Bidder Response to Combinatorial Auctions in Truckload Procurement

by

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Abstract

This thesis explores how truckload carriers use conditional bids within the framework of a combinatorial auction to win more business and balance their existing networks. Because a considerable portion of a truckload carrier's cost of serving a given lane is associated with the probability of finding a follow-on load (i.e. economies of scope), bidding on a lane-by-lane basis may not accurately reflect a carrier's true cost of serving that lane.

In a combinatorial auction, a truckload carrier can more accurately reflect its true cost of serving a given lane by offering package discounts, conditional on winning lanes that increase the probability of finding follow-on loads. Though a considerable amount has been written about the economics of truckload carrier's operations and the benefits of combinatorial auctions to shippers, few have studied conditional bidding from a bidder's (carrier's) perspective.

This thesis makes three contributions. First, an explanation of why bidders do and don't submit conditional bids in combinatorial auctions is provided. Second, a model of carrier costs functions, including package discounts (a measure of economies of scope) is developed. Finally, this thesis examines regional pricing differences, and quantifies the amount by which carriers will change their prices in different regions of the US.

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Chapter 1

Introduction

Truckload motor carriers, those who dedicate a truck to a single shipment between an origin-destination pair, represent over 40% of the US transportation expenditure (Sheffi, 2002). Despite its $240 Billion in annual revenues, few industries are as fragmented as truckload transportation. The U.S. Census report estimates that, with over 30,000 companies of varying sizes, the truckload transportation industry is one of the three most fragmented business sectors in the country (CSFB 2000).

Truckload carriers have felt a number of pressures in the past years, including overcapacity, a shortage of professional drivers, and increases in the costs of insurance and fuel. In addition to these persisting challenges, lately, as a result of a sluggish economy, truckload carriers have experienced demand shortages. "Almost every other sector [besides automotive] is down or flat" says Scott Arves, President of Schneider National, the nation's largest privately held truckload carrier (Schulz, 2003). To remain competitive, and in some cases, remain in business, truckload carriers are searching for ways to wring more profit from their existing business.

In a 2000 study of outsourced logistics, Credit Suisse First Boston projected that "asset-based carriers should be able to realize immediate improvements to earnings and improvements to both returns on invested capital and returns on equity" through new technologies and services offered by third party logistics providers (3PL's) and "eLogistics" companies. CSFB goes on to hypothesize that carriers should be able to see improvements in asset utilization of 5% to 10% as a result of applying these technologies.

Combinatorial auctions are one technology capable of improving carrier asset utilization that has become increasingly prevalent in the past few years. Often called "conditional auctions," these are arrangements in which a carrier submits a series of bids whose prices that are dependent upon receiving a commitment of volume, or percentage of traffic, in a set of lanes. It has been hypothesized that, by allocating portions of a shipper's network to those carriers whose existing networks and cost structures most complement specific-origin destination pairs, both shippers and carriers will benefit in the form of lower freight rates and increased asset utilization, respectively.

Though combinatorial auctions have been explored from the perspective of a shipper in a number of papers, little has been written about the value truckload carriers receive from such auctions. This thesis investigates how truckload carriers react when given the opportunity to submit conditional bids and how combinatorial auctions create value for truckload carriers.

1.1 Key Definitions

Truckload transportation, and the procurement thereof, often uses a language of its own. Following are some frequently used terms that we found helpful in understanding the dynamics of combinatorial auctions from a carrier's perspective.

Truckload– Truckload (TL) trucking, as opposed to less-than-truckload (LTL) trucking, usually involves a single tractor-trailer combination vehicle dedicated to one shipment between a single origin and destination.

Lane – In truckload trucking, a "lane" represents a unique origin – destination pair. For example, "Columbus, OH to Tempe, AZ" would represent a unique "lane."

Deadhead – Deadhead represents the empty miles a carrier incurs in relocating a piece of equipment from the destination of one shipment to the origin of another. As with any cost, carriers seek to minimize deadhead.

Dwell time – Like deadhead, dwell time represents a cost of waste which carriers seek to minimize. Specifically, dwell time refers to the time a piece of equipment sits idle waiting for a follow on load.

Bidder – For the case of this paper, a "bidder" is a truckload carrier submitting a price, or *rate per mile*, on one or more of the *lanes* offered by the *auctioneer*.

Auctioneer – Though definitions throughout the literature differ considerably, here we define an "auctioneer" as an entity that uses a procurement auction to offer a lane or combination of lanes to a group of truckload carriers who may be interested in servicing that lane. Under this definition, the "auctioneer" could be either the shipper or the software vendor, because the two are seen as one by the carrier.

Discrete / Unconditional Bid – As in most procurement auctions, a "bid" represents a bidder's offered price. A discrete bid is an offer for a single lane whose offered price is not conditional on being awarded any other lanes. A carrier will be awarded the lane in a discrete bid only if its offered price is lower than that of all other bidders. For example, if Buckeye Trucking Company submits a discrete bid of $1.24 per mile for the "Columbus, OH to Tempe, AZ" lane and Hurricane Trucking Company submits a discrete bid of $1.25 for the same lane, and no other lanes or bidders are involved, Buckeye Trucking company will be awarded that lane.

Package / Conditional Bid – Conversely, a package bid represents an offer for a single lane whose price is conditional on being awarded some other lane or combination of lanes. A carrier will be awarded the lanes from a package bid if the total cost of all lanes in that package is less than the total cost for the comparable lanes from competing bidders. For example, Buckeye Trucking Company would be awarded a package bid containing the "Columbus, OH to Tempe, AZ" lane and the "Ann Arbor, MI to Columbus, OH" lane if the total cost for those lanes is lower than the total cost for both lanes submitted by all competing bidders.

1.2 Research Objective

The intent of this thesis is to continue to explore the "Truckload Procurement Problem," which Caplice (1996) describes as "how shippers procure transportation services from truckload carriers." Specifically, this thesis focuses on how carriers react when given the opportunity to submit conditional bids in a combinatorial auction. Building upon previous literature on combinatorial procurement and the economics of truckload transportation, we set out to answer the following questions:

- What do the package bids carriers construct in combinatorial auctions "look like;"
- Which lanes do carriers bundle together and why do they bundle those lanes;
- By how much will a carrier discount its unconditional price to be able to bundle lanes together;
- How competitive are carriers in bidding; and
- What factors drive the price a truckload carrier charges?

1.3 Thesis Outline and Methodology

Chapter 2 examines the driving economics of truckload transportation, and explores the extent to which the industry exhibits characteristics of economies of scale, scope and density. In addition to a review of the relevant literature in this space, this chapter presents our findings from interviews with those with experience in truckload transportation procurement. We present insights from a diverse group of truckload carriers who represent a broad spectrum of experiences. The carriers with whom we spoke included:

- *Bohren Logistics* - A relatively small, regional trucking company operating approximately 100 Flatbeds, Dry Vans and Refrigerated Vans within the Midwest;
- *Cannon Express* - A Southeastern based Dry Van carrier operating about 500 power units and serving the eastern two-thirds of the US;
- *TMC Transportation* - One of the nation's largest flatbed trucking companies, with over 1500 power units and a service region throughout the eastern 2/3 of the country;
- *Falcon Transport* – A medium-size, privately held diversified Flatbed and Dry Van Truckload serving the Midwestern automotive industry.
- *Sitton Motor Lines* - A family owned Dry Van Truckload carrier based in the Midwest that operates approximately 600 power units;
- *Transport America* - A Texas-based Dry Van Truckload operation operating approximately 2000 power units;
- *Swift Transportation* - A publicly held Dry-Van truckload carrier based in the Southwest with a national presence and over 10,000 power units; and
- *Schneider National* - A privately held, diversified, national carrier with over 10,000 power units.

In addition to carriers, we present the insight of several firms with experience in buying truckload transportation in conditional auction, including:

- *Owens Corning* - A Fortune 500 manufacturer of building materials with 113 plants throughout North America.
- *C.H. Robinson* – The nation's largest third-party logistics firm who in 2002 earned more than $3 Billion, primarily from brokering truckload transportation.
- *Manhattan Associates* – A technology based "supply chain execution" company using its OptiBid technology to "improve carrier assignments."
- *i2 Technologies* – A "supply chain optimization company" using an auction based RFQ to "conduct collaborative freight rate negotiations."
- *Schneider Logistics* – A spin-out of Schneider National delivering "technology powered solutions."
- *Manugistics* – A software developer focused on pricing and supply chain solutions, including NetWORKS Transport RFQ, an auction technology.

Chapter 3 describes the truckload procurement process and explores some of the issues truckload carriers consider when setting prices. As before, Chapter 3 combines a review of the relevant literature with our interviews with the truckload carriers and buyers of truckload transportation services mentioned above.

Chapter 4 examines actual strategies truckload carriers pursued in package bidding and analyzing the results of thirteen independent combinatorial auctions. Using actual bids of recent combinatorial auctions, we show how carriers package lanes and explore a number of cost models explaining which factors drive the prices truckload carriers charge.

Finally, Chapter 5 summarizes our findings from each of the preceding chapters, presents our conclusions and discusses areas of potential future research.

Chapter 2

Carrier Economics

One point of discussion in the literature, as well as in practice, has been the extent to which truckload carriers seek to increase their traffic in the lanes they currently serve, versus increasing the number of lanes they serve. Three economic concepts we found useful in exploring this trade off, as well as prevalent in the literature, included: (1) Economies of Scale; (2) Economies of Density; and (3) Economies of Scope. Though abstract, these concepts help us to understand why truckload carriers bid the way they do.

While we will show that scope is the most significant economic force in truckload transportation, we also found that truckload carriers exhibit economies of scale and, to a lesser extent, economies of density.

2.1 Economies of Scale

In a 1996 paper, Oum and Waters describe Returns to Scale (RTS) as the marginal cost savings of increasing the spatial size of, and the number of lanes in, a carrier's network at the same rate it increases "traffic", or volume of shipments within that network. Jara-Diaz and Basso (2002) go on to explain that "in the transport case, scale economies are related with the convenience or inconvenience of expanding proportionally the flows in all [lanes]."

Caplice (1996) examines the presence of economies of scale in truckload operations and reports that "[b]ecause TL carriers have very low fixed costs and are more sensitive to the balance of the loads, they tend to have slight diseconomies of scale."

George Kuharick of Cannon Express reports that he would offer lower rates for higher volumes in a single lane in his existing network, a characteristic of economies of scale. However, cautions Kuharick, this is driven primarily not by large volumes, but rather by predictable, repetitive shipments. Consistent shipments, such as these, give the company a greater ability to balance its network, implying more than simply economies of scale.

Larry Johnson, the Vice President of Customer Service of Transport America suggests that his firm's current pricing strategy was designed to build "Lane Density." Having significantly expanded the spatial size of the company's service network in recent years, Transport America will discount lanes with higher density, that is lanes with higher shipment volumes and/or more freight available at the destination to build balance within its network.

Thus, our conversations with carriers confirm that truckload transportation is driven more by balance among lanes than simply by increasing traffic proportionally across all lanes. It is important to note, however, that, as in any business, some subtle, underlying economies of scale do exist. This can be seen in that that larger carriers have more purchasing power for fuel, tires, equipment and insurance (CSFB 2000).

