

Exchange Mechanisms for Shipper-Carrier Negotiations

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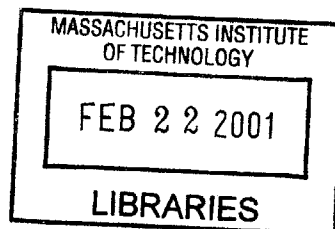
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Abstract

This research was motivated by the increase in the number of Internet based trucking exchanges that have come into existence during 2000. This thesis categorizes currently operating transportation exchanges according to their price setting mechanism and strategies.

A trucking exchange for truckload carriers with a carrier-centric price setting mechanism is considered in this thesis. A game theoretic model is formulated to represent the analytical basis of carriers' bidding strategies in the exchange. Carriers bid based on their costs and perceptions about their competitors' bidding strategies. Through consecutive auctions of similar loads, carriers update their perceptions about their competitors' bidding strategies.

Single round sealed bid auctions with first price mechanism, button auctions, and a monopoly situation are simulated to represent successive bidding by carriers for similar loads. A theoretical basis for identifying carriers' optimal bidding strategies in each auction is suggested. Their equilibrium bids are observed. Further, the participating carriers' aggregate profits in each auction quantify the auction efficiencies for shippers and carriers.

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CHAPTER 1 INTRODUCTION

Exchanges are marketplaces where people and businesses trade goods, based on negotiations. An example is a stock exchange, several of which were founded in countries around the world during the last few hundred years to formalize trading of shares of companies - the New York Stock Exchange, for example, was founded in 1792 (<http://www.nyse.com>). Exchanges adopt certain mechanisms/rules to facilitate smooth and efficient transfer of goods and services between individuals. This research studies exchange mechanisms for the trucking industry, where instead of individuals the entities participating in the marketplace are companies buying and selling motor carrier services.

Section 1.1 discusses fundamental concepts of the trucking industry. Section 1.2 describes the various mechanisms through which trucking services are procured. Section 1.3 summarizes the research objectives, followed by an outline of this thesis.

1.1 Trucking Industry Fundamentals

This section introduces the primary players in the trucking industry along with their specific functions. Then, types of trucking operations are described, followed by a description of the current structure of the trucking industry emphasizing its importance in the US economy. Lastly, economic considerations that govern the operations of trucking companies are discussed. Examples are included wherever deemed necessary, to clarify the terminology and concepts.

1.1.1 Shippers and Carriers

Shippers and *Carriers* are the primary players in the trucking industry.

Shippers are companies that procure transportation to meet their business needs, including retailers such as Wal-Mart, manufacturers such as Procter & Gamble, and distributors such as Arrow Electronics. Wal-Mart Stores¹, Inc., for example, the largest retailer in the world, buys over \$1 Billion in motor carrier services in the US alone each year. The Procter & Gamble² (P&G) Company manufactures fabric and home care, baby

¹ Source: <http://www.walmart.com> (2000)

² Source: <http://www.pg.com> (2000)

care, feminine care, tissues and towels, beauty care, health care, and food and beverage products. It also buys over \$1 Billion of motor carrier services in the US alone each year. Arrow Electronics³, Inc., the world's largest distributor of electronic components and computer products, also buys over \$1 Billion of transportation services each year.

Carriers are companies that provide transportation services to shippers. They maintain their own fleets and equipment. Examples of carriers include J.B. Hunt and Yellow Freight. J.B. Hunt Transport Services⁴, Inc. for example, a truckload carrier (see definition later) with annual revenues of over \$2 Billion operates over 9,400 trucks, and 38,000 trailers and containers. Yellow Freight⁵ is a less-than-truckload carrier (see definition later) with annual revenues nearing \$3 Billion.

1.1.2 Third party logistics companies and Brokers

In addition to shippers and carriers, important participants in the trucking marketplace are intermediaries including third party logistics (3PL) companies and various brokers.

3PLs manage the logistics, and within it the transportation function on behalf of shippers. The services offered by 3PLs to shippers include transportation, warehousing and inventory management, shipment consolidation, customs brokerage/documentation, freight forwarding, management of logistics' information systems, carrier selection, rate negotiation, product returns, fleet management (for shippers maintaining their own private fleets), re-labeling/repackaging, order fulfillment, product assembly/installation, inventory replenishment, order processing, management of customer spare parts, and so on⁶. To carriers, 3PLs act as customers (shippers) procuring transportation, in turn to serve the end shippers.

³ Source: <http://www.arrow.com> (2000)

⁴ Source: <http://www.jbhunt.com> (2000)

⁵ Source: <http://www.yellowfreight.com> (2000)

⁶ Third-Party Logistics grows up, Cooke, J.A., Logistics Management and Distribution Report Online, November 1998

Based on net logistics revenue for 1999, Ryder Integrated Logistics was the largest 3PL with \$1.3 Billion/year, followed by Penske Logistics with \$959 million⁷. All three companies are 3PLs, but maintain their own fleet and equipment in addition to relying on other transportation companies to provide transportation and other services to the shippers.

In order to differentiate themselves from their competitors, transportation companies have also started providing services similar to those provided by 3PLs. Schneider Logistics⁸, for example, with annual revenues at \$1 Billion/year, grew out of its parent trucking company. J.B. Hunt's logistics arm, which in 2000 merged into Transplace.com, provided integrated transportation and logistics solutions to its customers⁴. Yellow Freight's value added services continue to provide its customers with several services typically offered by 3PLs⁵.

Some 3PLs rely solely on other transportation companies for the services they offer to the shippers. An example is Fritz⁹ Companies, an international forwarder¹⁰ offering transportation services but having no transportation assets.

Transportation brokers primarily match available capacity of carriers with shippers' demand for transportation, apart from offering other services such as payment and credit management. They receive information from carriers about their empty trucks/capacity at various locations, and they receive requests from shippers for transportation of loads that need to be moved between locations. They then match the shippers with the appropriate carriers. An example is C.H. Robinson¹¹, a multi-billion dollar broker. Apart from matching availability with demand for truck capacity, brokers may take into account other factors such as prices, level of service, etc. in the criteria for matching shippers with carriers. Section 1.2.2 discusses the evolution of the mechanism

⁷ 3PLs: Riding the Wave, Cooke, J.A., Logistics Management and Distribution Report Online, July 2000

⁸ Source: <http://www.schneider.com> (2000)

⁹ Source: <http://www.fritz.com> (2000)

¹⁰ A forwarder is an agent who performs services such as receiving, transshipping, or delivering, to move goods to their destination

¹¹ Source: <http://www.chrobinson.com> (2000)

through which brokers facilitate contacts and subsequent negotiations between shippers and carriers.

1.1.3 Truckload versus Less-than-truckload Operations¹²

The cost of operating a truck is almost independent of its load. Thus, all else being equal, it costs less per unit of freight, to haul full truckloads than it costs to haul less than truckloads. If a shipper has enough freight from a given origin to a given destination on a given day to fill a truck, the carrier would haul the shipment directly using a single vehicle. This type of carrier operation: taking a full truck directly from a shipper's origin to a destination is known as a truckload (TL) operation and the carriers are called TL carriers. TL operations have irregular routes and unscheduled operations.

In cases when it is too expensive to use a direct service, in other words when the shipment is too small to justify a dedicated conveyance for the trip, shipping is based on consolidation. Consolidation involves a network of freight processing centers. Shipments from multiple origins are loaded into a truck heading to a terminal located in the general direction of the destinations of these shipments. In the terminal the shipments are unloaded, sorted, combined with shipments from other origins, and re-loaded onto trucks heading to a more specific set of destinations. This process may repeat several times and thus a shipment may be sorted in several terminals on its path from the origin to its destination. This type of carrier operation: taking shipments from a shipper's origin to a destination through consolidation processes is known as a less-than-truckload (LTL) operation and the carriers providing such services are called LTL carriers. LTL operations have regular routes and schedules.

1.1.4 Industry Structure

In 1997, \$503 Billion was spent on freight transportation in the US¹³. Figure 1.1 describes the distribution of freight expenditures among transportation modes. Trucking is the dominant mode and accounts for nearly 80% of all transportation spending.

¹² Some of the explanations in this section have been adapted from draft chapters of the book by Sheffi Y., Logistics Systems Analysis (1998)

¹³ National Transportation Statistics (1997), US Department of Transportation

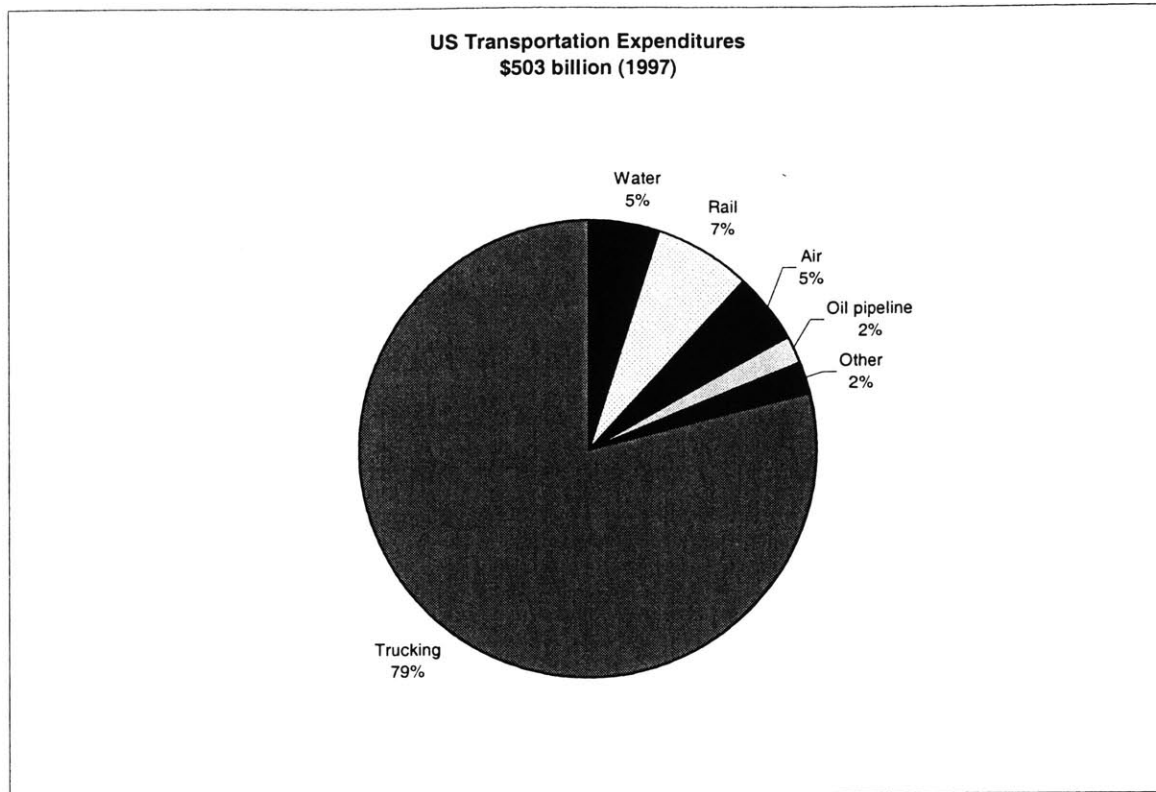


Figure 1.1 US Transportation Expenditures (1997)

Figure 1.2 provides segmentation by type and number of firms for the motor carrier industry¹⁴. The TL sector is the most fragmented with approximately 50,000 firms. The four largest TL carriers account for just 12% of the revenues for the sector. The LTL sector is more concentrated with the four largest carriers accounting for 57% of total revenues for the sector. The next largest transportation mode, rail, is highly concentrated with the four largest rail carriers accounting for 99% of industry revenues.

