehicle goes loaded in one direction and returns back to the warehouse empty.

The third point to note is that the specific method by which a shipper selects and communicates to a carrier was not discussed in detail. In fact, this is the major topic of the paper. The processes for carrier selection and communication during daily operations are intertwined. They can be as simple as a ranked list of carriers on an index card for selection and a phone for communication or they can be highly sophisticated software systems, featuring an electronic catalog with exception management logic and automatic escalation to public or private exchanges. The more sophisticated carrier selection and communication systems are quite common and are embedded in most top-tier TMS that shippers use to manage their daily TL operations.

2.2. TL Freight Networks

Truckload transportation networks are best characterized as having many arcs (lanes) and nodes (origins and destinations), with most of the total volume distributed on few lanes, while the majority of the lanes have little volume.

For example, a typical consumer package goods manufacturer with just under $300 million in annual TL expenditures will have 1,000–2,000 specific ship-to and ship-from points. The number of lanes within the TL network depends on the geographic specificity used to represent the origins and destinations. For example, using 5-digit postal code regions to define each location results in over 5,000 distinct lanes, using 3-digit postal code regions results in 3,000 distinct lanes, and using state level regions results in just over 500 lanes.

Regardless of the level of location specificity, however, the distribution of volume on lanes within a TL network follows a power law distribution where a very low percentage of traffic lanes carry a very high percentage of the volume. Typically, about 30% of the TL volume will flow on just 1% of the lanes and 80% of the volume will flow on 12 to 14% of the lanes. Also, most TL networks will have 15 to 30% of their lanes carrying only 1 load per year (Caplice 1996; Harding 2005). The ratio of the mean to the median volume of loads per year per lane ranges from 8 to 13.

2.3. Network Representation

Prior to running a strategic auction, the shipper must determine how to represent his network to the carriers. A shipper will rarely include every 5-digit postal code to 5-digit postal code lane in an auction. Instead, he will segment his network into different types of lanes by changing the level of geographic specificity of the origins and locations. Lanes are generally classified as point to point, point to zone, zone to point, or zone to zone (Caplice 1996). A point location is usually a 5-digit postal code region with anything larger being considered a zone. An annual threshold volume is typically used to determine how large a zone to use.

The shipper will auction off the higher volume point-to-point, point-to-zone, and zone-to-point lanes with a forecasted volume at an annual, monthly, or weekly level. These are sometimes referred to as *guaranteed traffic* or *primary* lanes. The small amount of volume not included in the primary lanes is typically spread across many lanes and will, therefore, not be explicitly auctioned. Instead, shippers will usually ask for back-up rates from carriers for a mutually exclusive and collectively exhaustive set of zones (typically in a state-to-state matrix) without providing any volume projections. The back-up rates are rarely considered in any TL auction. Instead, the carriers that win any primary lanes in the auction have their state-to-state matrix rates uploaded into the TMS.

When establishing the representation of the network, the shipper must consider both effectiveness and coverage. The more specific a lane is, the more effective it will be in that the carrier's costs will be more accurately reflected. As the size of the origin or destination gets larger, the uncertainty of the amount of required deadhead increases. However, the shipper also must collect rates on those regions where traffic might materialize over the course of a year.

The net effect is that a shipper will receive rates for overlapping lanes. For example, suppose the shipper has a plant in Atlanta, GA 30301 that delivers to a number of destinations in the state of Illinois that include an average of 10 loads a week to a major distribution center in Chicago, IL 60601, an average of 3 loads a week to smaller customers located around Chicago, all in the 606 postal code region, and about 1 load a month to occasional sites elsewhere in the state. The shipper could offer three distinct lanes:

Point to point: Atlanta, GA 30301 to Chicago, IL 60601 for 10 loads/week;

Point to zone: Atlanta, GA 30301 to IL 606 for 3 loads/week;

Zone to zone: Georgia to Illinois as a back-up rate (no volumes provided).

A carrier could submit bids on all three of these lanes with very different rates. Interestingly, and counterintuitively, the rates on the most specifically defined lanes are not always the lowest rates. Sometimes the back-up rates can be lower than the rates a carrier provides as a primary lane. This is because the primary lane assignment implies some level of acceptance ratio commitment. The carrier is expected to have capacity available for these loads. For back-up rates, the carrier only must provide a truck if he has one that is convenient—thus, he can charge a lower rate and only honor it when it makes economic sense.

The network representation of a shipper's TL freight and the resulting multiple overlapping contract rates impact the way shippers utilize the three different forms of electronic markets: auctions, catalogs, and exchanges. The next two sections explore the use of these mechanisms at the strategic and operational levels.

3. Strategic Procurement: Auctions[2]

Shippers have been using reverse auctions to establish long-term TL transportation contracts since the U.S. surface transportation industry was deregulated in the 1980s. Initially, these were rather manual processes with, perhaps, the use of spreadsheets to sort and rank each carrier's bids by lane.

The first reported use of optimization to determine the winner of a transportation auction (that is, solve the *winner determination problem* or WDP) can be traced to the Reynolds Metals Company in the late 1980s. Moore, Warmke, and Gorban (1991) describe how Reynolds centralized its transportation management system and how it bid out and assigned lanes of traffic to carriers. They developed a mixed integer program (MIP) model that minimized transportation costs by assigning carriers to specific shipping locations and traffic, taking into consideration individual carrier capacity constraints, equipment commitments, and other transportation-specific concerns. Although it allowed for simple bids with volume constraints, it did not permit package or combinatorial bids.

Porter et al. (2002) described combinatorial auctions (which they referred to as "combined value auctions") run in 1992 by Sears Logistics Services, in what was probably the first application of package bidding in the transportation context. They reported savings of 6 to 20%. Although the model allowed package bids, it did not permit the use of any business-specific side constraints, as did the model developed by Moore et al. (1991).