2.2 Economies of Density

Economies of Density, according to Oum and Waters (1996), exist when a carrier enjoys a marginal cost savings from increasing the volume of shipments within its network, but holding the number of lanes it serves and the spatial size of its network constant. Yevdokimov defines returns to density as "a decrease in average total cost of transportation due to increase in capacity utilization of the existing transportation network." Jara-Diaz and Basso (2002) support this and add that "if network size was optimal (RTS=1) the firm must exhibit increasing returns to density" because RTS<RTD.

Caplice (1996) explains that economies of density result from increasing the number of shippers within given area (economies of customer density) or from increasing the number of shipments from a single shipper (economies of shipment density). Caplice further explains that economies of density tend to be more prevalent in consolidated carriers than in line-haul truckload carriers and are "essentially economies of scale for their local [pickup and drop off] movements."

Thus, while economies of density are present in truckload carrier operations, their effect, according several of the carriers with whom we spoke, is small and relatively insignificant when compared to the impact of economies of scale and scope.

2.3 Economies of Scope

In economics, increasing returns to scope imply adding more outputs to the production line will decrease marginal costs, suggesting it is cheaper for a single firm to product more products. Jara-Diaz, Cortes and Ponce (2001) paraphrase Panzar and Willig (1981) in making the observation that "scope analysis deals with the enlargement of the set of outputs produced, while scale analysis relates with producing more of each component of the same set of outputs."

In terms of truckload transportation, economies of scope suggest that a carrier enjoys a marginal cost savings by supplying / serving more lanes, where each lane is considered a unique "product" or output (Jara-Diaz and Basso, 2002).

Caplice (1996) describes this in more practical terms by explaining that truckload carriers are driven primarily by economies of scope "because the cost of serving [a lane] is strongly affected by the probability of finding a follow-on load out of that destination location." According to Caplice (1996), balanced lanes, those in which the volume of freight inbound to one destination point is approximately equal to the outbound volume from that point, should be less expensive for carriers to serve than lanes in which inbound and outbound volumes are different.

Kim Johnson of TMC Transportation supports Caplice's description by saying that her company's pricing department weighs heavily the amount of dead-head miles and layover / dwell times in their pricing strategy and confirms that they will charge more in lanes in which they expect a truck to incur excessive dwell time or deadhead miles.

Tony Colombo, Director of Pricing for Sitton Motor Lines also confirms Caplice's description and adds that, by understanding the points in its network where the probability of finding a follow-on load is low, his firm is able search for complementary lanes that increase the probability of getting a follow-on load. For these lanes, Sitton will offer a discounted price so as to avoid dwell time or deadhead costs.

Wayne Hollister of Schneider National, argues that at these points of freight imbalance, a carrier has a relative cost advantage over other truckload carriers because, if the carrier does not secure balancing volume in that lane, it must either wait for a load, deadhead the truck elsewhere, or look to the spot market. Because both dwell time and deadhead reduce a carrier's return on assets and because prices in the spot market tend to be volatile and unpredictable, carriers will prefer to lower their price and secure volume.

Thus, our interviews with truckload carriers confirmed that, because the cost of serving one lane is dependent on the availability of freight in follow-on lanes, economies of scope are the controlling economics of truckload transportation.

2.4 Driving Economics of Truckload Transportation

Understanding that economies of scope drive truckload transportation, we inferred that truckload carriers would try to increase the scope of their networks when bidding in auctions. In speaking with carriers, we confirmed that many were using combinatorial auctions to increase the number of lanes they served.

Similarly, in a 2003 paper, Song and Regan argue that "the carrier's objective ... is to find an effective strategy for estimating their valuations on any combination of new lanes and hence construct their bids to win the lanes most profitable for them." Rather than trying to win as many lanes as possible, Song and Regan explain, a carrier seeks only to win those lanes "that can make its current operation more efficient."

Under this rationale, and given that, because of economies of scope, carriers benefit from serving more lanes, each carrier would have a unique valuation for each lane, depending upon all other lanes in the shipper's network and the carrier's network. Thus, we inferred that each carrier would submit a unique bid for each lane in an auction.

In their 2002 paper, Jara-Diaz and Basso suggest that factors both endogenous and exogenous to the carrier drive its lane valuations, and thus how it bids in an auction. Some of the exogenous factors impacting a firm's economies include:

- The Lane Demand Structure - the quantity shipments demanded in each lane;
- The location of the Nodes; and
- The Physical Network.

Given these conditions about a shipper's network, a truckload carrier must make decisions about the following endogenous factors:

- A Service Structure – the pattern vehicles will use to serve each of the nodes;
- A Route Structure; and
- A Link Sequence / Operating Rules – the order in which vehicles will visit nodes.

Jara-Diaz and Basso (2002) also point out that, while in certain cases, a single carrier may be able to manipulate endogenous factors to create a cost advantage, in most cases, the economics of a network are determined by the externalities; primarily the physical network and the lane demand structure.

Jara-Diaz and Basso (2002) go on to show that by adding new lanes to its existing network (i.e. adding new "products," or more scope) a truckload carrier can improve its asset utilization. Thus, conclude Jara-Diaz and Basso, the economies of a carrier's operations are primarily dependent on exogenous factors such as the shipper's physical network and location of the nodes.

The carriers with which we spoke confirmed that shippers' networks are the primary driver of their economies and reported that the most difficult part of their business was choosing which lanes to serve and at what price. Our interviews suggest that operational-level complexities are the reason why network expansion is often very difficult to plan.

2.5 Operational Complexities

According to the carriers we interviewed, even long-term contracts do not ensure a steady flow of freight, meaning that on any given day, a carrier doesn't know exactly how many shipments its customers are planning or where those shipments are going.

Further complicating matters, carriers often don't know until the very last minute when a shipment is going to be available. Therefore, given the uncertainties described above, carriers may, at times, have to send equipment outside of their network to avoid dead-head or excessive dwell time, or to help a customer who can't get the load moved any other way. Some of the major considerations on carriers minds' each day include:

- Having a re-load available when each truck is empty to minimize waiting or "dwell time";
- Finding a re-load origin in close proximity to the destination point of the truck's previous load so as to minimize unloaded, or "dead-head" miles;
- Selecting a route structure that will allow the driver adequate time at home, while minimizing out-of-route miles.
- Selecting a route structure that maximizes a driver's available hours of driving time, as designated by the U.S. Department of Transportation.

These interviews suggest that, depending upon the networks they are serving and the state of their growth, different carriers enjoy different economies based on their customer's networks, and thus prioritize the above decisions differently.

Because truckload transportation is an asset and labor intensive business, carriers stand to benefit significantly by increasing their fleet and driver utilization. However, depending upon the size of the shipper's network and the traffic within that network, the extent to which economies of scope, scale and density are present may vary.

2.6 Competition

Caplice (1996) relates that, since the deregulation of the motor carrier industry, the number of carriers with revenues greater than $3,000,00 has decreased slightly, the number of carriers with revenues less than $3,000,000 has increased nearly 500%.

Paraphrasing Rakowski, Souther, and Jarrell (1993), Caplice explains that this phenomenon may reflect two separate truckload markets; one perfectly competitive market made up of a large number of commodity-like small, simple carriers; and one differentiated market made up of a few advanced, differentiated carriers.

Though none of the carriers with which we spoke were smaller than $3,000,000 in annual revenue, several confirmed Rakowski, Souther, and Jarrell's description of two separate competitive markets for truckload transportation.

Chapter 3

Truckload Transportation

Within this chapter, we explore how shippers procure truckload transportation, how and why carriers choose the prices they do, and what experience some truckload carriers have with combinatorial auctions.

3.1 Truckload Transportation Procurement

Shippers procure truckload transportation services by auctioning each of their lanes (an origin – destination pair) using a first price, sealed bid reverse auction. Shippers begin by sending a Request for Proposal (RFP) or Request for Quote (RFQ) to a group of carriers, and finish by running a set-covering, price minimization problem to find the combination of bids that covers all required lanes and meets all required constraints for the minimum cost.

Sheffi (2002) describes the task of transportation procurement as "inherently burdensome" because "even medium-size bids involve thousands of different, non-independent items/products, each with its own quantity." In addition to prices, Caplice (1996) identifies a number of additional considerations such as reliability, equipment availability and consistency shippers may use in developing the business rules behind an auction and in awarding lanes.

John Gentle, Global Carrier Relations Leader for Owens Corning, leads an effort to maintain competitive rates for all of Owens Corning's truckload transportation in North America. Gentle coordinates procurement auctions for Owens Corning's 113 facilities about every twelve to eighteen months. Though Owens Corning is very selective about the carriers it allows to participate in its auctions, serving its massive network requires over 100 carriers bidding in each auction, confirming the complexities associated with choosing the "right" combination of lanes to award.

To combat this complexity, Gentle runs only one auction at a time. Besides easing the computational strain on his staff, Gentle has found that carriers "pay more attention to each [auction]" when offered only one. While Gentle believes that allowing carriers to bundle lanes from a number of Owens Corning's facilities may result in some price discounts, he has not done so because of the difficulty in administrating larger auctions.

3.2 Truckload Carrier Bidding

In the past decade, truckload carriers have seen a dramatic increase in the number of RFQ's and RFP's they receive. For carriers too, the RFP/RFQ process presents significant challenges.

The bidding process begins when a truckload carrier receives an RFQ or RFP. In our research, it appeared that the number of requests to which a carrier could respond depended on the size of the carrier. Rick Plummer, the Operations Manager of Bohren Logistics, processes and responds to about half of the roughly 10 small bid requests his company receives monthly.

Kim Johnson, Director of Pricing at TMC Transportation, and her department of four, process the three to four large bid packages they receive weekly, and respond to about 90% of them.

Larry Johnson, the Vice President of Customer Service of Transport America says he receives about 500 RFP's per year. While his pricing department tries to review every bid package they receive, they pay particular attention to those of current or "high potential" customers, and respond to only a fraction of the actual bid requests they receive.

3.3 Detailed Information is Critical

Many carriers told us that, when they receive very specific information, such as the lane-demand structure and physical network described in chapter 2, before an auction begins, they are better able to understand how the new lanes may fit into their network, and thus may be able to offer a better price.

George Kuharick, Director of Pricing for Cannon Express stressed that sharing information about lane demand structures is vital to improving equipment utilization and thus lowering the carrier's prices. By understanding some of his customer's lane demand structures, Kuharick initiated negotiations for combinatorial bids with a number of shippers in the absence of auctions, resulting in lower costs to the shipper and greater profitability for Cannon.

Tony Colombo of Sitton Motor lines adds that most carriers would be able to offer significantly lower prices if shippers were to present detailed information on lane volumes, seasonal fluctuation and shipment times (time of day, day of week, week of year, etc.), so that carriers would be able to plan accordingly when bidding on lanes.

John Gentle of Owens Corning confirmed these claims and adds that he has found when he (the shipper) provides more detailed information, such as the day of the week, the time of day and the season in which freight will ship, carriers are able to provide much more competitive rates. Gentle speculates that carriers can offer more competitive rates when given better information because they have more time to find follow-on loads.

3.4 Carrier Pricing Considerations

After receiving a request, a truckload carrier will take into account a number of different factors in setting its price for each lane. While some of the more sophisticated carriers depend on rigorous processes and expensive software applications, others rely upon their experience.