According to Goldman Sachs, in 2004, the amount of freight transportation sales that originate on the Internet will reach \$40.5 billion¹⁵. The presumption of many industry analysts is that a large portion of these sales will be initiated on business-to-business transportation marketplaces that represent transactions between many buyers

¹⁴ Standard & Poors (1998)

¹⁵ B2B: 2B or Not 2B?, Goldman Sachs Investment Research, Goldman Sachs (November 12, 1999)

and many suppliers rather than carrier web sites that provide access to a single carrier's set of services.

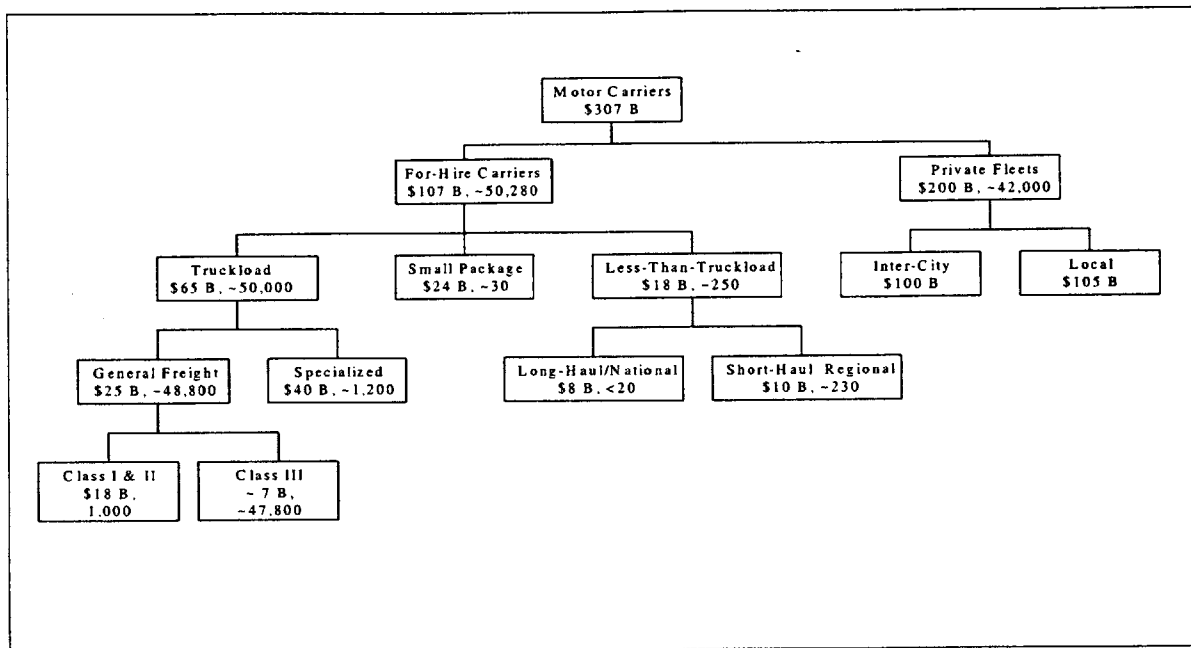


Figure 1.2 Trucking Industry Structure (1997)

Note: Revenue Classification: Class I, greater than \$10 million; Class II, \$3-\$10 million; Class III, less than \$3 million

1.1.5 Transportation Cost Components

Transportation is fundamentally different from goods and other services that are traded between buyers and sellers. Transportation is defined by what is shipped, when it is shipped, where it is shipped (origin and destination of the shipment), and how it is shipped. These aspects are tied into three economic factors that influence carriers' costs: economies of scale, scope, and density. Among them economies of scope exist in TL operations, and is relevant to this thesis. Economies of scale and density exist in LTL operations, and are not discussed.

Economies of scope are present when the cost of serving a set of lanes by a single carrier are lower than the cost of serving the same set by multiple carriers, where each carrier serves a subset of lanes. This effect is strong for TL carriers but it is also significant for LTL carriers. In both cases, the additional lanes for a carrier mitigate the

costs of repositioning vehicles and crews. As described in the following paragraphs, the effect of economies of scope on TL carriers' costs is quantified by "location costs" in this thesis.

The primary components of a carrier's cost in moving a load include operational costs and location costs.

Operational costs: A carrier incurs direct costs in transporting loads, including fuel costs, drivers' wages, maintenance costs, overhead expenses, and so on. Some of the carrier's costs are variable costs that are directly associated with transporting a load, and some are fixed costs that need to be allocated over all loads. The operational cost to a carrier for moving a certain load is the sum of the variable costs and the allocated fixed costs associated with the load. Every carrier also charges a markup on every load to contribute to its profits.

Location costs: A carrier provides transportation services over a network of locations. Apart from operational costs for transporting loads, a carrier may incur costs in repositioning its trucks from the destination location of a load to another location for its follow-on utilization. Alternatively, it may incur costs due to the time that the truck may need to stay idle at the destination location of a load before being utilized further. These factors are considered by the carrier in computing location costs for each location in its network. Thus, a location cost indicates the relative attractiveness of a location with regard to its expected potential in generating profits for the carrier in the future. Location costs are computed on the basis of historical data. Expected equipment availability at a location, expected demands for transporting loads to all possible destinations out of the location, and the corresponding revenues, are used to compute its location cost¹⁶. Location costs change as the demands and equipment availabilities at different locations in the carrier's network change. The difference in the location costs of the origin and destination locations of a load indicates the "strategic cost" to the carrier in transporting the load.

¹⁶ Maximizing Profits for North American Van Lines' Truckload Division: A New Framework for Pricing and Operations, Powell, W.B., Sheffi, Y., Nickerson, K.S., Butterbaugh, K., Atherton, S., Interfaces 18, January – February 1988

1.2 Mechanisms of Logistics Services Procurement

Shippers and carriers negotiate long term contracts (typically 12-18 months) based on their expected transportation requirements and truck availability, respectively. Mostly, they agree on a flat rate on individual or packages of lanes for the entire duration of a contract. Large shippers commit most of their forecast loads to carriers at the time of negotiating contractual agreements due to their belief that these carriers will offer them the lowest prices on the assigned lanes at all times and have equipment available for them whenever needed, in addition to satisfactory levels of service. Thus, they participate in spot markets to procure transportation only for their unexpected daily loads. For small shippers, procuring transportation through contracts often proves to be more expensive than doing it through spot markets. Thus they participate in spot markets to procure transportation at lower rates. TL carriers participate in spot markets to procure loads to achieve higher equipment utilization and minimize their repositioning costs. This section describes the evolution of the mechanism through which shippers and carriers negotiate to match their daily demands and available capacities in spot markets.

Until the recent proliferation of advanced telecommunications equipment, bulletin boards at truck stops were the primary points of contact between shippers and carriers. A truck intending to procure loads looked up bulletin boards at truck stops on its way for available loads at convenient locations. Shippers who were in need of trucks, posted their requirements on bulletin boards at nearby truck stops. Thus, shippers and carriers having complementary requirements came into contact with each other through the bulletin boards, most of which were managed by brokers. At the same time, carriers could also inform appropriate brokers directly about available capacity on trucks passing through different locations, and shippers could inform them about their transportation requirements. Brokers matched shippers' loads with carriers' truck capacities based on the information that they received from them, and additional information from postings at the truck stops. In cases where shippers would post prices along with their loads, negotiations between them and the carriers taking their loads would not be necessary. In other cases, shippers and carriers coming into contact with each other directly through the bulletin boards would further negotiate the terms of transportation. In cases when contact would be intermediated by brokers, the broker could help them negotiate with each other.

The Internet has enabled faster and more efficient communication between shippers, carriers, and brokers. Bulletin boards at truck stops have manifested themselves on the Internet in the form of web sites designed as digital bulletin boards. Digital bulletin boards enable shippers to post their transportation requirements, carriers to post their available truck capacities, and brokers to post their customers' requirements. Further, they allow shippers, carriers, and brokers to find appropriate matches between their requirements and the listings using automatic search capabilities. DAT Services¹⁷ is an example of a company that provides digital bulletin board services to shippers, carriers, and brokers. The company grew out of Jubitz Truck Stop¹⁸, a company that has load monitors and call-boards at 1100 truck stops nationwide.

During 2000, Internet-based transportation exchanges in the form of web sites, have emerged. These exchanges bring shippers, carriers, and intermediaries in contact with each other. Further, they enable them to post and edit the terms of transportation for loads, such as price. (In the rest of this thesis, intermediaries will be regarded as shippers or carriers depending on whether they are servicing a shipper or a carrier, and will not be mentioned explicitly.) Internet-based transportation exchanges can be categorized according to their price-setting mechanisms.

Carrier-centric price setting mechanism exists in exchanges where carriers bid the price at which loads are to be transported, and shippers choose from among the bidding carriers. In anticipation, carriers may also post their available capacities at different locations in their network along with desirable prices, and shippers may choose from among them to fulfill their transportation requirements.

Shipper-centric price setting mechanism exists in exchanges where shippers bid the desirable prices, which they are willing to pay to transport the loads, and carriers choose from among the shippers' posted loads. In anticipation, carriers may also post their available capacities at different locations, and shippers may bid to procure transportation from among them.

Some currently operating transportation exchanges are discussed in Section 2.1.

¹⁷ Source: <http://www.dat.com/> (2000)

¹⁸ Source: <http://www.jubitztruckstop.com/jubitztruckstop/> (2000)

1.3 Research Objectives

Shippers and carriers participate in trucking exchanges on the Internet in real-time. In this thesis, trucking exchanges with a carrier-centric price setting mechanism are considered. At the time a shipper needs to procure transportation for its unexpected daily loads, it requests bids on a trucking exchange. Carriers bid on the shipper's loads, and the shipper chooses the winning carriers to transport its loads. In this thesis, it is assumed that shippers will use software programs to post their loads in transportation exchanges as they become available, and carriers will use software programs to bid on them, based on their current costs. This section summarizes the objectives of this thesis.

1.3.1 Carriers' Best Response Bidding Strategy

At any time, a carrier has its trucks at different locations in its network, some moving loads, some moving empty to locations in expectation of follow-on loads, and some idle waiting for follow-on loads. When a shipper requests bids to procure transportation for its loads, each carrier bids based on its expected operational costs for transporting the loads, its location costs of the origin and destination locations of the loads, and its perception of the competing carriers' bidding strategies. Higher bid values reduce the chances of a carrier's winning the load, but increase its profit if it does. Conversely, lower bid values increase the chances of a carrier's winning the load, but reduce its profit if it does. Thus, a carrier's bid value for each load includes a trade-off between its chances of winning the load, and its profit if it does. This thesis aims at recommending bidding strategies for carriers that maximize their expected profits in the auction process. Such bidding strategies are referred to as "best response" bidding strategies in game theory and are further explained in section 3.2.2.

1.3.2 Equilibrium Bidding Strategies for Carriers

When a shipper requests bids to procure transportation for its loads, several carriers willing to transport the loads bid for it. Each of the carriers bid according to some strategy. When each of the carriers bid rationally, they bid according to their best response bidding strategy mentioned in section 1.3.1. Bid values based on the best response bidding strategy depend on a carrier's expected operational costs for transporting the loads, its location costs for the origin and destination locations of the

loads, and its beliefs about its competitors' bidding strategies. At equilibrium, no carrier can increase its expected profits in the auction by changing its bid values unilaterally. Best response bidding strategies for carriers that enable the existence of an equilibrium condition, are referred to as equilibrium bidding strategies, and the corresponding bid values are referred to as equilibrium bids. Section 3.2.3 further explains equilibrium bidding strategies for carriers.