The use of combinatorial auctions for transportation services (incorporating both package bids and business side constraints) increased dramatically throughout the 1990s, as described by Caplice and Sheffi (2003, 2006) and Elmaghraby and Keskinocak (2003). The first commercially available software specifically designed for combinatorial auctions for transportation services, OptiBid, was released in 1997. Other software companies followed suit and by 2005 approximately half a dozen transportation procurement software packages that incorporate package bids were available in the market. Since 1997, hundreds of companies have run optimization-based combinatorial TL auctions using these software tools, including The Procter & Gamble Co., Sears Roebuck and Co., K-Mart Corp., Wal-Mart Stores, Inc., Best Buy Co., Inc., PepsiCo, International Paper, Crown Cork & Seal, The Home Depot Inc., Bridgestone Corp., Ford Motor Company, Compaq Computer Corp., Staples, Inc., Limited

[2] Most of this section is adapted from Caplice and Sheffi (2006).

Brands, Inc., Ryder System, Inc., the Rite Aid Corp, and many others.

The remainder of this section discusses the standard auction process, the bidding language used in TL auctions, and different formulations of the WDP.

3.1. Strategic TL Auction Process

Strategic TL procurement events are usually conducted annually in a reverse auction. The items procured are hauling commitments on primary lanes. In addition to the rates submitted by the carriers, many non-financial factors can be considered, including level of performance, type of carrier, number of carriers, etc. Because of these additional considerations, the predominant mechanism used is a single-round, sealed bid combinatorial auction utilizing optimization to solve the WDP. Although multiple-round combinatorial auctions are exceptionally rare, in any TL auction there is usually a last soft-negotiation round after the WDP is solved. In many cases, incumbent carriers are provided an opportunity to match the current winning rates on lanes they might lose.

It is important to stress again that the outcome of a strategic TL auction is not completely binding. As discussed previously, the carrier will not always have equipment available when the shipper requests it and the shipper does not guarantee a minimum volume or dollar amount to the winning carriers. Suppose, for example, a shipper runs an auction and awards the lane from Chicago to Atlanta to a carrier. If, over the course of the year, no truckload traffic materializes on that lane, then the carrier will receive no financial compensation. The carrier is, however, contractually bound to honor the rate for a lane he won in an auction if he in fact does haul a load on that lane.

Strategic TL auctions all follow a standard three-step process consisting of pre-auction, auction, and post-auction activities.

During the pre-auction stage, the following tasks are completed:

- The shipper forecasts the demand for the upcoming period and creates a representative network of expected weekly (or monthly) flows on each primary lane. The issues of lane definition and geographic specificity mentioned in Section 2.3 apply here.
- The shipper determines which carriers to invite to the auction—the number of carriers invited to participate in TL auctions ranges from a dozen to hundreds. An analysis of a sample of 50 TL auctions run between 1997 and 2003 showed a correlation of 0.34 for the number of carriers invited and the value of the business being auctioned off. It is rare for incumbent carriers to not be invited to participate, so most of the bidders in a TL auction have at least some private information concerning the shipper's business.
- The shipper determines what information the carrier is required to submit back. This usually includes the form of the price (per move, per mile, per weight, etc.), service details (days of transit, capacity availability, equipment type, etc.), and the types of bid allowed (see Section 3.2).

During the auction stage, the following steps are performed:

- The lanes are communicated to the carriers. Although e-mail is the most common communication tool used for transportation auctions, larger shippers using specialty software typically use some sort of Web interface (Caplice, Plummer. and Sheffi 2004).
- The carriers analyze the network, determine the rates to offer, and submit their bid rates. Depending on whether the format of the auction has single (most common) or multiple rounds, the carriers may receive feedback information and have to resubmit updated rates.

During the post-bid stage, the following tasks are performed:

- The shipper receives the carriers' bids and solves the WDP.
- Once the shipper solves the WDP, the results are uploaded to the electronic catalog (routing guide) used in operations. This is discussed in greater detail in Section 4.

The use of combinatorial auctions with side constraints is widespread for TL services procurement. Combinatorial auctions permit carriers to use sophisticated bidding language to better capture their underlying economics and allow shippers to consider non-financial aspects in the carrier selection decision. The next two sections discuss each of these points.

3.2. Bidding Language

The communication language used during the auction determines how the carriers can respond to the shipper's request for bids. Traditional practice in transportation is for carriers to submit a per-shipment or per-mile rate for haulage on each lane, regardless of the volume of business they might win on that lane or any other lane. These are usually called "*simple bids.*" This form of bid language leads to the carriers hedging their bid prices to cover those instances where they do not win any supporting business.

Combinatorial auctions allow carriers to make explicit their otherwise implicit pricing assumptions. They can provide a lower bid price, given certain other conditions are met. In transportation, these are sometimes referred to as "conditional bids." That is, the bid rates submitted are conditional on a pre-defined set of actions also taking place. Lane-based package bids are but one type of conditional bids.

The different types of conditional bids that are currently in use within transportation auctions are described below.

3.2.1. Simple Lane Bid

A bid rate applies to all shipments on that lane, regardless of the volume awarded. The number of shipments awarded to the carrier on that lane is determined by the shipper. Each bid may include specific service capabilities (transit time, trailer size, weekend coverage, additional safety factors, etc.) that are only available if that bid at that rate is awarded. This is the most widely used type of bid. Oftentimes shippers do not even provide carriers with lane volume estimates or forecasts. Carriers can include different service levels in multiple simple bids for the same business to "de-commoditize" their offerings.

3.2.2. Simple Lane Bid with Volume Constraints

A bid rate applies to all shipments on a lane but only if the carrier is awarded at or above the minimum commitment constraint and at or below the maximum capacity constraint for that lane, region, set of lanes, or system, as specified.

Capacity (upper bound) constraints are more commonly submitted by carriers than minimum commitment constraints. They are equivalent to budget constraints in that they allow carriers to bid beyond their available capacity on different lanes. Shippers rarely allow minimum commitment constraints as a result of the issues of feasibility in solving the WDP.

3.2.3. Static Package Bids (AND)

Static package bids are a set of individual lane bid rates that apply to each lane within that set, conditional on the shipper awarding the carrier all lanes within the set at the exact volume levels specified by the carrier. Most commercially available software tools handle static package bids.

3.2.4. Static Either/Or Package Bids (XOR)

Static either/or package bids have two or more package bids with rates that apply conditional on the shipper (1) only awarding the carrier one of the bids and (2) awarding that carrier all lanes within that package bid.