Larry Johnson of Transport America described the bidding process as beginning with understanding what level of service the customer requires. Not considering dedicated equipment, some of the factors carriers use in understanding truckload shippers' requirements include the number of drop-trailers required, shipping times, scheduled versus unscheduled loading and unloading times, driver friendliness and shipment consistency.

From these requirements, a carrier then tries to extrapolate the costs to serve a particular lane, including vehicle licensing, truck – to – trailer ratio, driver costs, administration and overhead, fuel, tolls and other "miscellaneous costs."

In setting rates, we found a fair amount of consistency in what carriers looked for. Rick Plummer of Bohren Logistics cites the following considerations in setting it prices.

- Market rates;
- Costs to serve;
- Lane Density / Balance.
- Rates in similar lanes;
- Freight characteristics;
- Layover requirements; and
- Loading / unloading delays.

George Kuharick of Cannon Express adds the following to the above list.

- Dead-head distance;
- Delivery time of day;
- Overhead / cost to administer;
- Miscellaneous costs (tolls, etc);
- Service Commitment; and
- Shipper's credit risk.

Based on costs and the market rates, the carrier will then determine whether the lane can meet his profit and revenue objectives. Though unclear about their true profit objectives, in most cases, we found that truckload carriers establish a rough "base-rate" annually. One carrier we interviewed budgets a "rate-per-all-mile" goal each year, which it seeks to meet or exceed in its bidding. This goal simply says that the company's revenue divided by the number of miles its trucks traveled that year will be above a certain level.

Another important consideration in carrier's pricing structures is "Lane Density." Carriers described this consideration as a combination of volume in the lane and balance of freight between the origin and destination, reinforcing economies of scope as the dominant economies of truckload transportation.

3.5 Network Balance / Lane Density

In most carriers' pricing models, lanes with higher density, that is lanes with higher shipment volumes and/or more freight available at the destination would carry a lower price than lanes with lower densities. Though this simple logic is embedded in virtually every carrier's pricing model, how a carrier decides when and by how much to adjust prices varies considerably among carriers.

Small, simple carriers tend to rely on experience and "gut feel" when setting prices, whereas larger carriers may have more sophisticated pricing mechanisms and account more for balance in their networks when setting prices. In considering these balance issues, one carrier describes a simple process by which he will lower rates "as he sees fit" to encourage volumes to and from a particular region to be approximately equal.

Rick Plummer of Bohren Logistics adds that when quoting a price on a lane, he will qualitatively consider the information provided from the shipper, as well as the availability of freight in the destination region, the average dwell time of equipment there and cost to dead-head out of that region.

A number of the larger, progressive and advanced carriers with which we spoke use proprietary software applications to determine how much more or less to bid on a lane, given its impact on the balance of the network. Therefore, if a lane provides a backhaul out of a congested area, this system will give the pricing department an idea of how much less they can bid on the lane to compensate for balancing the network.

One such system, which references the previous thirty day's shipments, considers not only the volume of shipments into and out of a zone, the average dwell time and cost of dead-head to a different zone.

Though sophisticated and robust, these pricing systems still allow for human judgment and experience. Kim Johnson of TMC Transportation, who reports using such an application, says that she frequently speaks with field sales reps and will adjust the recommended prices to attract a potentially large or strategically important customer.

3.6 Combinatorial Auctions

Increasingly, these RFP's / RFQ's allow carriers to bid on combinations or lanes or "packages." The price carriers submit for each lane in a package is conditional on the carrier being awarded all lanes in that package.

Song and Regan (2003) describe combinatorial auctions as "those in which the auctioneer places a set of heterogeneous items out to bid simultaneously and in which bidders can submit multiple bids for combinations of these items."

It is important to note that, while combinatorial auctions may be useful in helping a carrier balance its network, they do not imply continuous moves. As we will explore in more detail later, "continuous moves" are an operation level tool to provide a truckload carrier with a predictable freight pattern that minimizes deadhead and dwell time. Conversely, combinatorial auctions provide a more strategic tool that allows carriers to reflect their true costs when securing freight volumes in unbalanced lanes.

In a combinatorial truckload procurement auction, carriers (bidders) submit not only simple single lane, or "discrete," bids, but also "packaged" bids for combinations of several lanes. Caplice (1996) describes combinatorial auctions as those that "allow the use of conditional bids," and says that such auctions include the following benefits:

- Efficient Allocation;
- Less threat of exposure for carriers;
- Greater ability for carriers to expose synergies; and
- More control for both shippers and carriers.

In addition to these benefits, Caplice (1996) also lists the following downsides:

- Complex implementation;
- Shipper must solve a complex optimization problem;
- Communication problems;
- Shipper and carrier unfamiliarity with combinatorial auctions.

Examples of Combinatorial Auctions

The first application of combinatorial auctions in transportation took place in the 1995 within Sears Logistics Services (SLS). Motivated by the understanding that truckload carriers could improve asset utilization by serving multiple lanes, SLS, in partnership with Jos. Swanson & Co (JS&Co) and Net Exchange (NEX), designed a "combined value" auction that lasted 5 rounds and yielded savings of 13% of Sears' total truckload transportation spending (Ledyard et al, 2000).

Ledyard et al (2000) attribute the success of this auction to a number of factors. First, SLS limited the number of carriers participating in the bid to 14. In doing so, SLS assured carriers that they stood to gain more business by participating in the auction. Second, SLS provided carriers with a great deal of very detailed information about lane demand structures, allowing carriers to understand the impact of each lane on their existing networks.

In another example of combinatorial auctions, Elmaghraby and Keskinocak (2000) tell how, in 1999, Home Depot contracted with i2 Technologies to identify synergies between its network and those of its carriers. Unlike SLS, Home Depot encouraged a large number of carriers to submit bids, collecting, in total, bids from 91 carriers in the first round and 36 carriers in the second round.

Like SLS, Home Depot believed that by providing carriers with more "visibility" of its lane demand structure, carriers would submit bids that more accurately reflected their true cost structure. Therefore, in addition to detailed information on origin and destination locations and lane details, Home Depot provided bidders in this auction with demand forecasts, projecting future volumes within each lane.

Not surprisingly, given the large number of participants, some carriers were not as happy with the outcome of the Home Depot auction as with the SLS auction. Though some carriers gave feedback such as "This is great, this is the future," other remarked "This is too complex, it can't work." This lack of satisfaction can also be seen in that only 36 of the 62 carriers invited to participate in round 2 submitted bids.

While Home Depot was pleased with the savings this auction generated, it acknowledged that carriers could have been more satisfied and, for future auctions, planed to spend twice as much time educating carriers before bidding begins.

Carrier's Experience with Combinatorial Auctions

Surprisingly, a number of the carriers with which we spoke reported at least some experience with combinatorial auctions and conditional / package bids. Though the carriers with package bidding experience did acknowledge that, at least in theory, combinatorial auctions may be able to help truckload carriers improve their asset utilization, many were quick to point out the short coming of package bids.

"Making [a package] bid doesn't work when you can be underbid on any one single lane," said Tony Colombo of Sitton Motor Lines. His experience with package bidding had been that most shippers fail to execute package bids, and instead revert to using either pre-bid prices or single lane prices from the package bid.

In addition to execution problems, several other carriers point out that package bids are only applicable in lanes with a large volume of predictable, consistent freight.

Rick Plummer, Operations Manager of Bohren Logistics, suggests that, while conditional bidding has allowed carriers to lower their deadhead miles, the increased pricing pressure they feel from auctions drives their prices lower.

Carriers, leery from shippers' inability (or unwillingness) to execute package bids, sometimes set their prices higher than they would if shippers approached bidding with a more collaborative attitude.

Despite these challenges, many carriers see the possibility for combinatorial auctions / package bids to result in significant savings if shippers focus on a few fundamentals.

1. *Execute* – Carriers lose faith when shippers request a bid and don't act on it, or don't act in the way they said they would. When carriers loose faith, and the

relationship between shippers and carriers begins to deteriorate, carriers will either set their prices higher, or will cease to do participate in new bids.

2. *Provide detailed lane demand structure information*– Carriers need to know the nitty-gritty details of the freight. Besides annual volumes, they need to know exactly when the freight will be available to ship, the level of shipment fluctuation, and the service level requirements.
3. *Minimize auction constraints* – Carriers suggest that by being able to secure multiple lanes through packaging, they can more accurately reflect their true cost structure in bidding. However, carriers cite examples of auctions in which the shipper had predetermined to award a large set of lanes to certain carriers before the bidding began. Carriers say that these constraints undermine their ability to win new package bids based on their true cost structure.

Chapter 4

Carrier Bidding Behavior

To more completely understand the value of combinatorial auctions for Truckload Carriers, we worked with four major vendors of auction software to study how truckload carriers bid when given the opportunity to submit packages. These vendors provided us with actual bid data from thirteen unique auctions, representing 644 truckload carriers, 5233 lanes, and 90908 individual bids, including 1294 packages.

From this analysis, we sought to answer the following questions:

- What do package bids "look like;"
- Which lanes do carriers bundle together;
- By how much will a carrier discount his or her unconditional price to be able to bundle lanes together;
- How often do package bids win; and
- What factors drive the price a truckload carrier charges?

4.1 Methodology

We begin by examining the circumstances under which carriers submit package bids. Section 4.2 shows how often carriers submit package bids and the number of lanes for which carriers submit package bids, while section 4.3 examines how many lanes carriers bundle into a single package. In addition, Section 4.4 we explore some of the strategies carriers employed in combining lanes in package bids.

Section 4.5 examines the distribution of package discounts throughout the different auctions. We define a "package discount" as the percentage by which a carrier is willing to lower its discrete bid on one individual lane to bundle one lane with others. It is important to note that we define package discounts on a lane-by-lane basis.

$$\text{Package Discount} = \frac{\text{Discrete Bid - Package Bid}}{\text{Discrete Bid}}$$

Section 4.5 goes on to compare the discrete and package bids for each of the 9880 packaged lanes and identified a frequency distribution of package discounts, as well as to project the number of package bids that are the lowest cost in their respective lanes.

Finally, Section 4.6 examines the factors that may drive the price carriers charge for each lane. We built models of carrier price functions for each auction, using ordinary-least-squares (OLS) regression, and explored the impact of volume, distance and number of packaged lanes on package discounts.

4.2 Combinatorial Auction Profiles

The objective of this section is to explore what combinatorial auctions "look like." In examining how often carriers submit packages we found that, out of a total of 644 carriers, only 178, or 28%, submitted package bids. While in two auctions the majority of carriers submitted packages, and in two others only about 10% of carriers submitted packages, in the majority of auctions, about 30% of carriers submit packages.

Table 4.1: Carriers submitting Package Bids

Source	Total Lanes	Lanes Packaged	% Lanes Packaged	Average Volume	Total Carriers	Carriers submitting Packages	% Carriers submitting Packages
Vendor 1 Data 1	268	125	47%	66	54	16	30%
Vendor 1 Data 2	149	104	70%	169	90	19	21%
Vendor 1 Data 3	534	254	48%	139	60	26	43%
Vendor 1 Data 4	793	146	18%	103	12	11	92%
Vendor 1 Data 5	533	381	71%	75	59	16	27%
Vendor 1 Data 6	215	215	100%	178	67	25	37%
Vendor 2 Data 1	101	101	100%	0	55	15	27%
Vendor 2 Data 2	1567	861	55%	133	49	13	27%
Vendor 2 Data 3	112	112	100%	288	70	6	9%
Vendor 3 Data 1	132	132	100%	1183	4	4	100%
Vendor 4 Data 1	99	69	70%	77	29	6	21%
Vendor 4 Data 2	590	224	38%	81	49	16	33%
Vendor 4 Data 3	140	41	29%	204	46	5	11%
Total	5233	2765	53%	119	644	178	28%

We asked several carriers to comment on why they may not submit packages in an auction, and found a number of reasons, including:

- Uncertainty of a load actually being available when needed;
- Belief that bids rarely win auctions; and
- Lack of faith that the shipper will actually execute on the bid.