1.3.3 Carrier and Shipper Efficiencies for Different Auction Designs

A shipper may auction its loads according to several auction designs. The auctions considered in this thesis are single round sealed bid auctions and button auctions¹⁹, for a single load. For each type of auction, there may be several sets of equilibrium bidding strategies for carriers. Among the several sets of equilibrium bidding strategies, one (or those) whose corresponding equilibrium maximizes carriers' aggregate profits, is referred to as the efficient equilibrium bidding strategy (or strategies) for carriers.

The winning carrier's bid value corresponding to the carriers' efficient equilibrium bidding strategies in the auction of a load indicates the shipper's cost of transporting the load according to that auction design. Among different possible types of auctions, one that minimizes the shipper's cost of transporting its load is referred to as the efficient auction type for the shipper.

This thesis identifies carriers' efficient equilibrium bidding strategies for different types of auctions, and efficient auction types for shippers.

1.4 Outline of Thesis

This thesis is organized into four chapters. Chapter 2 describes exchange mechanisms and their economic characteristics. Chapter 3 states the problem addressed in this thesis, and discusses the research methodology adopted. Chapter 4 discusses results from experiments performed to illustrate the research methodology, and summarizes this thesis stating its contributions and directions of further work.

¹⁹ The various dimensions of auction design are further explained in section 2.2

CHAPTER 2 EXCHANGE MECHANISMS

A transportation exchange can facilitate negotiations between shippers and carriers according to different auction designs. Section 2.1 describes some of the currently operating Internet-based transportation exchanges. Section 2.2 differentiates among various dimensions of auctions. Section 2.3 outlines the economic characteristics of a trucking exchange, and the last section summarizes.

2.1 Operating Transportation Exchanges

This section categorizes some of the currently operating transportation exchanges according to their niche strategies, as shown in Figure 2.1. Further, the working mechanisms for price negotiations between shippers and carriers are described, along with their price setting mechanisms and revenue models. Note that though some exchanges may set the prices themselves based on prevailing market rates, to ensure that all shippers' demands and all carriers' capacities are fulfilled with time, they do need to incorporate either a shipper centric price setting mechanism, or a carrier centric price setting mechanism, or both.

2.1.1 Strategic Categories of Operating Transportation Exchanges

For some time, shippers that wanted to consolidate their shipments and gain efficiencies in their supply chain looked up to their 3PLs for advice. In return, 3PLs, already managing information from their relationships with multiple shippers leveraged their information base and relationships to make each of their shippers efficient with respect to transportation costs and levels of service. As mentioned in section 1.1.2, Ryder and Penske are examples of such traditional 3PLs, and will not be further described. The expectation of a possible increase in efficiency arising out of the merger of two or more 3PLs led to Transplace.com, which resulted out of the merger of the logistics arms of J.B. Hunt Transport, Covenant Transport, M.S. Carriers, Swift Transportation Co., U.S. Xpress Enterprises, Inc., and Werner Enterprises, Inc. Information-based providers such as 3plex.com provide 3PLs with Internet-based software to gain the benefits of consolidating capacity without the legal and technical hassle of merging.

TYPE	SUB GROUPS	EXAMPLES
Third Party	Traditional	Ryder, Penske
	Merging	Transplace.com
	Supporting	3plex.com
Transportation Exchanges	Industry Neutral	Logistics.com, NTE
	Industry Specific	ShipChem.com
	Equipment Specific	CarrierPoint.com

Figure 2.1 Operating Transportation Exchanges²⁰

During 2000, many industries have seen the advent of Internet based procurement exchanges for their products. Likewise in transportation, exchanges such as NTE and Logistics.com have emerged. These exchanges are neutral to all parties, allowing shippers and carriers to have full control over their information, and to maintain their brand recognition. In such an exchange, shippers and carriers retain the same amount of bargaining power in negotiations that they would have if they were to negotiate one-on-one with their counterparts outside the exchange. Some exchanges also offer to automate and optimize demand with capacity, to manage all the freight – not just the spot market, to add flexibility on who to select for each move, and the ability to create private or tailored exchanges for all participants.

However, procurement and transportation exchanges are facing competition from those that are uniquely designed to offer supply chain solutions for a specific industry. ShipChem.com is an example of a company that is positioning itself as the virtual global logistics provider for the chemical industry.

Another set of exchanges that is emerging concentrate on the management of specific transportation equipment. This was the initial strategy behind CarrierPoint.com, which focused on equipment for ocean transportation to start with.

²⁰ Trading Exchanges in Transportation, Manrodt, K, Supplement to Logistics Management and Distribution Report, September 2000

Digital bulletin boards such as that provided by DAT Services are described in section 1.2. They do not enable price negotiations between shippers and carriers, and thus do not qualify as transportation exchanges.

2.1.2 Mechanisms of Operating Transportation Exchanges

This section discusses on the working mechanisms for price negotiations between shippers and carriers, the revenue models, and the price setting mechanisms in some of the operating transportation exchanges cited in section 2.1.1.

Transplace.com²¹

Transplace.com includes an Internet-based service, free to shippers, that allows them to post their shipments to solicit capacity at a “market rate” from a pre-qualified group of carriers, which each shipper can specify. Member carriers review available shipments and commit their capacities at spot prices for individual shipments. A shipper accepts a carrier’s capacity at the spot rate and tenders the freight to the carrier. The transactions are conducted directly between shippers and carriers.

In Transplace.com, spot rates bid by carriers for loads form the basis of the “market rates” that Transplace.com reveals to the shippers, indicating a carrier-centric price setting mechanism. Its fees are not generated from the exchange but from other services to its carrier members.

3plex.com²²

3plex.com is an Internet-based service for transactions between 3PLs and TL carriers. 3PLs post their loads, offering prices for each of them. Carriers post their trucks along with their desired origins and destinations for prospective loads. The web site matches a 3PLs’ load with a posted truck. The 3PLs’ matching carrier is informed of the prospective load along with the offered price. Upon the carrier’s acceptance of the load, 3plex.com processes payment and communicates delivery information between the 3PL and the carrier.

3Plex.com serves as an Application Service Provider (ASP), providing 3PLs with the exchange applications they need to automate their spot market operations. 3plex.com

²¹ Source: <http://www.transplace.com> (2000)

²² Source: <http://www.3plex.com> (2000)

charges fees to its member 3PLs in order to generate revenues for itself. It is also possible that 3plex.com charges a fee to carriers for every load they procure through the exchange. However, the nature of the fees is not publicly available on their web site.

In 3plex.com, the prices offered by the 3PLs are used to transport loads. If a load is not served by a carrier for a continued period of time the respective 3PL probably increases the offered price for the load. Considering the 3PL as the shipper in the exchange, the price setting mechanism in 3plex.com is shipper-centric.

Logistics.com²³

Logistics.com's primary software, OptiBid enables shippers to request bids using one of its three components as appropriate. Further, it provides carriers with software that enable them to bid competitively.

The first component allows shippers to bid out their entire networks for contracts. It includes a forecasting tool which shippers use to estimate their expected loads on each lane²⁴ in their network during the period of the contract. In addition, it provides carriers with combinatorial bidding tools that enable them to bid prices on optimal combinations of lanes ensuring economies of scope in their operations. Currently, the network component of OptiBid allows single round auctions only. Shippers using this component pay fees to Logistics.com.

The second component of OptiBid allows shippers to bid out their individual lanes for service contracts, which may be from weeks to months long. Carriers bid prices for the shippers' lanes in addition to other attributes such as percent on-time delivery, and capacity. A weighted index based on all the bid attributes including price, enable shippers to compare between different carriers. The lane component allows carriers to revise their bids. Shippers using this component pay fees to Logistics.com.

The third component allows shippers to bid out their daily loads in the spot market. Biscayne auctions, which require each bidding carrier to submit its reservation value, its starting bid price, and its desired margin above or below its competitors' bids, is used. The exchange computes the carriers' final bids based on their criteria. The load

²³ Source: <http://www.logistics.com> (2000)

²⁴ An origin-destination pair between which loads are moved directly is referred to as a lane.

component does not allow carriers to revise their bidding criteria. Shippers using this component, and participating carriers not brought in by the shipper pay fees to Logistics.com.

Each of the components requires carriers to bid prices, implying a carrier-centric price setting mechanism. However, note each of the components present shippers with the participating carriers' final bid prices or indices. A shipper uses its discretion in choosing the winning carrier, which may not always be based on prices or indices only.

NTE²⁵

NTE has both shippers and TL carriers identify their available shipment or capacity needs. The exchange collects shipment orders, and matches them to truck routes provided by carriers. NTE recommends market prices to shippers based on prevailing LTL rates for similar loads. When the delivery of the shipment is confirmed, NTE pays the carrier and bills the shipper.

NTE's members include manufacturers, retailers, distributors, wholesalers, 3PLs and various brokers. NTE has its fees built in to the load price, and thus generates revenue from every transaction.

NTE may also have a carrier-centric price setting mechanism, or a shipper-centric price setting mechanism, or both in place, to ensure a clearance mechanism for each load and available capacity posted on the exchange.

Information on the auction mechanisms and revenue models adopted by ShipChem.com and CarrierPoint.com is not publicly available. Thus, they are not discussed here.

2.2 Auction Design Variables

As discussed in section 2.1, transportation exchanges enable shippers and carriers to match loads with available capacity according to certain auction mechanisms. In such procurement auctions, each shipper acts as the auctioneer for its loads, trying to procure transportation for them, and carriers act as bidders, offering to provide transportation at their bid prices.

²⁵ Source: <http://www.nte.net> (2000)

In transportation auctions, the term reservation value for a seller is the lowest bid that it is willing to make, and that for a buyer is the highest bid that it is willing to accept. Carriers compute their bid values based on their reservation values. A carrier's reservation value is assumed to be composed of two components: operational costs and location costs, which have been explained in section 1.1.4. It is in the interest of the shippers to encourage carriers to bid their true reservation values²⁶.

The dimensions along which procurement auctions in a trucking exchange may be differentiated are as follows.

2.2.1 Ascending and Descending Auction Mechanisms

In an ascending auction, the shipper sets a low bid price²⁷ to start the bidding process. In successive rounds, the bid price is increased until any one carrier accepts the load at the current bid price.

In a descending auction, the bid price is successively reduced until only a single carrier remains, and the winning carrier wins the load at the final bid price. The auction may proceed by the shipper calling out reduced bid prices or by the carriers calling out reduced bid prices in consecutive rounds.

In both the auction mechanisms, if there is more than one carrier at the same bid price, the shipper uses its discretion to choose between them.

NTE, which usually expect shippers and carriers to accept the "market prices" suggested by them, possibly resort to the ascending auction mechanism to procure transportation for loads that remain in the exchange for more than a certain period of time. 3plex.com, which requires a shipper to offer a price for its load works as an ascending auction, since the shipper needs to revise its offer price for the load if it remains without being accepted by any carrier for a certain period of time. Button auctions described in section 3.5, is an example of a descending auction.

²⁶ Discussion on the computation of a shipper's reservation value is not within the scope of this thesis.