This communicates the message, "give me this set of lanes, or this set of lanes, but not both." The message, "Give me this set of lanes or that set of lanes or both" is referred to as an OR bid. It can be achieved through the use of non-overlapping AND bids.

3.2.5. Flexible Package Bids

A set of individual lane bid rates applies to each lane within that set, conditional on the shipper awarding the carrier all lanes within the set within volume ranges specified by the carrier for each lane within the set. Note that with static package bids the shipper does not determine the specific volume level awarded on each lane within that package. The carrier determines the lane volume as part of the submission of the static package bid. With flexible package bids, on the other hand, the shipper selects the specific volume level awarded on all lanes within the awarded package bid, as long as it adheres to the carrier's ranges. This means that although a carrier knows the total value of a static package bid at the time of bid submission, he only knows the potential range of values for a flexible package bid at that same time. Only after the WDP is solved will the carrier know the actual number of shipments and total dollar value of a flexible package bid.

The carrier specifies for each lane within the package both the rate per load and the minimum and maximum volume per week, month, or year. Additionally, the carrier can provide package level capacity ranges. If the shipper is awarding only one carrier per lane, then these bids are equivalent to static package bids.

3.2.6. Simple Reload Bids

A carrier specifies that the total number of awarded inbound loads to a facility is equal to, or within some parameter of, the number of awarded outbound loads from the same facility. The WDP model determines the actual volume awarded, so that the conditional bid only specifies the ratio of the awards. This is done to improve the balance at a specific site and increase the potential for *continuous moves* at that site. It differs from flexible package bids in that it includes the condition that balance between two sets of lanes must be met.

3.2.7. Tier Bids

A schedule of bid rates applies to a lane for a predetermined set of volume ranges on that lane. The relevant rate is applied to each shipment depending on the volume of loads processed that week or month. This captures the economies of scale of volume on a lane. Because the actual rate charged is determined during execution, it more accurately maps the carrier's costs.

Regardless of the type of conditional bid used, the end result is a rate per load for each lane used in execution. Although the total value of each bid is used for analysis, it is always divisible and easily allocated to each specific lane. In fact, the final upload to the downstream transportation management system is typically just a set of individual lane rates for each winning carrier.

3.3. Winner Determination Problem

The WDP is at the heart of optimization-based auctions. For all TL auctions, the WDP is formulated as a MIP. Although most software systems use a thirdparty solver, such as CPLEX, to solve the WDP, there has been some recent work around developing other more specialized solution approaches (Sandholm et al. 2005).

The WDP assigns volume to carriers by lane (a single carrier is responsible for hauling on each lane) or by load (each carrier is assigned a number of loads to haul on each lane awarded). In practice, most software applications use models that assign by load because this permits other network and business-specific aspects to be considered.

The most straightforward carrier assignment model permitting both simple bids and static package bids results in the formulation

$$\min \sum_c \sum_k \left[\left(\sum_{\forall i,j \in k} {}_c c^k_{i,j} {}_c \delta^k_{i,j} \right) {}_c y^k + \sum_{i,j} ({}_c c^k_{i,j} {}_c x^k_{i,j}) \right], \quad (1a)$$

$$\text{subject to} \sum_c \sum_k ({}_c x^k_{i,j} + {}_c \delta^k_{i,j} {}_c y^k) = x_{i,j} \quad \forall \; i, j \quad (1b)$$

$${}_c x^k_{i,j} \geq 0 \; \forall \; i, j, c, k \quad (1c)$$

$${}_c y^k = [0, 1] \; \forall \; c, k, \quad (1d)$$

where the notations are as follows.

Indices:

i: Shipping origin region

j: Shipping destination region

k: Bid package identification

c: Carrier identification.

Decision variables:

${}_c x^k_{i,j}$: Number of loads per time unit (week, month), on lane i to j, assigned to carrier c, under package (which in this case is a simple bid) k

${}_c y^k$: = 1 if carrier c is assigned static package bid k; = 0 otherwise.

Data:

$x_{i,j}$ Volume of loads from shipper s, on lane i to j, that are being bid out

${}_c c^k_{i,j}$: Bid price per load on lane i to j, for carrier c, as part of conditional bid k

${}_c \delta^k_{i,j}$: Volume of loads on lane i to j that carrier c is bidding on as part of package bid k

The objective function [1a] minimizes the cost of assigning carriers to haul loads over the shipper's network. The package bid cost coefficient is the total cost per planning time period for all volume on all of the lanes included in the package bid k submitted by carrier c. Constraints [1b] ensure that the planned volume on each lane is covered—either by simple or static package bids. Note that the carrier must specify the exact number of loads requested for each lane within each static package bid, ${}_c \delta^k_{i,j}$. Static package bids are the most common form of package bids used in transportation auctions—the carrier specifies the lanes and the exact level of flow per each lane. Most of the commercial software programs use similar formulations.

More recently, flexible package bids are being discussed, both with and without capacity limits. This is essentially just the introduction of package level capacity constraints. By introducing flexible package bids, the model becomes

$$\min \sum_c \sum_k \sum_{i,j} ({}_c c^k_{i,j} \quad {}_c x^k_{i,j}), \quad (2a)$$

$$\text{subject to} \sum_c \sum_k {}_c x^k_{i,j} = x_{i,j} \; \forall \; i, j \quad (2b)$$

$$- {}_c M^k_{i,j} {}_c y^k + {}_c x^k_{i,j} \leq 0 \; \forall \, c, k, i, j \quad (2c)$$

$$- {}_c LB^k_{i,j} {}_c y^k + {}_c x^k_{i,j} \geq 0 \; \forall \, c, k, i, j \quad (2d)$$

$$- {}_c UB^k_{i,j} {}_c y^k + {}_c x^k_{i,j} \leq 0 \; \forall \, c, k, i, j \quad (2e)$$

$$- {}_c PL^k {}_c y^k + \sum_{ij} {}_c x^k_{i,j} \leq 0 \; \forall \, c, k, i, j \quad (2f)$$

$${}_c x^k_{i,j} \geq 0 \; \forall \; i, j, c, s, k \quad (2g)$$

$${}_c y^k = [0, 1] \; \forall \; c, k, \quad (2h)$$

where the additional variables and data are as follows:

${}_c LB^k{}_{i,j}$: Lower bound in loads on lane i to j that carrier c is bidding on as part of flexible package bid k;

${}_c UB^k{}_{i,j}$: Upper bound in loads on lane i to j that carrier c is bidding on as part of flexible package bid k;

${}_c PL^k$: Lower bound in loads across all lanes that carrier c is bidding on as part of flexible package bid k.