Greg Malys of Falcon Transport tells us that his firm has been successful in using packages to improve asset utilization by reducing deadhead miles and dwell time. However, Malys has found that, when shippers cannot specify when a load will be available, dwell time may increase significantly so that even if a carrier is awarded a package, its asset utilization does not improve because freight does not become available when the carrier has a truck available.

Throughout our conversations, we found comments like those of Mr. Malys to be fairly common, suggesting that some portion of carriers are using package bidding to construct continuous moves. In Chapter 3, we highlighted the differences between package bids and continuous moves, and pointed out that, while in some situations, package bids may create a quasi-continuous move, their real value comes in adding balance to a carrier's network.

In addressing the second reason that carriers may not submit packages, George Kuharick of Cannon Express reports that "more often than not, shippers do not use any of the packaged bids [a carrier submits]." As a result, Kuharick says, carriers such as his lose interest after their initial experience of losing and will not spend the time to create package bids in future auctions.

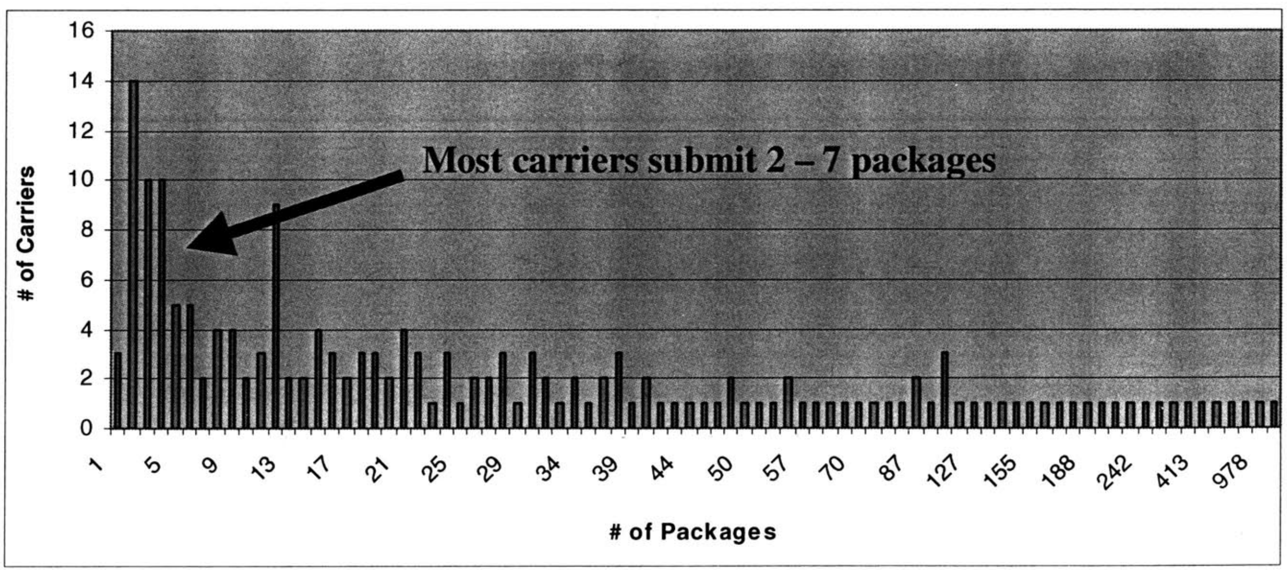
Carriers have also found that even if they are awarded package bids, shippers may not execute on them. In examining why shippers fail to execute on bids collected in auctions, we found that shippers may reject bids when their cost are significantly higher than what that shipper is currently paying. John Gentle of Owens Corning confirms this and adds that, even though shippers try to avoid reneging, they will sometimes accept only part of an auction to avoid exceeding their annual budget.

Another reason we found that shippers fail to execute on packages is that they lack the operational level tools to do so. Matt Harding of Manhattan Associates, reports that, in many circumstances, he has found that shippers lack an IT system capable of tendering awarded packages. Similarly, Josh Martin of i2 Technologies reports that his firm actually had to develop a tool to allow its customers (i.e. shippers) to tender the packages they awarded.

Number of Packages Submitted

Understanding that only a portion of carriers will submit packages, we found that even when carriers do submit package bids, they usually do not submit a large number of them. In this case, of the 28% of carriers that submit packages, most submitted between 2 and 7 packages.

Figure 4.1: Distribution of Packages per Carrier



For each auction, a slightly different distribution of packages per carrier emerged. This suggests that the number of packages a carrier submits is dependent on the shipper's network and supports Jara-Diaz and Basso's (2002) assertion that the value of any network is unique depending on the location of the nodes and the lane demand structure.

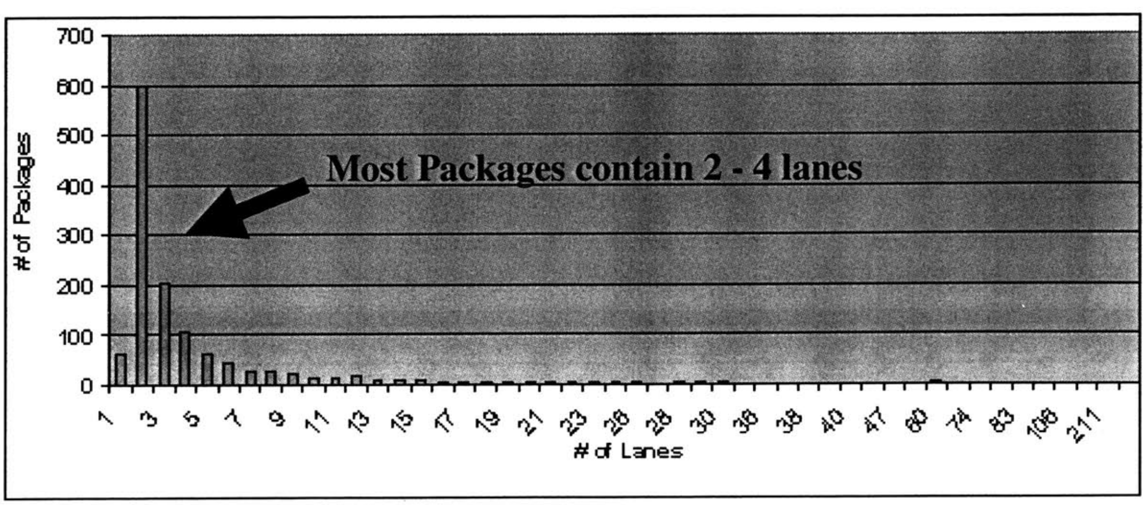
Table 4.2: Distribution of Packages per Carrier

Source	Packages per Carrier					
	Min	Mean	Median	Mode	Max	Std Dev
Vendor 1 Data 1	2	18	8	2	63	19
Vendor 1 Data 2	1	56	19	1	436	113
Vendor 1 Data 3	2	21	12	12	135	27
Vendor 1 Data 4	14	166	128	-	592	160
Vendor 1 Data 5	2	172	55	12	978	255
Vendor 1 Data 6	2	91	19	56	1514	299
Vendor 2 Data 1	2	15	8	2	51	17
Vendor 2 Data 2	3	117	59	87	645	171
Vendor 2 Data 3	2	19	8	8	57	22
Vendor 3 Data 1	29	60	52	-	106	37
Vendor 4 Data 1	12	26	19	12	50	16
Vendor 4 Data 2	2	24	19	15	89	22
Vendor 4 Data 3	3	13	8	24	24	11
Total	1	64	19	2	1514	160

Package Size

In further examining how carriers package lanes, we found that the vast majority of packages submitted were small, usually containing between two and four lanes.

Figure 4.2: Distribution of Lanes per Package



Unlike the number of carriers submitting packages, the number of lanes per package appears to be relatively stable among auctions.

Table 4.3: Lanes per Package

Source	Total Packages	Total Lanes	Lanes per Package					
			Min	Mean	Median	Mode	Max	Std Dev
Vendor 1 Data 1	70	268	1	4	2	2	28	4
Vendor 1 Data 2	214	149	1	4	2	2	39	5
Vendor 1 Data 3	117	534	1	4	3	2	37	4
Vendor 1 Data 4	274	793	2	3	2	2	47	4
Vendor 1 Data 5	220	533	1	7	2	2	219	21
Vendor 1 Data 6	200	215	2	7	4	2	211	16
Vendor 2 Data 1	22	101	1	3	2	2	15	2
Vendor 2 Data 2	41	1567	1	12	6	2	98	17
Vendor 2 Data 3	8	112	1	9	4	4	26	8
Vendor 3 Data 1	0	132	29	60	52	-	106	37
Vendor 4 Data 1	19	99	2	8	8	2	29	7
Vendor 4 Data 2	87	590	2	6	3	2	22	6
Vendor 4 Data 3	0	140	2	4	3	2	8	2
Total	1294	5233	1	5	2	2	219	12

Small Packages

In speaking with carriers, we found that the primary reason packages tend to be small is that many carriers receive a large number of RFQ's and lack the resources to commit a great deal of time to each auction.

As we highlighted in Chapter 3, Rick Plummer, the Operations Manager of Bohren Logistics is responsible for all of the company's pricing, in addition to the daily operations of the fleet, leaving him little time to compile package bids.

Wayne Hollister of Schneider National reports that his company, one of the largest fleets in the nation, can spend up to three weeks analyzing each combinatorial auction in which they are involved. Wayne speculates that few other carriers have the ability to conduct as thorough an analysis as Schneider.

Kevin McCarthy of C.H. Robinson, the nation's largest freight broker, confirms these statements and tells us that in his experience, most truckload carriers not only lack the complex modeling systems required to complete a robust combinatorial auction, but also the personnel and time to do so.

Large Packages

Though most packages contained between 2 and 4 lanes, we found that a few contained significantly more. In trying to understand why carriers submit large packages, we analyzed five of the largest, containing 219, 211, 98, 47 and 39 lanes, respectively. Four of these five packages were made up of a disparate collection of disjointed lanes, with multiple origin and destination points, while one consisted of outbound shipments from a single point to multiple destinations.

Surprisingly, we found that the carrier's package bids were lower than their discrete bids in only two of these five large packages and in none of the packages did the packaged price "beat" the lowest total cost of the discrete bids for those same lanes.

Some hypothesize that large, uneconomical packages, such as these may result from carriers negotiating with shippers before the auction begins. As we discussed in Chapter 3, George Kuharick of Cannon Express has been successful in approaching shippers outside of an auction to propose conditional bids. Similarly, John Gentle of Owens Corning reports negotiating with carriers before, during and after an auction to ensure all lanes are covered at an acceptable price and by a carrier capable of delivering the level of service required in that lane.

4.3 Packaged Lanes

Within this section, we explore how carriers use the lanes within a combinatorial auction. Specifically, we examine how many lanes, from a given auction, carriers will combine into packages and, if a lane were combined into a package, how many different packages would include that lane.