²⁷ A low bid price refers to a price which is lower than the shipper's expectation of all the carriers' reservation values

2.2.2 Single and Multiple Round Auctions

In a single round auction, the carrier with the lowest bid price in the round wins the load (or loads). In this type of auction, the carriers have little or no flexibility to change their bids. Thus, the carriers are motivated to submit bids based on their reservation values, unless they think they can win at higher prices.

In multiple round auctions, carriers are able to submit bids in successive rounds based on their reservation values, the lowest bids in previous rounds, and the previous round bids of the other carriers if known. A shipper decides on the last round at some time during the negotiation process based on a threshold price that it targets, or based on other bidding conditions, such as no changes in the carriers' bids for a certain number of rounds.

Logistics.com provides single round auctions for contract negotiations of shippers' networks and lanes, and spot market negotiations of their daily loads.

2.2.3 Open and Sealed Bid Auctions

In an open bid auction, each carrier has information about other carriers' bids in previous rounds or auctions of similar loads. In this type of auction, carriers bid based on their expectation of their competitors' bids estimated from the information they obtain from previous rounds or auctions.

In a sealed bid auction, carriers have no information about other carriers' bids except the lowest bid in a round. Thus, each carrier's bid in any round is based on their reservation value and the lowest bids in previous rounds.

Open bid auctions have been discussed here for completeness. Internet based transportation exchanges are all sealed bid auctions.

2.2.4 First and Second Price Auction Mechanisms

In a first price auction, the winning carrier wins the load at the final bid price. In a sealed bid auction, this would mean that the winning carrier wins the load at the bid price it quoted. It can be shown that in an open bid auction, it would mean that the winning carrier wins the load at the reservation value of the lowest losing carrier assuming that carriers wish to procure loads at prices higher than or equal to their reservation values.

In a second price auction, the winning carrier would win the load at the bid price of the lowest losing carrier. Though not yet popular in transportation auctions, this auction mechanism would assure carriers of getting a fair price, despite bidding lower than that would be required, for them to win the load. This would encourage carriers to bid their true reservation values.

It may be shown that the outcomes from a first price sealed bid auction and an ascending auction are the same while, the outcomes from a second price sealed bid auction and a descending auction are also the same²⁸. All transportation auctions currently function according to first price auction mechanism only. Second price auction mechanism is described here for completeness.

2.2.5 Sequential and Simultaneous Auctions

In auctions procuring transportation services for shippers' networks, a number of lanes need to be negotiated. In this context, sequential auctions are auctions where each lane is negotiated separately one after the other. Simultaneous auctions are auctions where multiple lanes are auctioned at the same time. At present, Logistics.com is the only transportation exchange that provides simultaneous auctions for contract negotiations.

2.2.6 Simple and Conditional Bidding Mechanisms

The major costs of logistics services involve the transportation of loads over a network. Due to economies of scope, it is sometimes possible for carriers to offer a better (lower) bid price when given a package of lanes instead of single lanes. In auctions with simple bidding mechanism, each lane is negotiated separately. In simultaneous auctions, bundling of lanes leads to better (lower) bid prices. This bidding process is referred to as conditional bidding. At present, Logistics.com is the only transportation exchange that enables conditional bidding mechanisms for contract negotiations.

²⁸ Klemperer, P., "Auction Theory: A Guide to the Literature", Journal of Economic Surveys, Volume 13, No. 3, July 1999, pp. 227-286

2.3 Characteristics of a Truck Exchange

Traditional markets consisting of a large number of buyers and sellers of each good are characterized by *perfect competition*, meaning that each of the participants has no influence on the prices of goods, acting as price takers. The prices at which supply and demand of each good are equal is referred to as their market price, and is accepted by the buyers and sellers of the good.

Markets where the number of buyers and/or sellers is small are characterized by *imperfect competition*. In such markets, each buyer/seller participating in the market choose price-quantity combinations that are most attractive to it. Moreover their favorable price-quantity combinations depend on their expectation about their competitors' choices.

This section describes the economic characteristics of trucking exchanges.

2.3.1 Imperfect Competition

As already mentioned, markets for goods in which the number of buyers and/or sellers is small, are usually characterized by imperfect competition. In such markets, which are referred to as auction markets, individual buyers and/or sellers are able to influence the prices of the goods being auctioned.

In a trucking exchange, shippers attempt to procure transportation at prices less than their reservation values, and carriers attempt to win loads at prices higher than their reservation values. Shippers and carriers aim at maximizing their respective auction profits by influencing the bid prices in the exchange, their profits being:

Shipper's auction profit = Shipper's reservation value minus Price at which transportation is procured

Carrier's auction profit = Price at which transportation is provided minus Carrier's reservation value

Thus, shippers attempt to procure transportation at the lowest costs possible, and carriers attempt to win loads at the highest prices possible.

Since the number of shippers procuring transportation for a load between a certain origin and destination and the number of carriers bidding to provide transportation for such a load at any point of time is small, each of them influences the price of transporting the load. Hence, a trucking exchange is characterized by imperfect competition.

2.3.2 Incomplete Information

A market where competitors possess complete information about the costs and/or profits of their competitors resulting from the various outcomes of a negotiation is rare. Most exchanges are characterized by incomplete information where competitors possess information only about their own costs.

In the context of trucking exchanges, even if it is assumed that the cost structures of different carriers are similar, different network structures, equipment availabilities, and customer bases of different carriers lead them to have different costs or reservation values for transporting each load. Thus, no carrier is aware of its competitors' reservation values.

2.3.3 Dynamic Nature

As in all exchanges, a carrier bids in a trucking exchange based on its reservation value, and its perception about its competitors' bidding strategies. A carrier's auction profit depends not only on its own bid, but on its competitors' bids as well. If a carrier observes that its competitors' bidding strategies are different from what it perceived it to be, the carrier changes its own bidding strategy in future auctions. Such alteration in carriers' bidding strategies over time introduces a dynamic nature in trucking exchanges.

In addition to the usual dynamic nature of exchanges, carriers' changing equipment availabilities and demands at various locations in their networks over time introduce another dimension of dynamism in the carriers' bidding strategies in an exchange. A carrier's acceptance of a load leads to additional equipment at the destination location and less equipment at the origin location of the load, resulting in changes in the carrier's location costs. In turn, these lead to revised reservation values for the transportation of future loads over the carrier's network, and subsequent alteration of its bidding strategy due to changes in its profits from the various outcomes of an auction.

2.4 Summary of Chapter

In trucking exchanges, shippers act as auctioneers participating in procurement auctions, and carriers bid on the shippers' loads wishing to provide transportation for them. Shippers may choose from different procurement auctions to minimize their transportation costs by encouraging carriers to bid their true reservation values. Carriers bid in the auctions to maximize their expected profits. Trucking exchanges are characterized by imperfect competition, incomplete information, and dynamism. These characteristics motivate the use of game theory to model the research problem that is addressed in this thesis.

CHAPTER 3 RESEARCH PROBLEM

This chapter describes the research problem and discusses the methodology used to address it. Section 3.1 describes the specific issue in truck exchanges that is addressed in this thesis. Section 3.2 models the problem within the framework of game theory. Section 3.3 discusses the assumptions that are made in solving for single round sealed bid auctions and button auctions, discussed in sections 3.4 and 3.5 respectively. The chapter is summarized in section 3.6.

3.1 Problem Statement

Internet-based trucking exchanges with carrier-centric price setting mechanisms such as Transplace.com and Logistics.com may be depicted as in Figure 3.1. As briefly described in section 1.2, the order of actions taken by shippers and carriers in such a trucking exchange is as follows.

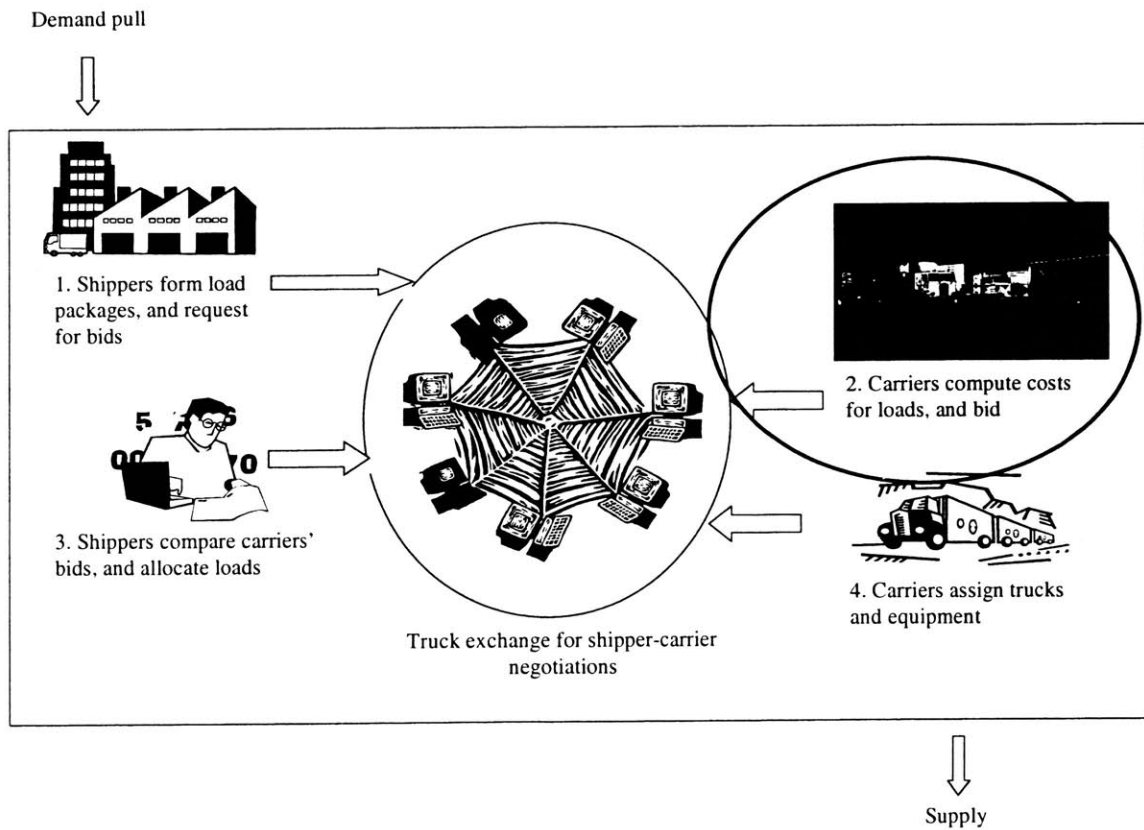


Figure 3.1 Structure of a Truck Exchange

1. *Posting of loads:* A shipper posts its load on the truck exchange, and requests for bids from several carriers.
2. *Bidding:* Carriers bid on the posted load on the basis of their expected operational costs for moving the load, current location costs for the origin and destination locations of the load, and other strategic factors such as their perception about their competitors' bidding strategies.
3. *Evaluation of Bids:* The shipper compares carriers' bids and allocates its load to the winning carrier. Shippers may have different criteria for comparison of bids. For example, in addition to bid prices offered by the carriers, they may compare carriers' service reliability.
4. *Assignment of trucks:* The winning carriers assign their equipment and crew to shippers' loads. After delivery confirmation, payment is processed between the shipper and carrier.

This thesis focuses on the 2nd step in Figure 3.1, that is, a carriers' strategy for bidding on a posted load. A carrier's operational costs and location costs corresponding to a load determine its reservation value for the load. Carriers bid on loads based on their reservation values, and their perceptions about their competitors' bidding strategies.