The objective function [2a] sums the product of the individual lane bid prices and the awarded lane volume on each lane within each conditional bid. Constraints [2b] ensure that the volume in each lane is covered by some carrier; constraints[2c] enforce the condition that any carrier assigned any volume on a lane within a flexible package bid is awarded the entire package bid; constraints [2d] and [2e] enforce the conditions that if any volume is assigned to a lane within a flexible package bid, it satisfies the carrier's specified minimum and maximum lane volume requirements for that bid; and constraints [2f] enforce the condition that if any volume is assigned to any lanes within a flexible package bid, the total package volume awarded to that carrier under that bid package satisfies the carrier's minimum volume requirement for the entire package.

Note that [2] is a more general formulation than [1] in that it handles simple, static package and flexible package bids, all within the same decision variables. Simple bids are modeled as flexible package bids consisting of just one lane. Static package bids are modeled as flexible package bids but with the upper and lower lane volume restrictions set equal to the same value. Thus, the same decision variable, ${}_c x^k_{i,j}$, can be used for all three of the primary conditional bid types.

Simple reload bids also can be incorporated into [2] by adding constraints [3a] and [3b] for each facility, j, that is subject to reload simple bid, k, for carrier c.

$$\beta_j \leq \sum_i {}_c x^k_{i,j} - \sum_i {}_c x^k_{j,i} \leq \beta'_j \quad \forall\ j, k, c \qquad (3a)$$

$$\alpha_j \leq \sum_i {}_c x^k_{i,j} / \sum_i {}_c x^k_{j,i} \leq \alpha'_j \quad \forall\ j, k, c \qquad (3b)$$

The terms β_j, β'_j, α_j, α'_j are absolute and relative constants, respectively, that capture the possible relationships between the outbound and inbound volumes. Shippers typically use either of these two sets of parameters, but rarely both. A simple reload bid would typically also contain minimum and maximum volume constraints at the lane and package levels.

Within the WDP, the shipper can apply different business rules or priorities through the use of relative and absolute conditions. Relative conditions imply that some sort of monetary trade-off is made, whereas absolute conditions are hard constraints.

3.3.1. Relative Conditions

Relative conditions are applied in the WDP by modifying the coefficients in the objective function—the ${}_c c^k_{ij}$ in [1a] and [2a]. This is typically done by allocating penalties and rewards to the bids based on various service attributes. For example, a shipper might want to favor incumbent carriers to minimize the churn involved with introducing new vendors to a system. Bids from incumbent carriers would be discounted by, say, 5% within the WDP. If the incumbent carrier wins, the original rate would be fed into the TMS. This allows the shipper to test out the cost and importance of an otherwise arbitrary business rule.

Many shippers consider the "utility exploration" process of agreeing on these relative factors across the organization one of the most important benefits of a structured auction process. One of the primary benefits of relative conditions is that they can be applied without any modification to the underlying formulation used to solve the WDP; only the cost coefficients must be adjusted.

3.3.2. Absolute Conditions

Absolute conditions applied in the WDP take the form of side constraints. The three most common are business guarantee, carrier size, and minimum volume constraints.

Business Guarantee Constraints. A shipper often wants to ensure the amount of traffic that a carrier, or set of carriers, wins is within a certain bound. The shipper might not want to rely too heavily on a single carrier, thus setting a maximum coverage. Conversely, the shipper might want to give enough business to a carrier to remain a significant customer, thus setting a minimum. Coverage can be measured in terms of loads won or in total estimated dollar value. The constraints below ensure that all carriers within some set of carriers C' are awarded business within some preset volume (dollar value) bounds.

$${}_{C'}\text{Min Value}^{K'}_{N'} \leq \sum_{c\in C'} \sum_{k\in K'} \sum_{ij\in N'} ({}_c c^k_{i,j} \quad {}_c x^k_{i,j})] \leq {}_{C'}\text{MaxValue}^{K'}_{N'}, \qquad (4a)$$

$${}_{C'}\text{MinVolume}^{K'}_{N'} \leq \sum_{c\in C'} \sum_{k\in K'} \sum_{ij\in N'} ({}_c x^k_{i,j}) \leq {}_{C'}\text{MaxVolume}^{K'}_{N'} \qquad (4b)$$

Note that these constraints can apply to a specified set of carriers (C'), bid packages (K'), or geographies (N'). Some common constraints include guaranteeing that the core carrier group is awarded, say, at least 100 loads a week out of a facility; ensuring that at least half of the loads covered in the northeast are awarded to carriers providing 53′ trailers; setting a maximum of 20% of the total volume in the network to be awarded to inter-modal services, etc. The constraints are easy to explain and shippers tend to think of their business in these terms. Care must be taken when MinVolume or MinValue constraints are used to ensure feasibility is maintained. There is a tendency for some shippers to over-specify or over-engineer a final award using these types of constraints.

Carrier Base Size Constraints. Another typical business constraint is the restriction of the total number of carriers winning—at the system, region, or lane levels. The number of carriers in the system or at a location can be restricted through the use of relative or absolute conditions. The absolute condition approach adds the following constraints to limit the number of carriers assigned at the system and facility levels:

$$-{}_c M^k_{i,jc} w_i + ({}_c x^k_{i,j}) \leq 0 \quad \forall\ c, k, i, j \qquad (5a)$$

$$\sum_c {}_c w_i \leq L_i \quad \forall\ i \qquad (5b)$$

$$-{}_c M^k_{i,jc} z + ({}_c x^k_{i,j}) \leq 0 \quad \forall\ c, k, i, j \qquad (5c)$$

$$\sum_c {}_c z \leq S \qquad (5d)$$

$${}_c w_i = [0, 1] \quad \forall\ c, i \qquad (5e)$$

$${}_c z = [0, 1] \quad \forall\ c, \qquad (5f)$$

where the additional variables and data are as follows:

${}_c w_i$: = 1 if carrier c is assigned to facility i,
= 0 otherwise;

${}_c z$: = 1 if carrier c is assigned to the network,
= 0 otherwise;

L_i: Location limit of carriers desired to serve facility i;

S: System limit of carriers desired to serve network as a whole;

${}_c M^k_{i,j}$: Large constant.