Surprisingly, we found that in 4 of the 13 auctions we reviewed, all lanes were used in packages. Even more surprisingly, in 8 of the 13 auctions, more than 50% of lanes were contained in packages, suggesting that the carriers who submit packages reflect a diverse set of networks that can increase their respective lane balances by incorporating portions of other shippers' networks.

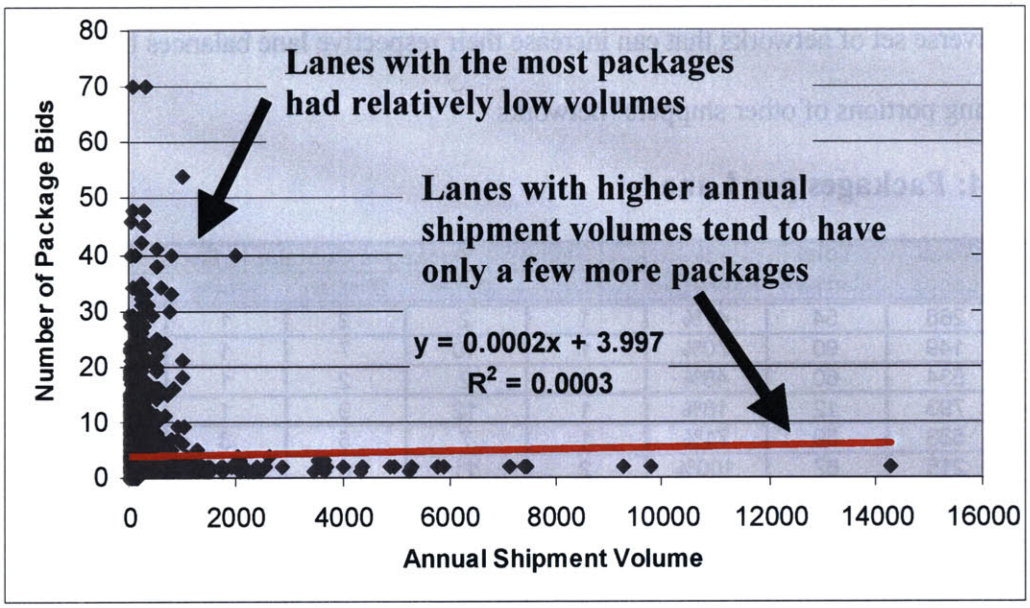
Table 4.4: Packages per Lane

Source	Total Lanes	Total Carriers	% Packaged	Packages Containing Each Lane					
				Min	Mean	Median	Mode	Max	Std Dev
Vendor 1 Data 1	268	54	47%	1	2	2	1	9	2
Vendor 1 Data 2	149	90	70%	1	10	7	1	70	12
Vendor 1 Data 3	534	60	48%	1	2	2	1	11	2
Vendor 1 Data 4	793	12	18%	1	12	9	1	41	10
Vendor 1 Data 5	533	59	71%	1	7	5	3	45	7
Vendor 1 Data 6	215	67	100%	2	11	8	4	54	8
Vendor 2 Data 1	101	55	100%	1	2	1	1	13	2
Vendor 2 Data 2	1567	49	55%	0	1	1	1	5	1
Vendor 2 Data 3	112	70	100%	1	1	1	1	1	0
Vendor 3 Data 1	132	4	100%	1	2	2	2	2	0
Vendor 4 Data 1	99	29	70%	1	2	2	1	7	1
Vendor 4 Data 2	590	49	38%	1	2	1	1	8	1
Vendor 4 Data 3	140	46	29%	1	2	1	1	5	1
Total	5233	644	53%	0	4	2	1	70	6

In examining the distribution of packages per lane, we found that both the percentage of lanes used in packages and the number of packages in which each lane vary significantly between auctions. This deviation suggests that not only is it difficult for auctioneers to predict how many lanes from a given auction will be bundled, but also that it is difficult to predict how often any given lane will be bundled.

In chapter 3, we discussed literature and interviews which suggested that the combinatorial auctions were particularly valuable in lanes with high volumes because such lanes offered a higher probability of quickly reloading a vehicle, and thus minimizing both deadhead and dwell times. In testing this notion however, we found little relationship between lane volume and the number of package bids. The following scatter plot compares the number of packages in which each lane was included with the annual shipment volume in that lane.

Figure 4.3: Lane Volume versus Number of Packages



As Figure 4.3 shows, a lane with 10,000 annual shipments is most likely to be included in only 2 more package bids than a lane with 1 annual shipment. Surprisingly, however, we found that the vast majority of package bids are for lanes with relatively small volumes. Therefore, while certain lanes are more likely to be packaged than others, high shipment volumes do not imply that a lane is more likely to be packaged.

In further testing, we found a very weak positive correlation between the number of carriers and number of packages ($\rho = 0.189$), suggesting that adding carriers to an auction increases the occurrence of package bids. This is not to say that each additional carrier will cause the rest to create more packages, but rather that adding carriers increases the likelihood of including a carrier who will submit a lot of packages.

4.4 Carrier Bidding Strategies

As we mentioned in chapter 2, Song and Regan (2003) present the case that "the carrier's objective in [a combinatorial] auction is to find an effective strategy for estimating their valuations on any combination of new lanes and hence construct their bids to win the lanes most profitable for them." Song and Regan continue and argue that a carrier seeks not to win as many lanes as possible, but rather only those lanes "that can make its current operation more efficient." Under this rationale, each carrier would have a unique valuation for each lane, depending upon that carrier's existing network.

Though not widely explored in literature, our interviews suggest that not all carriers share a common strategy and that several levels of complexity exist in the way carriers construct packages.

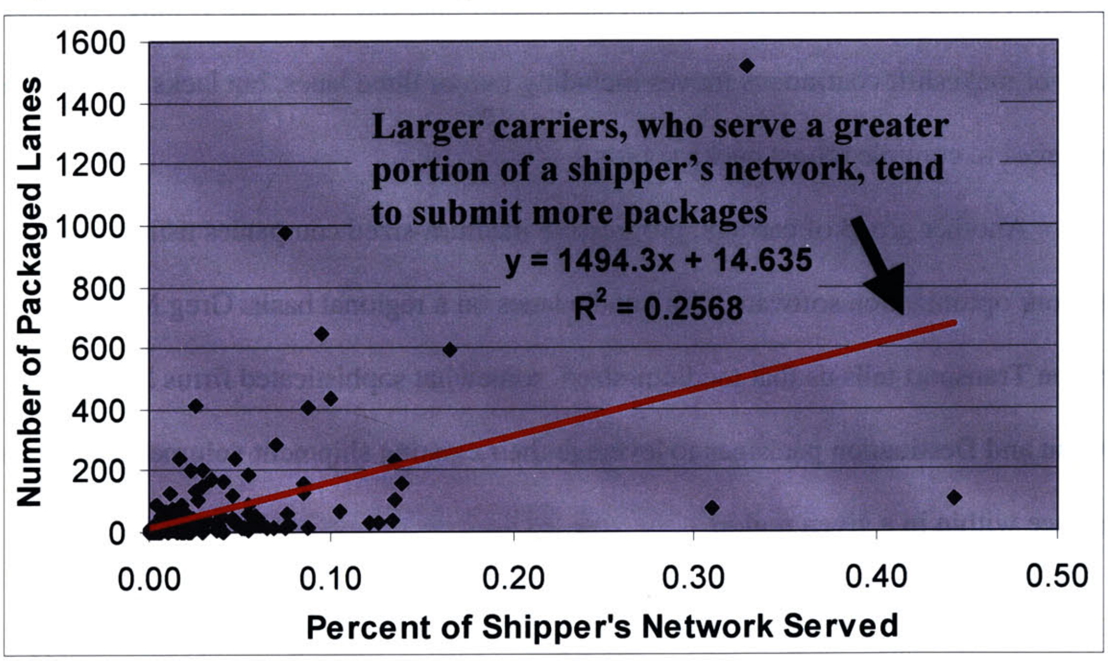
One group of carriers, simple, small companies with limited resources for pricing and constructing bids, seeks only to build continuous moves. Rick Plummer of Bohren Logistics explains that his organization uses conditional bids to secure volumes in single lanes or makeshift continuous moves including two or three lanes, but lacks the time and resources to compile robust package bids.

Another group of carriers, progressive medium-sized companies using some network optimization software, will bundle lanes on a regional basis. Greg Malys of Falcon Transport tells us that medium-sized, somewhat sophisticated firms like his use Origin and Destination packages to leverage their existing shipment volumes and create balance within in a given region.

A third group, the largest, most advanced carriers, uses sophisticated software applications to gauge the impact of all lanes in every auction they participate on their overall network. Both John White of Swift Transportation and Wayne Hollister of Schneider National, the two largest truckload carriers in North America, tell us that their respective companies not only consider the impact of each new lane on their network, but also will bundle unconnected lanes to create balance throughout their network. This comprehensive analysis appears to be the most similar to the process Song and Regan (2003) proposed to construct bids and allows carriers to continuously work to balance their network.

Not surprisingly, we found that large carriers, those with the resources available to compile a robust set of package bids, tended to submit more packaged lanes than did smaller carriers. We observed this trend by assuming that larger carriers would serve a greater percentage of a shipper's network and constructing the following scatter plot showing the number of packaged lanes a carrier submitted with the percentage of the shipper's network that carrier proposed to cover.

Figure 4.4: Number of Packages versus Carrier Size



To validate these observations and explore how carriers used combinatorial auctions to complement their existing networks, we examined some of the real bids carriers submitted and found four commonly reoccurring patterns.

- Round Trip / Closed Loop Packages;
- Destination / Inbound Packages;
- Origin / Outbound Package; and
- Disparate Packages.

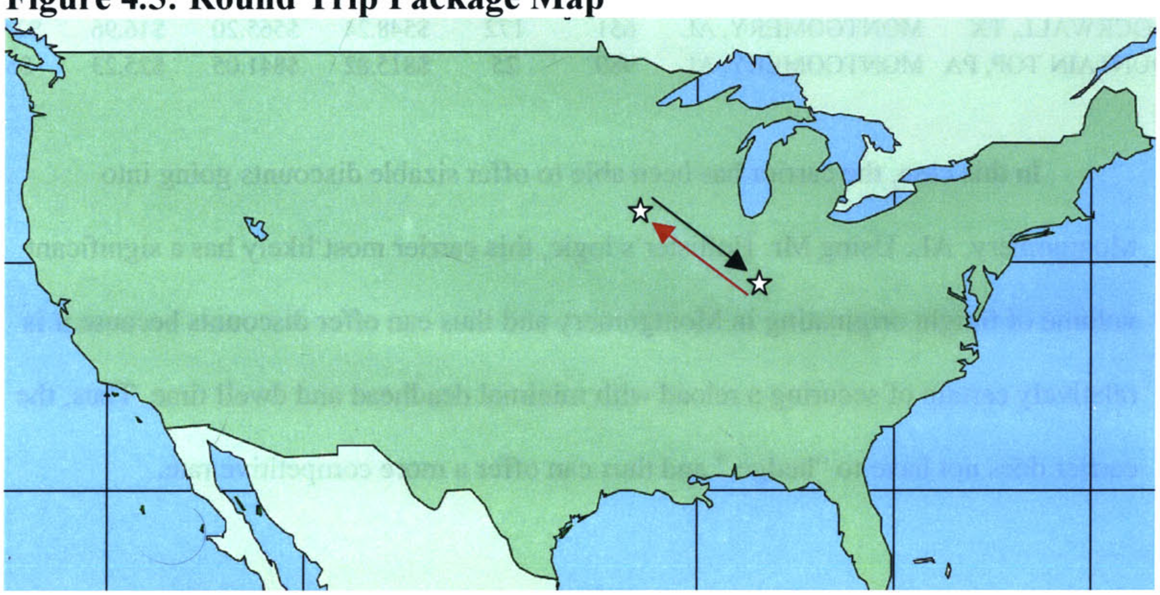
Round Trip Packages

The simplest form of packages we observed were round trips, such as the one shown in table 4.5. An important point to remember, one that is often confused, is that round-trip, or "closed loop" packages are not "continuous move" shipments. As we pointed out in chapter 3, package bids do not guarantee a continuous movement Rather, these are tools to improve balance within a carrier's network.