The mechanism according to which carriers bid based on their perception about their competitors' bidding strategies is often subjective. This thesis attempts to develop a theoretical model for carriers' bidding strategies that they could use to automate their bidding. Further, the model is also intended to help shippers in adopting appropriate auction mechanisms to procure transportation.

3.2 Game Theoretic Model

A game is a formal representation of a situation in which a number of individuals interact in a sense of strategic interdependence, meaning that each individual's welfare depends not only on its own actions, but also on the actions of the other individuals²⁹. Thus, the actions that are best for an individual to take may depend on what it expects the other individuals to do.

²⁹ Basic Elements of Non-cooperative Games, Mas-Colell, A., Whinston, M.D., and Green, J.R., Microeconomic Theory, pp. 219, 1995

The characteristics of imperfect competition, incomplete information, and dynamism motivate the application of game theory to the problem. This section represents the strategic competition among carriers to win a load within a game theoretic framework.

3.2.1 Components of the Game

Four things need to be identified to describe a game. They are as follows.

1. *The players* are the individuals participating in the game. In a trucking exchange with a carrier-centric price setting mechanism, the carriers are the players.
2. *The rules* describe the way the game is played including the possible actions by the players. In auctions, the specific auction design sets the rules of the game.
3. *The outcomes* denote the result of the game for each possible set of actions by the players. In trucking exchanges, the outcomes indicate the winning and losing carriers for each possible set of bids.
4. *The payoffs* denote the players' profits corresponding to the possible outcomes. In the context of the problem addressed, the carriers' auction profits are their payoffs.

3.2.2 Best Response Bidding Strategy

A central concept of game theory is the notion of a player's strategy. A strategy is a complete contingent plan, or a set of decision rules, that specifies how the player will act in every possible circumstance.

In a game representing strategic competition among carriers to win a load, a player's strategy is the way that a carrier bids on a load. Among the different bidding strategies that a carrier may adopt, those that maximize its expected profits if its conjecture about its competitors' bidding strategies were true are its best response bidding strategies.

3.2.3 Equilibrium Bidding Strategy

The most widely used solution concept in applications of game theory to economics is the Nash equilibrium³⁰. In a Nash equilibrium, each player's strategy choice

³⁰ Non-cooperative Games, Nash, J.F., *Annals of Mathematics* 54: 289-95, 1951

is a best response to the strategies actually played by its rivals. Thus, in a Nash equilibrium, none of the players have any incentive to unilaterally deviate from their current strategies. Players' strategies corresponding to a Nash equilibrium are referred to as the players' equilibrium strategies.

In the problem addressed in this thesis, a Nash equilibrium exists when each carrier's bidding strategy is a best response to the strategies actually adopted by its competitors. Thus, in a Nash equilibrium none of the carriers will have any incentive to unilaterally deviate from their current bidding strategy. The carriers' strategies corresponding to a Nash equilibrium are their equilibrium bidding strategies.

3.2.4 Shipper and Carrier Efficiencies

The Italian economist, Vilfred Pareto provides a precise definition for the concept of economic efficiency, which was first enunciated by Adam Smith as the existence of an "invisible hand" that helps allocate resources efficiently in properly functioning markets. Pareto defines an allocation of resources to be efficient if it is not possible (through further reallocations) to make one person better off without making someone else worse off.³¹ In the context of transportation procurement auctions, the concept of efficiency is addressed from two perspectives in this thesis: carriers' efficiency in an auction, and a shipper's efficiency in procuring transportation.

An outcome of an auction is defined to be efficient if it maximizes the carriers' aggregate profits. Thus, the efficiency of any outcome is defined as the ratio of the carriers' aggregate profits from the outcome to the carriers' aggregate profits from an efficient outcome.

From the shippers' perspective, an auction is defined to be efficient if it minimizes its transportation costs for moving a load. Thus, the efficiency of any auction is defined as the ratio of the shipper's transportation costs from the auction to its transportation costs from an efficient auction. It is assumed that a shipper's transportation costs from an auction is equal to the winning bid corresponding to an efficient outcome of the auction.

³¹ Source: Microeconomic Theory: Basic Principles and Extensions, Nicholson, W., 1998

3.2.5 Summary

To summarize, the strategic competition among carriers in an auction is modeled as a game. The best response strategies of the players in the game form the basis of carriers' best response bidding strategies in a procurement auction. Each carrier bids according to its best response bidding strategy expecting its competitors' to bid according to certain bidding strategies. A Nash equilibrium exists when each of the carriers bid according to their best response bidding strategies, and none of them has the incentive to change its bidding strategy unilaterally. If there are several Nash equilibria in an auction, one that maximizes the aggregate profits of all carriers is defined as the efficient Nash equilibrium. Among the auctions considered, one that minimizes the shipper's transportation costs is defined as an efficient auction from the shipper's perspective.

3.3 Assumptions

This thesis applies the game theoretic model discussed in section 3.2, to two types of procurement auctions: single round sealed bid auctions with first price mechanism, and button auctions. These auctions are described in detail in sections 3.4 and 3.5 respectively. This section discusses two assumptions that have been made to simplify the game theoretic solutions to the mentioned auctions.

3.3.1 Myopic Strategy

As discussed earlier, a carrier bids for loads based on its reservation value for the load and its perception of its competitors' bidding strategies from previous auctions. Further, if a carrier observes that its competitors' bidding strategies are different from what it perceived it to be, the carrier alters its own bidding strategy in future auctions which affects all the carriers' profits in the future auctions.

The game theoretic model implies that a carrier bids in an auction according to its best response bidding strategy so as to maximize its profits. Since carriers participate in auctions of similar loads over time and their current bidding strategies affect their profits in the future auctions, a carrier's best response bidding strategy can mean to maximize the carrier's aggregate profits in a number of similar auctions taken together. To simplify the game theoretic solution to each of the auctions considered, each carrier is assumed to devise its best response bidding strategy maximizing its profits in the current auction

only. The impact of the carriers' current bidding strategies on their profits in future auctions is not considered.

3.3.2 Constant Reservation Value

As discussed in section 2.3.3, each carrier's reservation value changes with changing equipment availabilities and demands at various locations in its network over time. Changes in carriers' reservation values lead to changes in their bidding strategies. To simplify the solution to each of the auctions considered, each carrier's reservation value corresponding to a load is assumed to remain constant over time.

3.4 **Single Round Sealed Bid Auction with First Price Mechanism**

This section discusses the game theoretic solution to a single round sealed bid auction with a first price mechanism consisting of 3 or more bidding carriers. A single load is considered in each auction. Each auction consists of carriers bidding for the load only once. The carrier bidding the lowest price is considered to win the load at its own bid price. After each auction, the lowest or winning bid is revealed to all the competing carriers.

A learning function is formulated to represent each carrier's updating of its perceptions/beliefs about its competitors' bids. Each carrier's best response bidding strategy based on its reservation value, and its belief about its competitors' bids is formulated. Consecutive single round auctions of similar loads are simulated to identify the Nash equilibria. Only one Nash equilibrium is identified, which is thus considered to be efficient. Corresponding to the Nash equilibrium, the carriers' aggregate profit is computed to quantify the carriers' and shipper's efficiency.

Some of the notations used to represent the game theoretic model are as follows:

Consecutive auctions are denoted by $t = 1, \dots, \tau, \dots, T$;

Competing carriers are denoted by $i = 1, \dots, N$;

Carrier i 's reservation value for the load in auction $t = \tau$ is denoted by $v_{i,\tau} = v_i$;

Carrier i 's bid in auction $t = \tau$ is denoted by $b_{i,\tau}$;

Bids of all carriers in auction $t = \tau$ is denoted by $\{ b_{i,\tau} \}$

Bids of all carriers other than i till auction $t = \tau-1$ is denoted by $B_{-i,\tau}$;

3.4.1 Beliefs

Each carrier's belief about its competitors' bids is based on the lowest bids in previous auctions. At any time, each carrier's belief is represented by a uniform distribution with an upper bound and a lower bound. The choice of a uniform distribution means that within the range of probable bid values that a carrier believes its competitors to bid from, it has no reason to believe that they are more likely to bid some values as compared to others in the range. Thus, carrier i 's belief about its competitors' bids in auction τ is represented by the uniform distribution function $u(B_{-i,\tau}^{\min}, B_{-i,\tau}^{\max})$. $B_{-i,\tau}^{\max}$ and $B_{-i,\tau}^{\min}$ denote the upper and lower bounds of the range of bid values within which the carrier expects its competitors to bid. To simplify notations, the probability density function corresponding to the uniform distribution function $u(B_{-i,\tau}^{\min}, B_{-i,\tau}^{\max})$, and representing a carrier's beliefs about its competitors' bids is represented by $f_{-i,\tau}(x)$, and the corresponding cumulative probability density function is represented by $F_{-i,\tau}(x)$ in the rest of this thesis. The following results are computed based on the properties of a uniform distribution function:

$$f_{-i,\tau}(x) = \frac{1}{B_{-i,\tau}^{\max} - B_{-i,\tau}^{\min}}; \quad (1)$$

$$\Rightarrow F_{-i,\tau}(x) = \frac{x - B_{-i,\tau}^{\min}}{B_{-i,\tau}^{\max} - B_{-i,\tau}^{\min}}; \quad (2)$$

$$\begin{aligned} \Rightarrow \text{Pr ob}(x \leq B_{-i,\tau}) &= 0; \forall x > B_{-i,\tau}^{\max} \\ &= \frac{B_{-i,\tau}^{\max} - x}{B_{-i,\tau}^{\max} - B_{-i,\tau}^{\min}}; \forall B_{-i,\tau}^{\min} \leq x \leq B_{-i,\tau}^{\max}; \\ &= 1; \forall x < B_{-i,\tau}^{\min} \end{aligned} \quad (3)$$

After every auction when the lowest bid is revealed, each carrier learns more about its competitors' bidding strategies and updates its beliefs, based on which it bids in future auctions of similar loads. An exponential learning function representing the process of each carrier's updating the parameters representing its beliefs, $B_{-i,\tau}^{\max}$ and $B_{-i,\tau}^{\min}$ is formulated as follows.

At auction $t = 1$, each carrier assumes a range r_i and sets:

$$B_{-i,\tau}^{\min} = v_i - r_i / 2; \text{ and}$$

$$B_{-i,\tau}^{\max} = v_i + r_i / 2 \quad (4)$$

After auction $t = \tau - 1$, each carrier updates:

$$B_{-i,\tau}^{\min} = (1 - \alpha)B_{-i,\tau-1}^{\min} + \alpha \min\{b_{i,\tau-1}\}; \text{ and} \quad (5)$$

$$B_{-i,\tau}^{\max} = (1 - \alpha)B_{-i,\tau-1}^{\max} + \alpha \min\{b_{i,\tau-1}\}; \text{ if } b_{i,\tau-1} \leq \min\{b_{i,\tau-1}\}$$

$$= \min\{b_{i,\tau-1}\} - \beta; \text{ otherwise} \quad (6)$$

where,

α denotes the rate of learning, and

β denotes the accuracy of estimating the upper bound

Thus, the upper and lower bounds of the uniform probability distribution functions representing each carrier's beliefs about its competitors' bids are updated based on the lowest bid that is revealed after every auction.