The traditional approach of using a single large "M" variable, while creating more compact formulations, can result in extremely fractional LP solutions, making it very weak in solving the IP. Barnhart et al. (1993) demonstrated that, in most cases, disaggregating the model leads to tighter bounds when solving the IP, as will minimizing the constant, M. Setting ${}_cM^k_{i,j}$ to the minimum of (${}_cx^k_{i,j}$) for each carrier, bid identifier, and lane combination accomplishes this.

Although the absolute constraints make sense at the facility or system levels, when applied to individual lanes it often results in one carrier winning the lion's share of the volume and the others winning the bare minimum to satisfy the constraint. This is less desirable in practice because many shippers want a more balanced distribution. One way to create more balance is to simply add in a maximum volume constraint for each carrier for the location or lane in question equal to the percentage of the business the largest carrier is desired to haul using the business guarantees constraints shown earlier.

A relative condition can also be used to discourage additional carriers from being awarded business by modifying the objective function as follows:

$$\min \sum_c \sum_k \sum_{i,j} ({}_cc^k_{i,j}\, {}_cx^k_{i,j}) + \sum_c \sum_i F^c_{ic} w_i + \sum_c F^c{}_c z, \quad (6)$$

where all variables are the same as previous models with the addition of

F^c: Cost of including carrier c into the system;

F_i^c: Cost of including carrier c to serve location i.

The fixed costs can be both carrier and location specific, as shown above, or the same for all carriers and all locations. Essentially, the fixed costs act as penalties for adding additional carriers to the winning set.

The two most common uses of these constraints are to limit the total number of carriers awarded any business and to limit the number of carriers serving a facility on both the inbound and the outbound sides so as to minimize the size of the required trailer pool. The latter consideration also encourages the use of continuous moves at that facility, because specific carriers will tend to win both inbound and outbound business.

Minimum Volume Constraints. Shippers will often wish to guarantee that if a carrier is awarded any business, then it has to be of a certain minimum level. Constraints [7] below ensure that if a carrier is awarded any business across the network, then it must be at least ${}_cSV$ loads.

$$-{}_cSV_c z + \sum_k \sum_{i,j} ({}_cx^k_{i,j}) \geq 0 \quad \forall\ c \quad (7a)$$

$$-{}_cM^k_{i,jc} z + {}_cx^k_{i,j} \leq 0 \quad \forall\ c, k, i, j \quad (7b)$$

The use of combinatorial auctions for the procurement of TL services revolutionized the industry. What was once a straightforward rate collection exercise is now a strategic planning event. Through the use of a wide variety of conditional bids, the carriers can better express their underlying economics and hopefully create better service networks. The use of both relative and absolute conditions within the WDP allows the shipper to apply business rules and priorities to the carrier selection process. Regardless of the types of bids allowed or the conditions applied within the auction, however, the end result is a set of carrier assignments (which carrier is awarded which lanes or what percentage of which lanes) and prices (how much is each carrier to be paid).

4 Operational Procurement: Catalogs and Exchanges

Although considerable attention has been paid in the literature to the details of combinatorial auctions, very little has been written on what happens when the auction ends. Operationalizing the results of a strategic procurement can be quite complicated. For TL services, most shippers use an electronic catalog for the majority of their business with exchanges for emergency, distraught, or distressed freight. This section discusses the issues surrounding the use of electronic catalogs, exchanges, and the automation of these technologies.

4.1. Electronic Catalogs

The output from a strategic TL auction is a set of rates and assignments of carriers to lanes. The rates and assignments can be thought of as a representation of the shipper's transportation strategy and business priorities because they were shaped by all of the side constraints and business rules that were applied by the shipper during the solving of the WDP. Carriers that were awarded volume on a lane in the WDP of the auction are usually referred to as "primary carriers" on that lane. Lanes may have more than one primary carrier. The rates and assignments are uploaded into a database commonly referred to as a routing guide. Additionally, a number of the non-winning rates for each lane are often loaded into the routing guide and used as back-up or alternate carriers.[3]

As mentioned earlier, most shippers' routing guide is an electronic relational database that interfaces with an execution software system, a TMS. The TMS is a decision support and transaction processing system that handles the day-to-day management of transportation operations. It is usually modular and can include such sub-systems as order management, load

[3] Carriers are expected to honor the rates submitted in an auction for a lane they did not win, but they are not held to the same carrier acceptance performance standards as the primary carrier.

aggregation, shipment consolidation, tendering, carrier selection, payment, and reconciliation.

The carrier selection and communication functionality of a TMS is essentially an electronic catalog. It is composed of three main components:

- a rating database that contains all valid and up-to-date rates for the different lanes;
- a routing guide that describes the priorities, carrier capacities, and other selection logic;
- a communication module that allows the shipper to send tenders to carriers and receive acceptances or rejections.

In some simple cases, the routing guide and the rating database are one and the same. But, as the rules surrounding the strategic selection of carriers get more complex, they are usually broken out separately to speed up the response time. The routing guide provides rules for hierarchy and order preferences. The rate database is then only a depository of rates with no imbedded logic.

Through the TMS, load planners at any location can determine which carriers are authorized for hauling on any lane. This capability allows a shipper to centralize procurement (through a firm wide auction) while decentralizing operations. The TMS ensures that each load planner will adhere to the strategic procurement plan. The user enters the origin, destination, and equipment type and the TMS returns the primary carrier or, perhaps, a list of the preferred and alternate carriers authorized for that lane. Only those carriers that have been approved by the shipper are listed in the catalog. Essentially, this is an aggregated electronic catalog for buyers. If a load planner deviates from the routing guide, this maverick buying behavior can be flagged, tracked, and measured.