Table 4.5: Round Trip Packages – Vendor 3 Data 2

Origin	Destination	Distance	Volume	Package Lane Cost	Discrete Lane Cost	Package Discount	Annual Discount
INDIANAPOLIS, IN	CEDAR RAPIDS, IA	387	725	$425.00	$425.00	$0.00	$0.00
CEDAR RAPIDS, IA	INDIANAPOLIS, IN	387	2617	$525.00	$550.00	$25.00	$65,425.00

Figure 4.5: Round Trip Package Map



Round trip packages are valuable because they lower the probability that a carrier will have to deadhead for or wait for a reload, reducing their need to "hedge," or allocate the cost of deadheading or waiting to a head-haul price, as described by Caplice (1996). The above package shows how a carrier will offer a discount for guaranteed volume in a given lane, as Rick Plummer of Bohren Logistics described.

Destination Packages

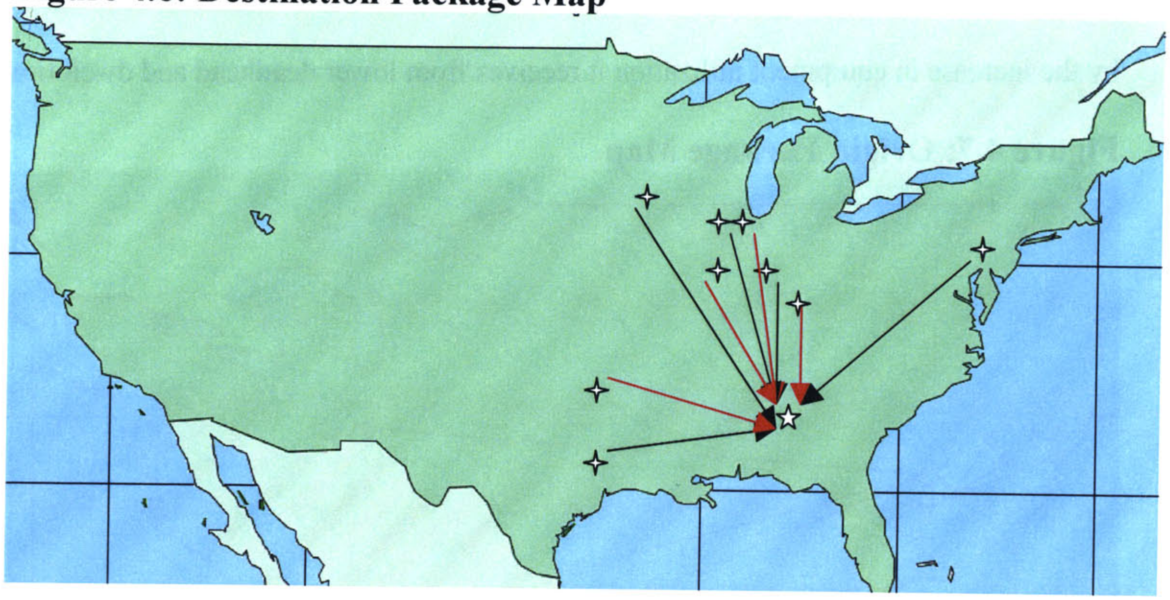
Another strategy carriers employed frequently was to group lanes going into a specific destination. Destination packages allow carriers to leverage existing freight coming out of some destination, by offering lower rates on lanes going into that destination, as Wayne Hollister of Schneider National described in Chapter 2.

Table 4.6: Destination Packages – Vendor 3 Data 2

Origin	Destination	Distance	Volume	Package Lane Cost	Discrete Lane Cost	Package Discount	Annual Discount
INDIANAPOLIS, IN	MONTGOMERY, AL	572	10	$683.85	$705.00	$21.15	$211.50
FLORENCE, KY	MONTGOMERY, AL	571	910	$661.21	$681.66	$20.45	$18,609.32
PEOSTA, IA	MONTGOMERY, AL	922	44	$961.56	$991.30	$29.74	$1,308.52
BUFFALO GROVE, IL	MONTGOMERY, AL	785	15	$864.85	$891.60	$26.75	$401.22
WEST CHICAGO, IL	MONTGOMERY, AL	782	24	$855.54	$882.00	$26.46	$635.04
CHAMPAIGN, IL	MONTGOMERY, AL	668	11	$772.99	$796.90	$23.91	$262.98
MUSKOGEE, OK	MONTGOMERY, AL	682	262	$647.36	$667.38	$20.02	$5,245.61
ROCKWALL, TX	MONTGOMERY, AL	651	172	$548.24	$565.20	$16.96	$2,916.43
MOUNTAIN TOP, PA	MONTGOMERY, AL	980	25	$815.82	$841.05	$25.23	$630.79

In this case, the carrier has been able to offer sizable discounts going into Montgomery, AL. Using Mr. Hollister's logic, this carrier most likely has a significant volume of freight originating in Montgomery and thus can offer discounts because it is relatively certain of securing a reload with minimal deadhead and dwell time. Thus, the carrier does not have to "hedge," and thus can offer a more competitive rate.

Figure 4.6: Destination Package Map



Origin Packages

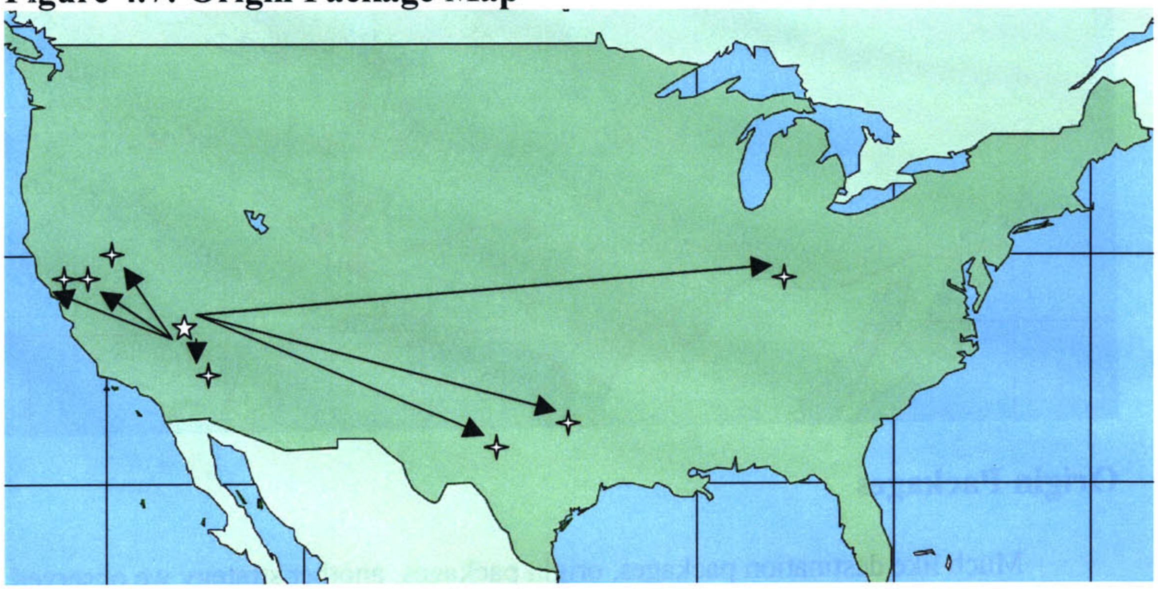
Much like destination packages, origin packages, another strategy we observed frequently, are attractive to carriers who have an imbalance of freight into and out of a given region. In this case, the carrier can bundle lanes leaving a given destination, increasing the carrier's probability of keeping its equipment moving.

Table 4.7: Origin Packages – Vendor 3 Data 2

Origin	Destination	Distance	Volume	Discrete Lane Cost	Package Lane Cost	Package Discount	Annual Discount
HENDERSON, NV	STOCKTON, CA	560	224	$875.00	$675.00	$200.00	44,800.00
HENDERSON, NV	GRAND PRAIRIE, TX	1211	51	$1,250.00	$1,325.00	($75.00)	-3,825.00
HENDERSON, NV	INDIANAPOLIS, IN	1823	26	$2,310.00	$2,110.00	$200.00	5,200.00
HENDERSON, NV	TOLLESON, AZ	313	237	$450.00	$500.00	($50.00)	-11,850.00
HENDERSON, NV	LAKE FOREST, CA	267	422	$650.00	$450.00	$200.00	84,400.00
HENDERSON, NV	OAKLAND, CA	574	60	$875.00	$675.00	$200.00	12,000.00
HENDERSON, NV	DALLAS, TX	1223	30	$1,250.00	$1,400.00	($150.00)	-4,500.00

In this case, again using Wayne Hollister's logic, the carrier is able to leverage a large volume of freight going into Henderson, NV (a suburb of Las Vegas) to offer lower outbound rates because this freight will offer a lower probability of incurring the cost of dwell time or deadhead. Given the annual volume in each outbound lane, the carrier can be reasonably confident that if it wins this package, its discounts will be more than offset by the increase in equipment utilization it receives from lower deadhead and dwell time.

Figure 4.7: Origin Package Map



This example of Origin packages reveals one interesting aspect of combinatorial auctions. Although the overall package offers an annual discount of $126,225, or 16% of the total annual cost, the carrier actually increases its price in some of the packaged lanes.

Kevin McCarthy of C.H. Robinson describes this phenomenon as "the free hand of Adam Smith at work," and confirms Wayne Hollister's assertions about carriers leveraging cost advantages in certain lanes. According to McCarthy, carriers, understanding that packages are compared and awarded by lowest total cost, not by individual lane discounts, will adjust their prices in each lane to more accurately reflect their true cost of serving that lane.