3.4.2 Objective Function

In every auction, each carrier bids to maximize its profits. To make profits in an auction, a carrier needs to win it by bidding the lowest price. At the time of bidding, a carrier only possesses beliefs about its competitors' bids. Bidding a low value implies good chances of a carrier's winning the auction but yields low profits, and bidding a high value implies low chances of a carrier's winning the auction but yields high profits if it does. Thus, each carrier bids x in an auction maximizing its expected profits which is represented by:

$$E(x) = [\text{Pr ob}(x \leq B_{-i,\tau})][x - v_{i,\tau}] \quad (7)$$

Assuming $B_{-i,\tau}^{\min} \leq x \leq B_{-i,\tau}^{\max}$,

$$\Rightarrow E(x) = \left[\frac{B_{-i,\tau}^{\max} - x}{B_{-i,\tau}^{\max} - B_{-i,\tau}^{\min}} \right] [x - v_{i,\tau}] \quad (8)$$

Applying the first order conditions for maximization to (8)

$$\Rightarrow \frac{\partial E}{\partial x} = 0 \Rightarrow x = \frac{B_{-i,\tau}^{\max} + v_i}{2}; \quad (9)$$

Applying the second order conditions for maximization to (8)

$$\frac{\partial^2 E}{\partial x^2} = \frac{-2}{B_{-i,\tau}^{\max} - B_{-i,\tau}^{\min}} \leq 0 \Rightarrow x \text{ is a global maximum} \quad (10)$$

Thus from (9) and (10),

$$\text{If } B_{-i,\tau}^{\min} \leq x \leq B_{-i,\tau}^{\max}, b_{i,\tau} = x = \frac{B_{-i,\tau}^{\max} + v_i}{2} \quad (11)$$

Bidding a value equal to the lower bound of the range of values within which a carrier's competitors are expected to bid yields at least the same amount of expected profit for the carrier as bidding a value lower than that yields. Thus,

$$\text{If } x < B_{-i,\tau}^{\min}, b_{i,\tau} = B_{-i,\tau}^{\min} \quad (12)$$

When the bid value implied by (9) is greater than the upper bound of the range of values within which a carrier's competitors are expected to bid, it can be shown that the carrier's reservation value corresponding to the load is greater than the upper bound. This means that the carrier expects to lose the auction if it bids any value equal or greater than its reservation value. In such a situation, a carrier refrains from participating in the auction, which may be represented as follows:

$$\text{If } x > B_{-i,\tau}^{\max}, b_{i,\tau} = v_i \quad (13)$$

Hence, the rules implied by (11), (12), and (13) constitute a carrier's best response bidding strategy. To identify the carriers' equilibria bidding strategies, consecutive single round auctions of similar loads are simulated. Carriers bid according to the above strategies in each auction, updating the parameters representing their beliefs after each auction. The results of the simulation are presented in section 4.1. Note that the rules derived in this section are based on the assumption that each carriers' beliefs about its competitors' bids can be represented by a uniform distribution.

3.5 Button Auctions

Button auctions have not yet gained popularity in Internet-based trucking exchanges, or other transportation exchanges. It is considered here due to its increasing popularity in Internet-based auctions.

A button auction literally consists of bidders placing their hands on a button. Similar to a descending auction, the bid price is reduced over time by an automated

system administered by the auctioneer. At different bid prices, different bidders lift their hands from their buttons to indicate that they are not willing to participate in the auction at or below the running bid price. Once a bidder lifts its hands from its button, it is not allowed to re-enter the current auction. Further, the auction stops when only one bidder remains. In a transportation procurement auction administered as a button auction, the buttons would be in the control of the carriers while the shippers would administer the auctions.

At bid prices greater than a carrier's reservation value for the load being auctioned, the carrier retains a chance of making a profit by winning the load, and thus continues to participate in the auction by keeping its hands on the button. At bid prices less than the carrier's reservation value for the load, the carrier incurs a loss if it wins the load. Hence in a button auction, a carrier's best response bidding strategy is to continue to participate in the auction of the load until the running bid price drops below its reservation value. Thus in a button auction, the only possible outcome is the carrier with the lowest reservation value winning the load at the reservation value of the second but last carrier to drop out of the auction. Since there is only one possible outcome in a button auction, it is also the Nash equilibrium. Carriers' aggregate profits are computed to quantify the carriers' and shipper's efficiency.

It is observed from the discussions in sections 3.4 and 3.5 that in button auctions, carriers bid irrespective of their beliefs about their competitors' bidding strategies, while in single round sealed bid auctions with a first price mechanism, carriers bid based on their beliefs about their competitors' bidding strategies.

3.6 Summary of Chapter

In trucking exchanges, carriers bid on shipper's loads. A carrier bids a value based on its reservation value for moving the load, and its perception of its competitors' bidding strategies. Following certain assumptions, a game theoretic model is formulated to recommend carriers' best response bidding strategies in single round sealed bid auctions with a first price mechanism, and button auctions. The solutions to the model also facilitate the identification of auctions that minimize a shipper's transportation costs.

Such solutions may provide a framework for the design of future software programs that help shippers and carriers to participate in Internet-based trucking exchanges.

CHAPTER 4 RESULTS AND CONCLUSION

Currently operating transportation exchanges such as Transplace.com and Logistics.com enable shippers to bid out their loads in spot markets through sealed bid auctions. Auctions provided by Transplace.com consist of a single round, while those provided by Logistics.com consist of multiple rounds conducted by the automated agents used in that auction. Winning carriers are identified by exchanges based on a first price mechanism. Though button auctions are not yet used in transportation exchanges, they have gained popularity in Internet-based auctions. This chapter demonstrates the solutions to the game theoretic model presented in Chapter 3, followed by a conclusion to this thesis. Section 4.1 presents simulations performed to evaluate single round sealed bid auctions with first price mechanism, and button auctions. Section 4.2 discusses the significance of this research to Internet-based trucking exchanges. Possible extensions of this research are summarized in section 4.3, followed by a concluding summary of this thesis.

4.1 Experiments and Results

Consecutive auctions of similar loads, each procuring transportation services for a single load are simulated. This section presents trends in carriers' bids and beliefs in single round sealed bid auctions with first price mechanism. Two cases are considered: a duopoly with 2 carriers, and an oligopoly with 3 carriers bidding in each auction. In each of the cases, each carrier bids according to the best response bidding strategies suggested by the solution to the game theoretic model in section 3.4. Carriers' equilibria bidding strategies are identified from the results of the simulations. Further, their aggregate profits in the duopoly and oligopoly are compared with that in a button auction and a monopoly situation, to evaluate the carriers' and shippers' efficiencies in each of the auctions.

4.1.1 Duopoly

Single round sealed bid auctions with first price mechanism are simulated. The reservation values for the two carriers bidding for a shipper's load in each auction are

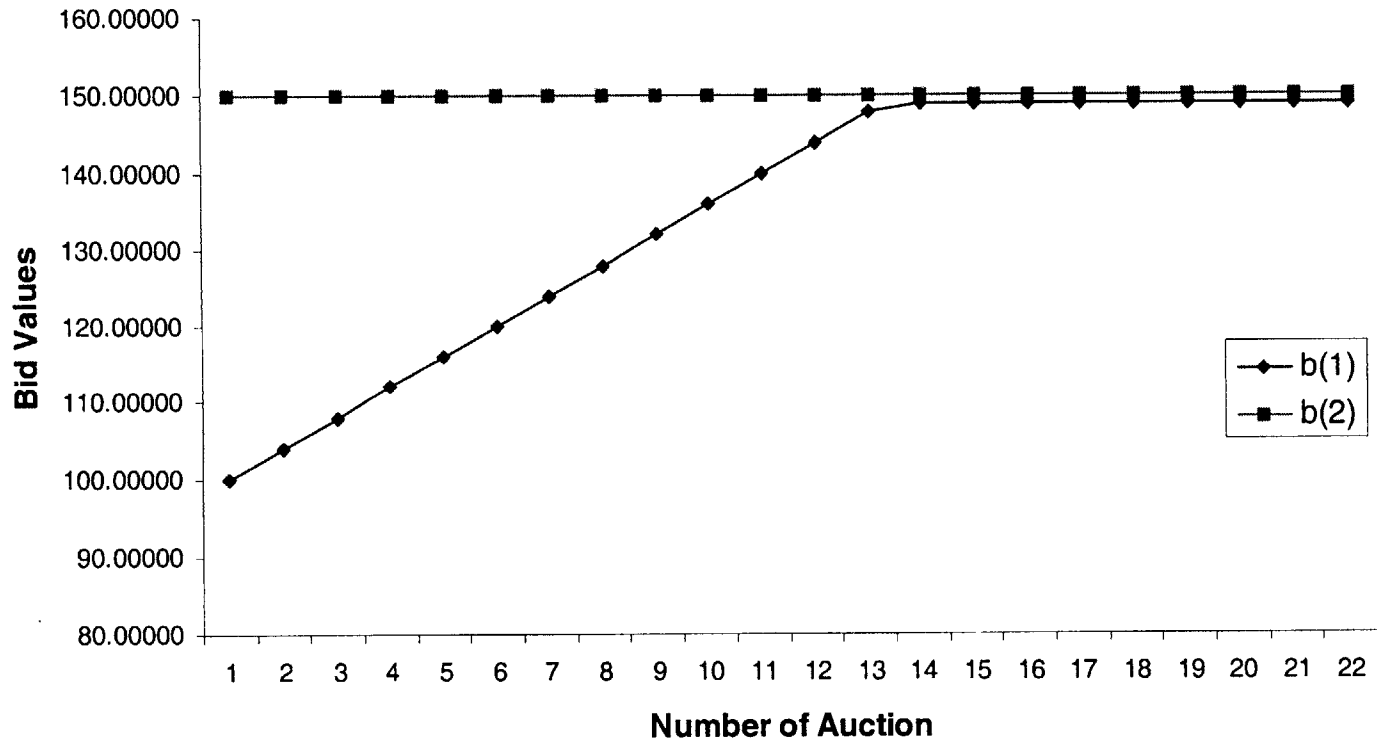


Figure 4.1 Trend of Bids in a Single Round Sealed Bid Auction with a First Price Mechanism having 2 Carriers (Duopoly) with Reservation Values, $v_1 = 100$, and $v_2 = 150$

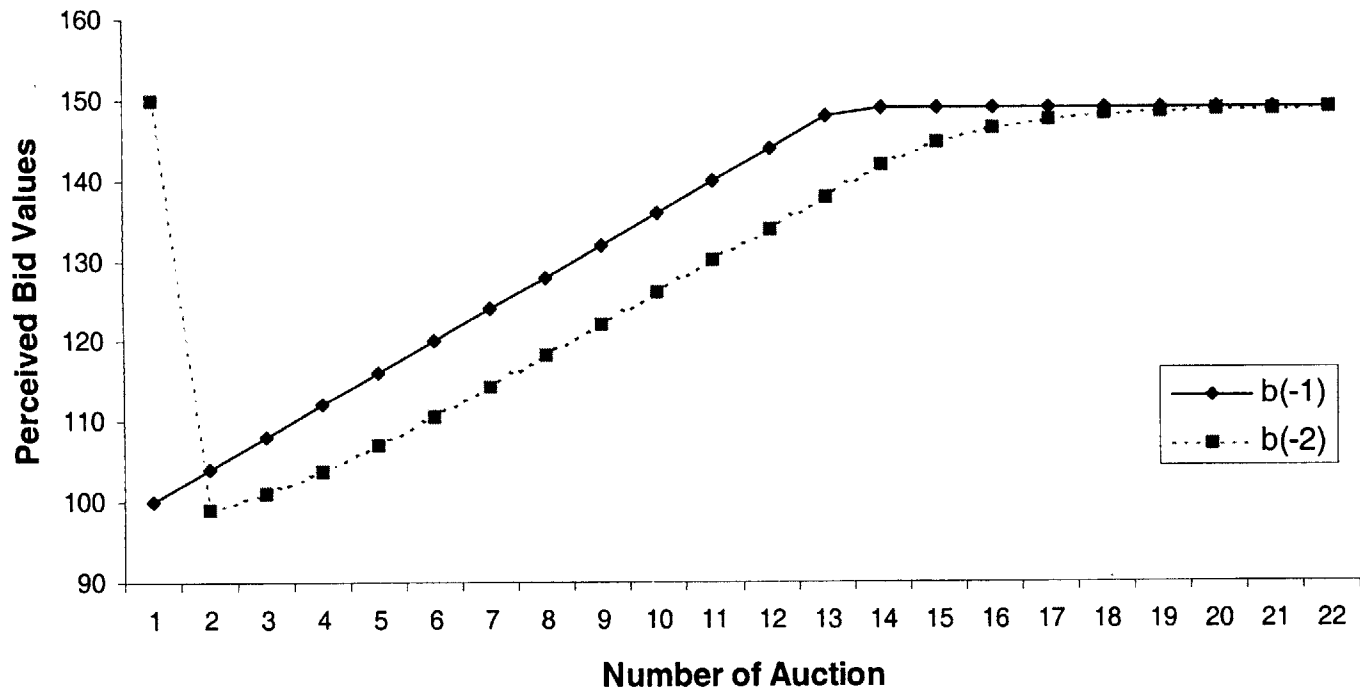


Figure 4.2 Trend of Beliefs in a Single Round Sealed Bid Auction with a First Price Mechanism having 2 Carriers (Duopoly) with Reservation Values, $v_1 = 100$, and $v_2 = 150$

arbitrarily chosen to be 100 and 150, which represent the dollar values below which each of the respective carriers is not willing to accept the load.