In sophisticated systems, the entire carrier selection and communication process is automated. The shipment is automatically matched to the correct rate and that carrier is communicated with using electronic data interchange (EDI) standards. Exception management can also sometimes be handled in an automated fashion.

The most common form of automation is known as a "waterfall" or sequential process. The shipment is first matched and then tendered to the primary carrier in the relevant lane. The carrier is given a set amount of time to respond. The allowed response time is usually based on the available lead time for the shipment and can range from minutes to days. If the carrier rejects the load, the TMS will move to the alternate carrier list for that lane and tender it to the next carrier in the list. The sequence of the alternate carriers on a lane is typically from the lowest to highest cost. The process continues sequentially cycling through carriers until either time or the number of alternates runs out. When this happens, the catalog has failed and the shipper typically escalates the search to an exchange, as described in Section 4.2.

Generally, the matching of a shipment to the appropriate carrier rate is straightforward. However, the more complex bid structures and constraints that are used within the strategic TL auction, the more sophisticated the electronic catalog must be. For example,

- Various geographic specificity: As discussed in Section 2.3, the lanes represented in the strategic auction might consist of zones or regions. This requires the routing guide to select which rate correctly applies. Using the same example as in Section 2.3, the shipper might have collected rates from the same carrier for the following three lanes:
- Atlanta, GA 30301 to Chicago, IL 60601 for 10 loads/week at $1.10/mile;
- Atlanta, GA 30301 to IL 606 for 3 loads/week at $1.25/mile;
- Georgia to Illinois for no volume guarantees at $1.15/mile.

The routing guide would need to know which of these rates to apply to a specific lane. This is handled either explicitly, by exploding and duplicating rates for zones into the finest grained representation possible, or through imbedded logic. For the explicit method, the shipper creates duplicate detailed rates at the finest detailed points within each of the zone locations. So, for example, 99 additional rates of $1.25 per mile would be added to the rating database for the lanes from 30301 to 60600, 60602, 60603, 60604, etc., that is, for every 5-digit postal code within the 606 region with the exception of 60601. The same would be done for the state-to-state lane rate. This approach would obviously significantly expand the size of the routing guide but it would not require any change to the simple matching logic. The second approach requires the routing guide to have some sort of search and prioritization logic. Typically, the rule most TMSs follow is to search from the most to the least geographically specific lane definition.

- Multiple Primary Carriers on a Lane: It is common for a shipper to assign two or more primary carriers to a high-volume lane.[4] The thought is that having more carriers on an important lane can provide additional capacity much more easily than a single carrier. In the WDP, each winning carrier is awarded a portion of that lane's total volume.[5] The routing guide, then, musto be able to determine which carrier to select on a load-by-

[4] An opposing school of thought is to single source each lane to one carrier and give them brokerage rights up to a pre-determined level, say, 15%.

[5] In the WDP carrier capacity is treated as an absolute value, whereas in the electronic catalog it is treated as a relative value.

load basis. Suppose two carriers are assigned primary status on a lane, one with 60% and the other with 40%. Some allocation logic must exist within the routing guide to ensure the volume is tendered equitably to each of the primary carriers. This requires that the routing guide store the awarded or planned capacity (usually as an allocation percentage) for each carrier for each lane, as well as keep track of the current count of all loads tendered to each carrier on each lane.[6] An even more sophisticated approach is to count not only loads hauled by each carrier, but also the turn-downs by a carrier as well. This serves to penalize poor performance. The allocation scheme usually tenders the next shipment to the carrier with the largest differential between tendered and awarded percentage.

- Tier Bids: These bids allow a carrier to specify a sequence of rates for a lane that are dependent on the weekly volume of traffic already awarded to that carrier on that lane. To apply these bids, the electronic catalog must track the weekly volume by carrier by lane, as well as retain multiple rates for the same lane that differ only in the volume range in which they apply. Very few TMSs can handle these types of rates.

In practice, the electronic catalog simply cannot handle the implicit assumptions or rules applied during the strategic auction. For example,

- Simple Lane Bids with Volume Constraints: Although the amount of traffic awarded to each carrier in the WDP is predicated on some forecasted flow on each lane, in practice, the amount of volume on a lane will vary dramatically from week to week. Indeed, the coefficient of variation of loads per week on a traffic lane is usually above 200% (Harding 2005). So, although the WDP might apply a system-wide or facility-specific maximum (or minimum) volume per week for a carrier, this is rarely enforced or even tracked within a TMS.
- Minimum Volume Constraints: In the WDP, the shipper can apply a constraint that guarantees that if a carrier wins any business (on a lane, from a facility, or across the system), then they must win at least some threshold volume. This is meant to ensure that a carrier has enough volume to justify his serving the lane in the first place. This also applies to the cases where a set of carriers are awarded some minimum level of business in the strategic auction. This can be minority carriers, regional carriers, or some other category. In the electronic catalog, however, the actual amount of business awarded to a single or set of carriers is not tracked or managed. In the best case, the actual awarded traffic is collected and reported on a monthly or quarterly basis during a carrier performance meeting. The only exception to this is where some shippers will measure carrier turn-downs differently if the total volume on the lane is above the total planned volume.
- Package Bids: One of the justifications for using optimization for solving the WDP is to allow for package bids. The implicit assumption that many carriers make when submitting package bids is that the sequence of shipments within a package bid will be such that a continuous move or tour will be possible. In practice, there is not only no guarantee of this, but also usually no mechanism to even check. In most TMSs a rate collected as a package bid is converted into a primary carrier rate for the relevant lanes and cannot be distinguished from a rate collected as a simple bid in the routing guide.

It is interesting that although there has been tremendous activity both in the literature and in practice to improve on and add to the sophistication of the strategic auction process, the real limiting factor for widespread adoption is the lack of sophistication in the electronic catalog or routing guide. Even some now-standard auction practices cannot be applied or enforced accurately, even in state-of-the-art systems.

4.2. Exchanges

TL transportation exchanges are used to access the spot market primarily when contracted rates fail. Although there were predictions during the Internet bubble that public freight exchanges would handle all of a shipper's TL needs through a centralized clearing house where matching would occur automatically, these have not come to fruition. We estimate the spot market comprises less than 10% of the total TL market and there does not appear to be any automatic matching occurring in practice. In all cases of a TL exchange, some human (from either the shipper or the carrier side) is pushing the requirement or confirming a recommended match. The phrase "freight doesn't just move" or the need to play "dial-a-truck" imply that to match a load to a truck in stressed times someone must get personally involved.