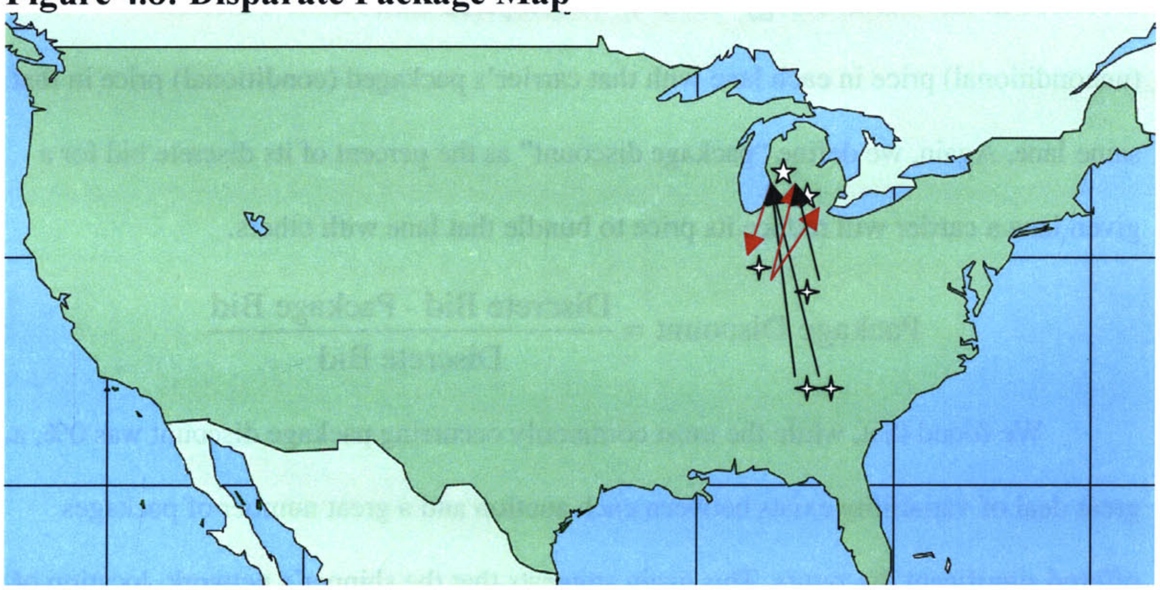
Disparate Packages

Another interesting strategy we found was a collection of disparate lanes. John White of Swift Transportation explains that large truckload carriers continuously strive to balance every portion of their network and will bundle uncorrelated lanes that to add balance in any way possible.

Table 4.8: Disparate Packages – Vendor 3 Data 2

Origin	Destination	Distance	Volume	Package Lane Cost	Discrete Lane Cost	Package Discount	Total Discount
HOLLAND, MI	INDIANAPOLIS, IN	272	3648	$400.00	$425.00	$25.00	$91,200.00
ADAIRSVILLE, GA	HOLLAND, MI	744	136	$840.00	$865.00	$25.00	$3,400.00
CARTERSVILLE, GA	HOLLAND, MI	760	589	$850.00	$870.00	$20.00	$11,780.00
INDIANAPOLIS, IN	LANSING, MI	255	535	$615.00	$625.00	$10.00	$5,350.00
INDIANAPOLIS, IN	GRAND RAPIDS, MI	304	212	$615.00	$625.00	$10.00	$2,120.00
FLORENCE, KY	HOLLAND, MI	368	618	$635.00	$650.00	$15.00	$9,270.00

Figure 4.8: Disparate Package Map



In this case, the carrier has bundled several lanes that appear to have little correlation. From this, a reasonable person would presume that the carrier has existing freight in his/her network that complements these lanes enough to justify discounts. Though simple in concept, this form of packaging becomes incredibly complex when dealing with networks like those of the largest carriers, which can feasibly include thousands of lanes.

Therefore, these data support our observations about carrier bidding strategies and would suggest that Simple carriers tend to submit the majority of Round Trip packages to balance individual lanes. Similarly, these data show how Advanced and Progressive carriers use Origin and Destination packages to balance regions of their networks while Advanced carriers use disparate lanes to balance their entire network.

4.5 Package Discounts

Having gained some understanding of what package bids "look like" and how carriers construct packages, we sought to understand the amount by which carriers would discount their discrete bids when given the opportunity to submit packages. As we described in the "Methodology" section, we compared each carrier's discrete (unconditional) price in each lane with that carrier's packaged (conditional) price in that same lane. Again, we define "package discount" as the percent of its discrete bid for a given lane a carrier will reduce its price to bundle that lane with others.

$$\text{Package Discount} = \frac{\text{Discrete Bid - Package Bid}}{\text{Discrete Bid}}$$

We found that, while the most commonly occurring package discount was 0%, a great deal of variability exists between each auction and a great number of packages offered significant discounts. This again suggests that the shipper's network, location of facilities and lane demand structure has a significant impact of the economies of serving that lane, as predicted by Jara-Diaz and Basso (2002).

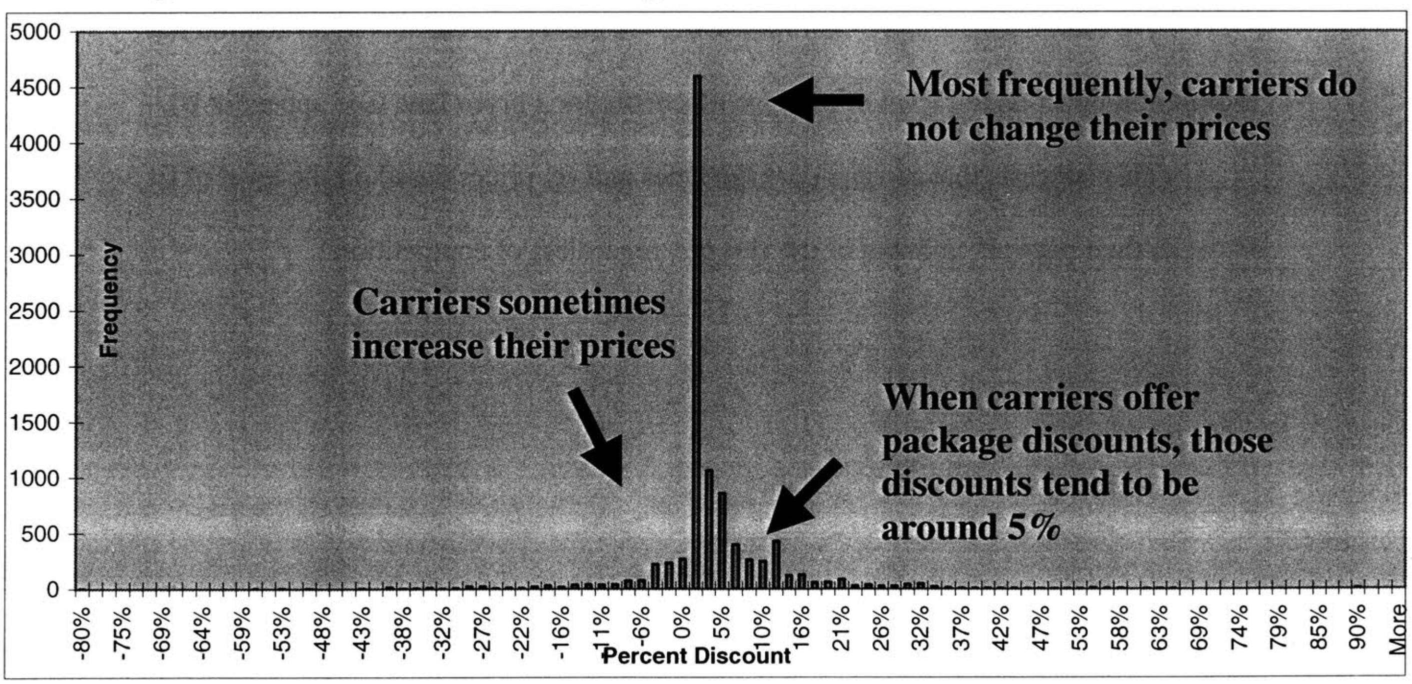
In this section, we will show a distribution of discounts and provide an approximate bidding guide. We will also show that the distribution of each auction is dependant on the underlying shipper, but independent of the software package being used. Finally, we will compare each package bid with the lowest discrete bid in that lane to identify how often package bids represent the lowest price in a given lane.

In examining the distributions of package discounts throughout each auction we found that, despite some commonalities, the distributions of package discounts are neither normal nor the same for any of the auctions. Again, this observation supports Jara-Diaz and Basso's (2002) conclusion that the value of any network is unique depending on the physical location of its nodes and its lane demand structure.

Table 4.9: Package Discounts

Source	Total Bids	Package Bids	% Lanes Packaged	Package Discounts					
				Min	Mean	Median	Mode	Max	Std Dev
Vendor 1 Data 1	3162	263	8%	-11.4%	4.9%	1.6%	0.0%	95.2%	10.7%
Vendor 1 Data 2	4053	977	24%	-50.0%	4.6%	2.9%	0.0%	89.8%	9.2%
Vendor 1 Data 3	8835	430	5%	-40.6%	6.5%	3.8%	0.0%	63.9%	13.0%
Vendor 1 Data 4	7415	1313	18%	-61.2%	4.5%	3.5%	0.0%	44.4%	9.1%
Vendor 1 Data 5	11882	2203	19%	-42.7%	2.2%	0.0%	0.0%	36.9%	9.1%
Vendor 1 Data 6	4200	2185	52%	-40.0%	0.0%	0.0%	0.0%	90.8%	5.4%
Vendor 2 Data 1	1881	217	12%	-45.7%	5.4%	1.7%	0.0%	33.3%	9.4%
Vendor 2 Data 2	23352	1432	6%	-80.0%	0.6%	0.0%	0.0%	88.7%	10.7%
Vendor 2 Data 3	3082	68	2%	-76.1%	25.2%	19.2%	5.0%	66.0%	25.8%
Vendor 3 Data 1	478	238	50%	-78.5%	1.9%	0.0%	0.0%	56.5%	13.6%
Vendor 4 Data 1	2827	153	5%	-0.7%	2.5%	2.2%	3.8%	13.0%	1.9%
Vendor 4 Data 2	17259	337	2%	-35.6%	1.6%	0.0%	0.0%	25.2%	4.4%
Vendor 4 Data 3	2482	63	3%	0.0%	4.2%	4.0%	7.4%	16.7%	3.2%
Total	90908	9879	11%	-80.0%	2.5%	0.0%	0.0%	95.2%	9.5%

Figure 4.9: Distribution of Package Discounts



Impact of Shippers Networks

Understanding that most package discounts are 0%, we set out to understand whether each of the individual data sets came from that same distribution. Using hypothesis testing (see appendix B), we found that the distribution of package discounts differed for each auction. Although several common distributions emerged, no single common distribution was found, reinforcing that the underlying shipper's physical network had a significant impact on the distribution of package discounts.

Impact of Software Vendors

Having shown that for each auction, the distribution of package discounts is different, we tested for similarities between data from the same software vendor (see appendix B) and found that the software vendor used had little significant impact on the distribution of package discounts Thus, we concluded that the primary driver of the distribution of package savings is the underlying shipper's network.

Impact of the Number of Bidders

We found, surprisingly, that increasing the number of carriers in an auction has almost no impact on the level of package discounts for a given lane (see appendix B).

This suggests that carriers package lanes and set prices based on the level of fit between their network and that of the shipper, regardless of competition.

Frequency of Package Discounts: A Bidding Guide

Given that each auction represents a different distribution, and that these distributions aren't normal, we compiled the frequency of package discounts from each auction in Table 4.10 to estimate an expected occurrence of several different levels of package discounts.