According to the rules of a single round auction each carrier bids in an auction only once. Each carrier bids the highest value that is lower than what it expects to be its competitor's bid value. In each auction, the shipper assigns its load to the lowest bidding carrier, as implied by a first price mechanism. Each carrier begins participating in the consecutive auctions with the belief that their competitor will bid a value equal to their own reservation value. After each auction, the carriers update their beliefs about their competitor's bid based on the lowest bid that is revealed, using the learning function (6) formulated in section 3.4.1. The parameter α is chosen to be 0.4 to represent steady updating of beliefs. The parameter β is chosen to be 1 to represent that carriers will be indifferent towards making an extra profit of less than \$1. The carriers' bids and beliefs in the consecutive auctions are presented in figures 4.1 and 4.2 respectively.

Bid Trends

Figure 4.1 shows each carrier's bids in the consecutive auctions. Carrier 1 with a reservation value of 100 begins by bidding 100, whereas Carrier 2 begins by bidding 150. Through consecutive auctions, Carrier 1 increases its bid to 149, whereas Carrier 2 continues to bid 150, being unable to bid below its reservation value for the load.

After the 15th auction, the carriers do not change their bids unilaterally, indicating that a Nash equilibrium has been reached. Note that the value of α influences the number of auctions that carriers take to reach their equilibria bidding strategies. With a small value of α , carriers take a large number of auctions to reach their equilibria bidding strategies, and vice-versa. Since only one equilibrium exists in the duopoly, it is also efficient.

Trend of Beliefs

Figure 4.2 shows each carrier's beliefs about its competitor's bids at the beginning of each auction. Before the 1st auction, Carrier 1 expects its competitor to bid 100, whereas Carrier 2 expects its competitor to bid 150. After the 1st auction, Carrier 2 updates its belief about its competitor's bid based on the lowest bid of 100. After each of the following auctions, each carrier updates its beliefs about its competitor's bid according to learning function (6), formulated in section 3.4.1.

Since Carrier 2 always bids 150, Carrier 1's learning curve representing its beliefs about its competitor's bids is linear. However since Carrier 1 increases its bid linearly from 100 to 149 during the 15 auctions, Carrier 2's learning curve is exponential in nature following the drop after the 1st auction.

4.1.2 Oligopoly

Single round sealed bid auctions with first price mechanism are simulated with the same 3 carriers bidding in each. The carriers' reservation values are arbitrarily chosen to be 100, 125, and 150, which represent the dollar values below which each of the respective carriers are not willing to accept the load. Each carrier bids according to its best response bidding strategy, formulated in section 3.4.2. Each carrier begins participating in the consecutive auctions with the beliefs implied by equation (4) in section 3.4.1. The initial range r_i representing the range around their own reservation values that each carrier expects its competitors to bid is chosen arbitrarily to be 40 for all the carriers. After each auction, the carriers update their beliefs about their competitor's bid based on the lowest bid that is revealed, using the learning functions (5) and (6) presented in section 3.4.1. As explained in the case of a duopoly, the parameter α is chosen to be 0.4 to represent steady updating of beliefs, and the parameter β is chosen to be 1, assuming that the carriers will be indifferent towards making an extra profit of less than \$1. The carriers' bids and beliefs in the consecutive auctions are presented in figures 4.3 and 4.4 respectively.

Bid Trends

Figure 4.3 shows each carrier's bids in the consecutive auctions. In the first auction, the three carriers with reservation values 100, 150, and 125 bid 110, 135, and 160 respectively, as suggested by their initial beliefs and their best response bidding strategies. Through consecutive auctions, Carrier 1 increases its bid to 124, whereas Carrier 2 and Carrier 3 bid their reservation values of 150 and 125, after losing in the 1st auction.

After the 8th auction, none of the carriers change their bids unilaterally, indicating that a Nash equilibrium has been reached. As mentioned in the case of duopoly, the value

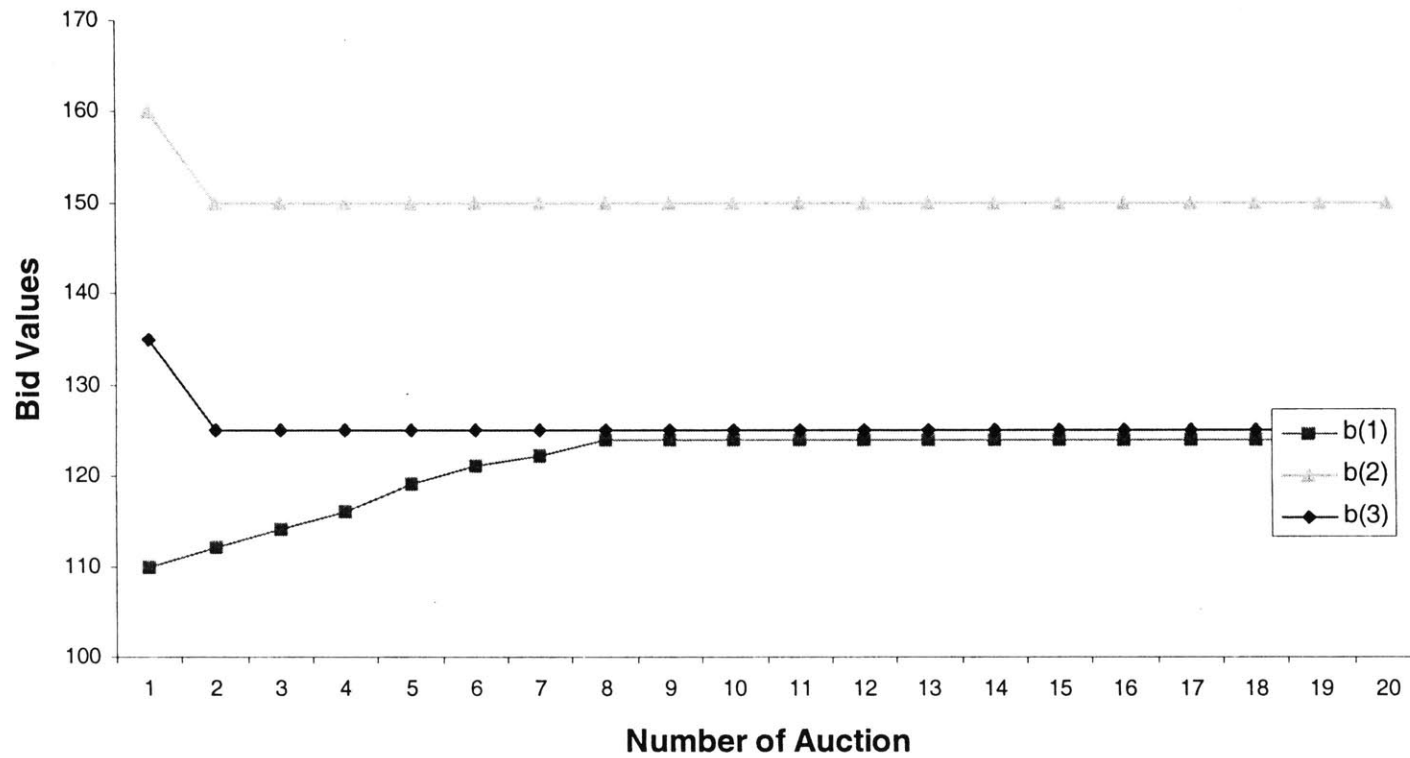


Figure 4.3 Trend of Bids in a Single Round Sealed Bid Auction with a First Price Mechanism having 3 Carriers (Oligopoly) with Reservation Values, $v_1 = 100$, $v_2 = 150$, and $v_3 = 125$

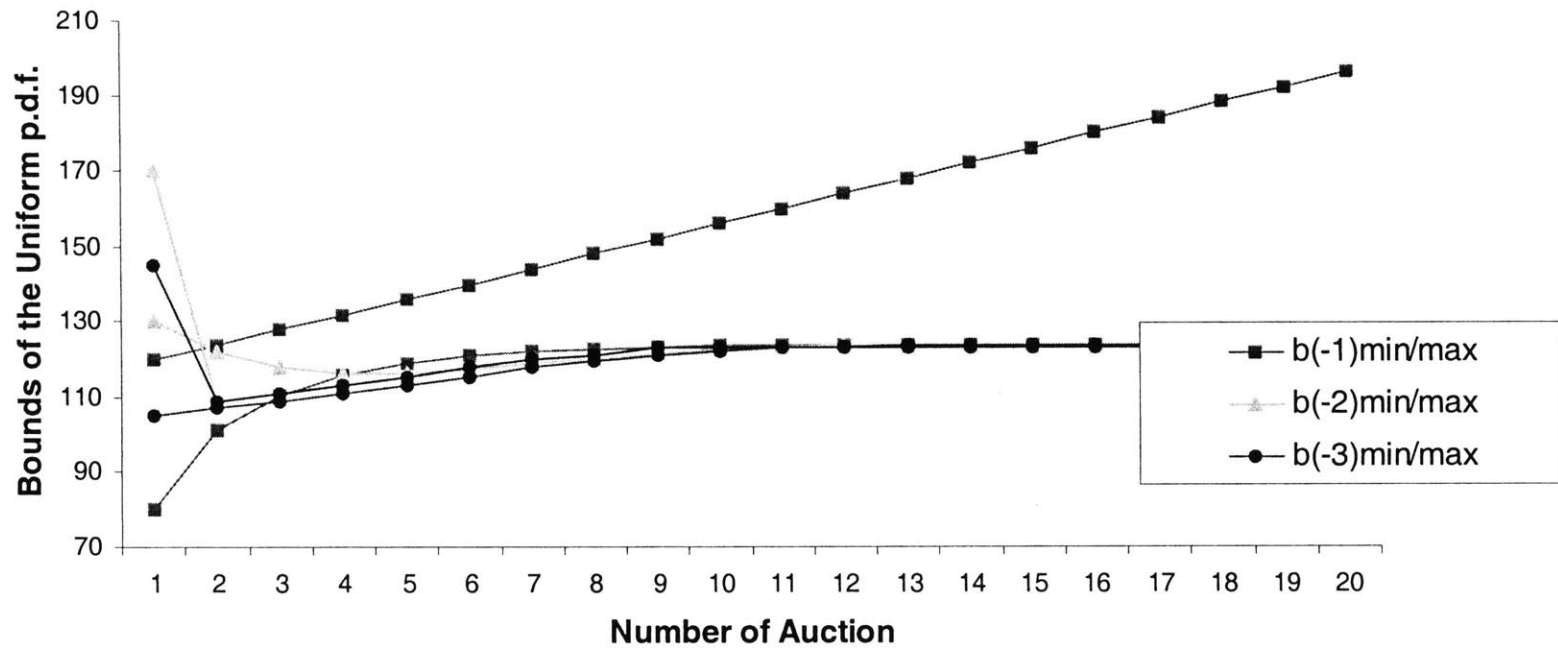


Figure 4.4 Trend of Beliefs in a Single Round Sealed Bid Auction with a First Price Mechanism having 3 Carriers (Oligopoly) with Reservation Values, $v_1 = 100$, $v_2 = 150$, and $v_3 = 125$

of α influences the number of auctions taken by the carriers to reach their equilibria bidding strategies. Since only one equilibrium exists in the oligopoly, it is also efficient.