There are very few public exchanges in the U.S. that handle spot traffic. The two most common public exchanges today for TL services are TransCore's DAT Connect[7] and Internet Truckstop. They are essentially automated electronic load boards. Shippers can post available loads while carriers can use sophisticated filters (geographic region, maximum distance from a

[6] The time period used to calculate the percentage of traffic awarded is typically weekly, but can be longer for some shippers.

[7] DAT originally stood for Dial-A-Truck.

city, timing, equipment type, etc.) to identify loads of interest. The filters can be created manually or set up as standing alerts where the user is notified, usually via email, if a load that fits the criteria becomes available. The shipper can post the load with a target rate included and the first carrier responding back is awarded the load. Or, the carriers could reply back with rates and the shipper can select the lowest cost. Similarly, carriers can post available equipment for shippers. Most large TL firms will employ a handful of load planners whose primary job is to cruise the load boards for potential backhaul opportunities.

Additionally, Transcore has placed over 1,000 computer monitor screens at truck stops throughout the United States. Drivers will watch these and can call in if they find a load that interests them. Note that in none of these systems does a shipment get automatically identified, matched, and tendered to a carrier without some human involvement. In that sense, the public exchanges act more like decision support for a load planner.

Just because large automatic-matching public exchanges did not take over the industry does not imply that exchanges disappeared completely, however. Buyer side private exchanges, where the shipper prescreens and authorizes selected carriers to join, are widely used. Carriers in a shipper's private exchange are typically primary carriers on some portion of that shipper's network. These private exchanges are often built into the shipper's TMS and are used as part of a freight escalation process. Sometimes referred to as automated event management, this allows the shipper to execute an established series of actions based on the status and characteristics of the shipment.

A typical sequence might be as follows:

- First tender the shipment to the primary carrier in the most geographic-specific lane in the routing guide.
- If rejected, cycle through the first six alternates on the carrier list, sequentially, allowing them 2 hours to accept or reject.
- If not accepted by any of the alternate carriers, send out an "offer" to the private exchange for that facility with a 2-hour window; the first response wins at contract rate basis.
- If the offer is not accepted by any carrier, send out an offer to the system-wide private exchange with a 2-hour window; the lowest bid wins and spot rates allowed.

Each action can be characterized along the following four characteristics:

- Message type—the action is either a tender to a carrier, so that if the carrier accepts it is awarded to them, or an offer, so that interested carriers will be considered for award. A tender constitutes a legal offering of business, whereas an offer is more of a request for interest.
- Carrier target–the specific carrier or set of carriers included in the action.
- Pricing format—the rate could be either an existing contractual rate or a spot rate (dynamic pricing) that is determined at the time of the transaction.
- Trigger—the events that can trigger a new action. There will typically be triggers for when there is and is not a positive response from the carrier target. For non-responses, there is usually a time limit set any where from 15 minutes for very distressed loads to 24 hours. For a positive response, the trigger usually depends on whether it is a tender or an offer. For a tender, an accept triggers the shipment to process and a reject triggers a move to the next scheduled action. For an offer, the trigger will either be time based (where the shipper is waiting to collect all interested responses) or first response.

A shipper can establish a portfolio of event management scenarios, each describing a particular sequence of message types, carrier targets, pricing formats, and triggers. These portfolios are in turn triggered by the characteristics of the shipment in question. For example, a location might have a portfolio of two scenarios: a standard waterfall scenario (as described above) and a short-response scenario (offer the shipment to the system-wide private exchange with a 30-minute time limit allowing for spot pricing). The selection between which scenario to run is determined by the shipment characteristics; in this case, it could be having a required pick up time within, say, 6 hours.

An alternate approach to using a private exchange is to sequentially query a set of carriers with very short response times, usually 15 minutes. Sometimes referred to as a "shotclock" approach similar to that used in basket ball, the technique has the advantage of not requiring the addition of a new message type to the communication system.[8]

4.3. Classification of Transactions

The use of these private exchanges within electronic catalogs allow for a wider use of more sophisticated operational arrangements. The two relevant characteristics are the nature of the carrier assignment and the nature of the carrier price. The price and assignment can be either static (established in a strategic auction ahead of time) or dynamic (established at the time of the tender or offer). The complete classification by

[8] When a shipper offers a load to a carrier and a carrier accepts it, the shipper still must send a tender message to the carrier to consummate the transaction. Most shipper and carrier systems use X12 ANSI Standard 204 transaction set to automate the tender process.

these two dimensions creates four unique types of transactions.

- Type I—Static assignment–static pricing: The carrier and price are determined during some strategic auction and contract rates are established. The shipper would use their electronic catalog (routing guide) for this type of transaction.
- Type II—Static assignment–dynamic pricing: The carrier is assigned to the specific lane during the strategic time frame, but the price is allowed to fluctuate based on other conditions. An example of this type of transaction is when tiered rates based on the total weekly lane volume are used.
- Type III—Dynamic assignment–static pricing: The specific carrier is selected at the time of the transaction, but the price paid is a contract rate that was pre-established. Examples include using alternate or back-up carriers in a routing guide or private exchanges with a fixed pricing format.
- Type IV—Dynamic assignment–dynamic pricing: The carrier and price are established during the time of the transaction. This is essentially the spot market.

Based on experience, we estimate that over 80% of a shipper's TL shipments move as Type I, 5 to 10% as Type III (mainly as back-ups to the primary carriers in a routing guide), and the remainder as Type IV. The use of Type II (static assignment–dynamic pricing) is rare due to the added complexity required in the downstream payment systems.

The benefit of Type I transactions is that they require little sophisticated technology in real-time operations. The complexity is handled in the strategic auction to simplify the execution of the plan. The negative side of relying solely on Type I transactions is that they are not responsive to changes in the system or marketplace. The introduction of more sophisticated real-time systems allowed more flexibility in daily operations, such as the use of Type III transactions.

Additionally, some systems allow for the monitoring of actual movements—whether on a firm's own private fleet or that of a core carrier. For example, suppose an inbound shipment hauled by a carrier is on schedule to arrive in time to pick up a subsequent outbound load, thus forming a continuous move. The capacity (at the carrier's discounted continuous move rate) will show up in the shipper's electronic catalog as another option. In these cases, a continuous move will jump to the top of the priority list ahead of the primary carrier on the lane. If the continuous move carrier is actually the primary carrier on the follow-on lane, the lower of the two rates will apply!

5 Summary and Areas for Future Research

The TL transportation industry utilizes all three of the major forms of electronic markets: auctions, catalogs, and exchanges. The use of combinatorial auctions for the establishment of contract rates is common practice for shippers of medium size or larger. The rates and assignments collected within the auction are loaded into shipper-specific electronic catalogs. The catalogs, or routing guides, contain the collected rates as well as other embedded logic. When the contracted carriers are insufficient to meet demand, shippers will utilize exchanges (mainly private) to secure spot capacity. State-of-the-art planning and execution systems automate these three electronic market forms, allowing shippers to create portfolios of scenarios that can be employed without human intervention.

Two observations and corresponding suggestions for future research can be made. First, although the use of sophisticated auctions is common for strategic TL procurement, the actual use of the auction results is quite limited. The sophistication captured within the optimization-based procurement event through the use of package bids and absolute and relative conditions is lost when the results are translated into simple carrier lane prices and assignments. Much of the logic is lost in order for it to be processed in the lowest common denominator execution system. More flexible and sophisticated execution systems must be developed to handle the business concerns that are applied during the strategic auction process. The gating factor for wider use of combinatorial auctions is not the solution speed of the model or limitations in the bidding language used; it is in the electronic catalog used to implement the actual auction results.

Second, the use of dynamic or spot rates in TL transportation is quite small and does not seem to be growing, except in severe capacity shortage situations. Although some of the reasons for this are historical, recent technical advances should expand the use of dynamic or spot rates. Research into how to incorporate more flexible or dynamic assignment and pricing processes into the overall transportation procurement process is worthwhile. Extensions of this include establishing more flexible contracts or using real options.

References

American Trucking Associations. 2002. *American Trucking Trends*. American Trucking Associations, Arlington, VA.

American Trucking Associations. 2004. *Standard Trucking and Transportation Statistics (STATS) Third Quarter 2004*. American Trucking Associations, Arlington, VA.

Ballou, R. 2004. *Business Logistics/Supply Chain Management*, 5th edition, Pearson Prentice Hall, Upper Saddle River, NJ, p. 14.

Barnhart, C., E. Johnson, G. Nemhauser, G. Sigismondi, P. Vance. 1993. Formulating a mixed integer programming problem to improve solvability. *Operations Research*, 41(6), 1013–1019.

Caplice, C. 1996. *Optimization-Based Bidding, a New Framework for*

Shipper–Carrier Relationships. Unpublished Ph.D. Dissertation, Massachusetts Institute of Technology, Cambridge, MA.

Caplice, C., Y. Sheffi. 2003. Optimization based procurement for transportation services. *Journal of Business Logistics*, **24**(3) 109–128.

Caplice, C., Y. Sheffi. 2006. Combinatorial auctions for truckload transportation. P. Crampton, Y. Shoham, R. Steinberg, eds. *Combinatorial Auctions*, MIT Press, Cambridge, MA.

Caplice, C., C. Plummer, Y. Sheffi. 2004. Bidder behavior in combinatorial auctions for transportation services. Working Paper, Massachusetts Institute of Technology, Center for Transportation & Logistics, Cambridge, MA.

Corsi, T. M., J. R. Stowers. 1991. Effects of a deregulated environment on motor carriers: A systematic, multi-segment analysis. *Transportation Journal* **30**(3) 4–28.

Elmaghraby, W., P. Keskinocak. 2003. Combinatorial auctions in procurement. C. Billington, T. Harrison, H. Lee, J. Neale, eds. *The Practice of Supply Chain Management*. Kluwer Academic, Dordrecht, The Netherlands.

Enslow, B. 2004. New strategies for transportation management: how transportation management practices are changing to meet today's market pressures. *Aberdeen Group Research Report.* Boston, MA.

Fontanella, J. 2000. Exchanges: Logistics in the fast lane. *Supply Chain Management Report* September/October.

Harding, M. 2005. *Can shippers and carriers benefit from more robust transportation planning methodologies?* Unpublished Masters Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Harding, M., C. Caplice. 2005. Robust transportation planning. Working Paper, Massachusetts Institute of Technology, Center for Transportation & Logistics, Cambridge, MA.

Kaplan, S., M. Sawhney. 2000. E-hubs:The new B2B marketplaces. *Harvard Business Review* **78**(3) 97–103.

Ledyard, J., M. Olson, D. Porter, J. Swanson, D. Torma. 2000. The first use of a combined value auction for transportation services. Social Science Working Paper 1093, Division of the Humanities and Social Sciences, California Institute of Technology, Pasadena, CA.

Moore, E. W., J. M. Warmke, L. R. Gorban. 1991. The indispensable role of management science in centralizing freight operations at Reynolds Metals Company. *Interface* **21**(1) 107–129.

Porter, D., D. P. Torma, J. O. Ledyard, J. A. Swanson, M. Olson. 2002. The first use of a combined-value auction for transportation services. *Interfaces* **32**(5) 4–12.

Sandholm, T., S. Suri, A. Gilpin, D. Levine. 2005. CABOB: A fast optimal algorithm for winner determination in combinatorial auctions. *Management Science* **51**(3) 374–390.

Sculley, A., W. Woods. 1999. *B2B Exchanges—The Killer Application in the Business-to-Business Internet Revolution.* ISI Publications.

Standard & Poor's. 2006. Industry surveys—Transportation: Commercial, 9 Feb 2006, 10.

USA Truck. 2006. Form 10-Q. Filed April 28, 2006.

Werner Enterprises. 2006. Form 10-Q. Filed May 1, 2006.

Wilson, R. 2005. 16th Annual State of Logistics Report, Security report card—Not making the grade. Council of Supply Chain Management Professionals.