Trend of Beliefs

Before each auction, each carrier expects its competitors' bids to be distributed according to a uniform distribution with a range r_i around its own reservation value. Thus, before the 1st auction the parameters of the uniform distributions representing the carriers' beliefs are: 80 and 120 for Carrier 1, 130 and 170 for Carrier 2, and 105 and 145 for Carrier 3. After each auction, the carriers update their beliefs about their competitors' bids, based on the lowest bid in the auction. Figure 4.4 shows the upper and lower bounds representing the carriers' beliefs in each auction. The upper and lower bounds representing Carrier 2 and Carrier 3's beliefs about their competitors' bids converge exponentially to 123.5 and 124.5, around the lowest bid of 124 in the consecutive auctions. Though the lower bound representing Carrier 1's beliefs converges exponentially to 124, the upper bound continues to increase linearly.

4.1.3 Summary of Results

Carriers' aggregate profits in the duopoly and oligopoly are compared with those in a button auction and a monopoly situation, to infer about the carriers' and shippers' efficiencies in the different situations. The carriers participating in the button auction are the same three carriers participating in the oligopoly. Each continues participating in each auction till the running bid price is less than its reservation value, resulting in Carrier 1 winning the load at a bid price of 124. Thus, the carriers' bidding strategies are independent of their competitors' bids. The shipper's highest acceptable bid is chosen arbitrarily to be 170, higher than the reservation value of all the 3 carriers. Thus in a monopoly situation with Carrier 1 as the only carrier in the marketplace, Carrier 1 moves the load at a price of 170.

Figure 4.5 shows that the equilibrium profit in a monopoly situation is higher than that in a duopoly, which is in turn higher than that in an oligopoly situation. Further in the oligopoly situation, carriers' aggregate profits increase to 24 in single round sealed bid auctions with a first price mechanism, whereas it is always 24 in button auctions. This implies that from the carriers' perspective, button auctions are more efficient than single

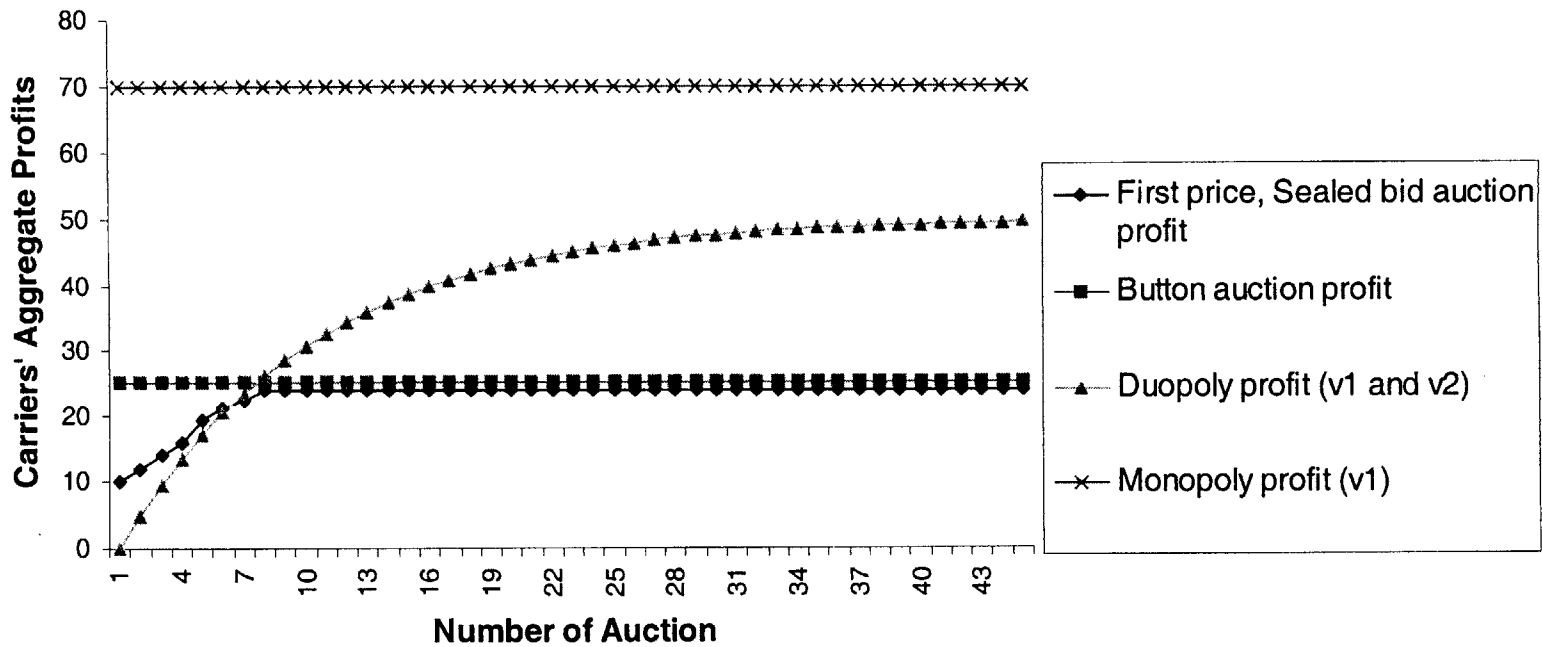


Figure 4.5 Comparison of carriers' aggregate profits in a single round sealed bid auction with first price mechanism (duopoly and oligopoly situations), a button auction, and a monopoly situation with the shipper's highest acceptable bid, $v_s = 170$.

round sealed bid auctions with a first price mechanism. However from the shippers' perspective, the reverse is true. The value of the parameter in the learning function, α influences the number of auctions taken for the carriers' aggregate profits to increase to 24 in the single round sealed bid auctions. A high value for α implies that the number of auctions taken would be small, and vice-versa.

Figures 4.1-4.4 representing single round sealed bid auctions with first price mechanism with 2 and 3 carriers, show carriers updating their beliefs about their competitors' bids, and bidding according to their best response bidding strategy in the consecutive auctions. Increasing the value of the parameter α reduces the number of auctions before which the carriers reach their equilibria bidding strategies, but makes the carriers sensitive to erroneous bidding by their competitors. Figure 4.5 comparing the carriers' aggregate profits from different auctions, suggests that compared to single round sealed bid auctions with first price mechanism, button auctions are more efficient for carriers and less efficient for shippers in the short-run, and after a certain number of auctions are equally efficient for both. The number of auctions after which button auctions and single round sealed bid auctions are equally efficient for shippers and carriers is influenced by the value of the parameter α .

4.2 Contribution

This research was motivated by the increase in the number of Internet-based trucking exchanges that have come into existence during 2000. This thesis categorizes currently operating transportation exchanges according to their price setting mechanisms and niche strategies. Transportation exchanges either have a carrier-centric price setting mechanism, a shipper-centric price setting mechanism, or both. Further, they are categorized according to their niche strategies. 3PLs and their consortiums providing services similar to transportation exchanges are described. Further, general and specialized transportation exchanges serving all and specific shippers and carriers, are described.

A trucking exchange with a carrier-centric price setting mechanism is considered in this thesis. A game theoretic model is formulated to represent the analytical basis of carriers' bidding strategies in trucking exchanges. Carriers' reservation values are

composed of their operational costs, and location costs³² that represent their strategic cost of moving a truck from one location to another in their network. Carriers bid based on their reservation values and their beliefs about their competitors' bidding strategies. Carriers are considered to participate in auctions of similar loads over time. Through the auctions, they update their beliefs about their competitors' bidding strategies using an exponential learning function that is formulated. Solution to the game theoretic model for single round sealed bid auctions with first price mechanism recommends carriers' optimal bidding strategies.

Simulations are performed to represent auctions of similar loads over time. Following certain assumptions, carriers' bids in single round sealed bid auctions are observed to reach equilibrium states. Carriers' aggregate profits in single round sealed bid auctions with first price mechanism, button auctions, and a monopoly situation are compared. In the short-run, button auctions are observed to be more profitable for carriers compared to single round sealed bid auctions with first price mechanism, also implying that shippers' transportation costs are lower in single round sealed bid auctions with first price mechanism than in button auctions. The carriers' rates of learning about their competitors' bidding strategies influence the number of auctions after which first price sealed bid auctions become as efficient as button auctions for both, shippers and carriers.

4.3 Extensions

Carriers' location costs vary with time based on their changing equipment demand and availabilities at different locations in their networks. Moreover, their operational costs also vary with time. Together, these lead carriers' reservation values to vary with time. To simplify the solutions to the game theoretic model formulated in this thesis, carriers' reservation values were assumed to be constant over time. Research may be performed to solve the game theoretic models for varying reservation values.

Carriers participate in auctions of similar loads. Their current bids affect their competitors' bids in future auctions, which in turn affect their profits in those. The carriers' optimal bidding strategies developed in this thesis assume carriers to be myopic

³² Location costs capture the economies of scope that exist in TL operations. By including a carrier's location costs in its reservation values, this thesis treats carriers as sellers of any good or service.

with respect to their profits, i.e., they are assumed to bid to maximize their profits in the current auction only. Research may be performed to formulate and solve game theoretic models representing carriers' bidding strategies for long-term profit maximization.

In this thesis, models were developed to represent carriers' bidding strategies for a single load. In reality, carriers bid for different loads over time. Research may be performed to develop carriers' bidding strategies in such cases.

In this thesis, single round sealed bid auctions with first price mechanism and button auctions were modeled within the framework of game theory. Research may be performed to model other auctions such as single round sealed bid auctions with second price mechanism, ascending auctions, and simultaneous auctions of multiple loads allowing conditional bidding within a game theoretic framework to determine their efficiencies with respect to shippers and carriers.

The methodologies developed in this thesis and the suggested extensions may be implemented as software programs for shippers and carriers. Shippers may use the software programs to bid out their loads in spot markets. Carriers may use the software programs to bid for shippers' loads. Using current technology like CORBA³³, such programs may be enabled to interact with each other automatically through the Internet, further reducing human interaction in trucking exchanges.

³³ CORBA is an acronym for Common Object Request Broker Architecture