Table 4.10: Package Discount Frequency

Source	Total Lanes	Average Volume	Package Bids	Package Discount Frequency					
				<= - 5%	< 0	= 0	<= 5%	<= 10%	<= 15%
Vendor 1 Data 1	268	66	263	3%	14%	11%	73%	85%	90%
Vendor 1 Data 2	149	169	977	3%	13%	29%	60%	68%	99%
Vendor 1 Data 3	534	139	430	9%	11%	11%	56%	75%	84%
Vendor 1 Data 4	793	103	1313	7%	15%	11%	63%	79%	91%
Vendor 1 Data 5	533	75	2203	6%	9%	52%	80%	88%	93%
Vendor 1 Data 6	215	178	2185	4%	12%	78%	96%	99%	99%
Vendor 2 Data 1	101	0	217	1%	2%	38%	69%	81%	85%
Vendor 2 Data 2	1567	133	1432	11%	24%	31%	86%	93%	95%
Vendor 2 Data 3	112	288	68	6%	10%	0%	21%	26%	35%
Vendor 3 Data 1	132	1183	238	3%	8%	58%	92%	93%	93%
Vendor 4 Data 1	99	77	153	0%	2%	12%	95%	99%	100%
Vendor 4 Data 2	590	81	337	2%	4%	51%	91%	94%	99%
Vendor 4 Data 3	140	204	63	0%	0%	16%	65%	97%	98%
Total	5233	119	9879	6%	13%	43%	79%	87%	94%

This table could be useful in helping carriers understand how to bid competitively. Depending on the carrier's interest in winning a lane, he or she could choose the appropriate package discount level.

For example, a carrier could see, from this table, that, in general, about 90% of package discounts are less than 10% of the value of the lane. If this carrier's cost to serve this lane is reduced by more than 10%, it would know that 90% of its competition in this bid would most likely not be bidding as low as it would.

Lowest Total Cost Package Bids

Finally, understanding the distribution of package bids within each auction to be dependant on the underlying shipper's network as described above, we sought to understand how often package bids win. Because we were not able to tell how often packages were awarded, we compared each package bid with the lowest discrete bid for that same lane.

Table 4.11: Lowest Cost Package Bids

Source	Packaged Lanes	Lowest Cost Packaged Lanes	% Lowest Cost Packaged Lanes
Vendor 1 Data 1	133	48	36%
Vendor 1 Data 2	160	38	24%
Vendor 1 Data 3	254	83	33%
Vendor 1 Data 4	377	220	58%
Vendor 1 Data 5	1007	292	29%
Vendor 1 Data 6	430	30	7%
Vendor 2 Data 1	101	10	10%
Vendor 2 Data 2	861	105	12%
Vendor 2 Data 3	112	41	37%
Vendor 3 Data 1	132	49	37%
Vendor 4 Data 1	91	11	12%
Vendor 4 Data 2	291	21	7%
Vendor 4 Data 3	41	3	7%
Total	3990	951	24%

We found that, in general, package bids do not win because, for that lane, some discrete bid is cheaper. Not surprisingly, we found the distribution of winning packages to be dependent on the specific auction (i.e. network), with a great deal of variability among all auctions. Specifically, we found that in about half of the auctions, about 10% of the packaged bids were priced lower than the lowest discrete bid in that lane while in the other half of the auctions, about 30% of package bids were priced lower than the lowest discrete bid in that lane.

While this highlights a point made in several of our carrier interviews that package bids often do not win, our carriers suggested that packages actually win less than often than suggested here. Matt Harding of Manhattan Associates suggests that shipper's unique business rules and constraints may be another reason why package bids do not win. For example, Harding explains, a shipper may stipulate that a certain carrier handle specific lanes or that a specific carrier be given dedicated routes. Under these circumstances, regardless of what other carriers bid, any packages including that lane will not win.

John Gentle of Owens Corning shared that his experience has been that regional carriers who focused on a relatively small network tended to win auctions. Gentle added that his company allows carriers to submit single lane bids conditional on volume. Viewed through the framework we outlined in the carrier bidding strategy section (4.4), this suggested that smaller carriers, who lacked the resources to compile robust package bids, accounted for the balance a given lane adds to their network in their discrete bids.

Rick Plummer of Bohren Logistics confirmed that his company, a small regional fleet lacking the time to compile robust package bids, accounts for balance in each of its lanes by making its single lane bids conditional on volume. This observation again supported Song and Regan's (2003) assertion that carriers try to win lanes that make their existing operations more efficient.

As we pointed out in chapter 2, Caplice (1996) observed that some small, privately held carriers seek only to earn a profit threshold, and that such a carrier will lower its prices beyond those of a profit maximizing firm so long as it can earn its desired threshold. Simple logic tells us that, in an auction environment, a bidder seeking a minimal profit threshold will continue to lower its price, until it reaches that threshold, to win that auction, thus validating Gentle's observation.

Understanding, then, from the framework we outline in the carrier bidding strategy section, that most packages come from larger, more sophisticated carriers, and given that most packages do not win based on low cost, as we showed in Table 4.11 above, we concluded that smaller, profit-threshold-seeking carriers do include balance in their pricing decision, and will in many cases lower their discrete bids beyond the discrete or package bids of larger, more sophisticated carriers.

4.6 Carrier Cost Functions

To get a better understanding of what factors drive a carrier's prices, we developed a series of cost models using ordinary-least-squares (OLS) regression. We first built a basic cost model consisting of a constant (β_0), a distance (per mile) cost (β_1) and a constant package discount (β_2).

Cost per Lane = β_0 + β_1(Distance) + β_2(Package)

After regressing all the lanes where package and discrete bids existed from all the auctions we reviewed, we found the following coefficients for each of our variables.

Cost per Lane = 124 + 1.13(Distance) - 31.8(Package)

SE Coef	4.633	0.00355	4.681
T	26.75	318.71	-6.80
P	0.000	0.000	0.000

S = 327.9 R-Sq (adj) = 83.8%

This basic model tells us that a carrier incurs a per-mile cost of $1.13 and will lower their price by $31.80 if given the ability to bundle one lane with others.

Given an average length of haul of 914 miles, we can estimate the cost of a discrete and a packaged lane as:

Discrete Cost per Lane *= $124.00 + $1.13 per mile * 914 miles =* **$1156.82**
Package Cost per Lane *= $124.00 + $1.13 per mile * 914 miles - $31.80 =* **$1125.02**

This tells us that, on average, carriers will discount their discrete bids by 3% for the ability to bundle lanes.

The Impact of Volume

Next, we sought to understand if the annual shipment volume within a lane had a significant effect on the price a carrier charged. We again regressed the lanes where both package and discrete bids existed, and incorporated a variable representing the annual volumes shipped with that lane.

$$\text{Cost per Lane} = \beta_0 + \beta_1(\text{Distance}) + \beta_2(\text{Volume}) + \beta_3(\text{Package})$$

Though statistically significant, we found that the addition of the volume component had little effect on the overall Lane Cost Function, as shown below.

Cost per Lane = 127 + 1.13(Distance) - 0.0118(Volume) - 31.8(Package)

SE Coef	4.767	0.00355	0.004891	4.680
T	26.57	318.42	-2.42	-6.80
P	0.000	0.000	0.016	0.000

S = 327.9 R-Sq (adj) = 83.8%

Given an average annual volume of 119 shipments, we found that the impact of adding a volume component to our model had basically no effect on the accuracy of the model, as we can see from the R-square value above and the calculations below.

Original Model: ***Cost per Lane*** *= $124.00 + $1.13 per mile * 914 miles =* **$1156.82**
New Model: ***Cost per Lane*** *= $127.00 + $1.13 per mile * 914 miles - $0.0118 per shipment * 119 shipments per year =* **$1158.42**

We further explored the connections between discount and volume by computing correlation, and found that, while volume within a lane has an impact on the package discount applied, that impact is insignificantly small. This small effect of volume on discounts and higher charges for more volume supports the literature that truckload carriers do not exhibit economies of scale.

Correlation: Package Discount %, Volume

		Discount
Volume	Pearson correlation	0.046
	P-Value	0.000

Because the R-squared value of the new model is no different than that of the original model, and because including a volume component had no significant difference on the cost of the lane, we did not include volume in the remainder of our analysis.

The Impact of Distance

Next, we tested whether package discounts were a function of distance. We again regressed all the lanes where package and discrete bids had been submitted and found a package discount of $ 0.32 per mile.

Cost per Lane = 108 + 1.15(Distance) - 0.323(Per Packaged Mile)

SE Coef	3.996	0.00411	0.00415
T	27.03	279.06	-7.78
P	0.000	0.000	0.000

S = 327.8 R-Sq(adj) = 83.8%

Surprisingly, we found a significant difference in the value of package discounts between the original model, which assigned a fixed package discount, and this model, which assigned a variable package discount based on the length of haul.

Discrete Cost per Lane *= $108.00 + $1.15 per mile * 914 miles =* **$1159.10**
Package Cost per Lane *= $108.00 + $1.15 per mile * 914 miles - $0.323 per mile * 914 miles =* **$863.89**

In testing the correlation between distance and package discounts, we found a negative coefficient of correlation, which told us that longer distances bring greater package discounts.

Correlation: Package Discount %, Distance

		Discount
Distance	Pearson correlation	-0.055
	P-Value	0.000

Kevin McCarthy of C.H. Robinson says that this is a function of reduced relative deadhead. "If a carrier has to deadhead 60 miles to get a load for a 3000 mile length of haul, the contribution of deadhead to the cost of serving that lane is only about .5%," says McCarthy. "However," he continues, "if that carrier has to deadhead 60 miles for a 300 mile length of haul, the deadhead cost is going to be a much more significant percentage of that lane's cost."

Impact of Package Size

Finally, we tested whether packages containing more lanes carried a larger package discount than relatively smaller packages. As before, we used OLS regression to build the following cost model, which tells us that adding more lanes to a package has a relatively small impact on the overall discount.

Cost per Lane = 110 + 1.13(Distance) - 0.02852(Per Packaged Lane)

SE Coef	3.856	0.00311	0.01649
T	28.51	340.32	-1.73
P	0.000	0.000	0.084

S = 305.5 R-Sq(adj) = 85.6%

This regression tells us that for each additional lane bundled into a package, a carrier will lower its bid by about three cents.

Surprisingly, when we computed the package discounts associated with some of the different sizes of packages we observed, we found little difference between the cost associated with the minimum number of lanes, the mean number of lanes, and three standard deviations above the mean number of lanes.

Discrete Cost per Lane *= $110.00 + $1.13 per mile * 914 miles* = **$1140.82**
Package Cost per Lane *(Min Lanes) = $110.00 + $1.13 per mile * 914 miles - $0.02852 per packaged lane* ***1*** *lane* = **$1140.79**
Package Cost per Lane *(Mean Lanes) = $110.00 + $1.13 per mile * 914 miles - $0.02852 per packaged lane * **8** lanes* = **$1140.59**
Package Cost per Lane *(Mean Lanes + 3σ) = $110.00 + $1.13 per mile * 914 miles - $0.02852 per packaged lane * **96** lanes* = **$1138.08**

To be certain this wasn't influenced by a few packages with a large number of lanes, we tested for correlation between the number of lanes per package and package discount and found a slight negative correlation, suggesting that as the number of lanes within a package increases, the package discount will decrease.

```
Correlations: Number of Lanes, Package Discount %

Pearson correlation = -0.121
P-Value = 0.000
```

This observation again supports Song and Regan's (2003) assertion that carriers try not to win as many lanes as possible, but rather only those select lanes that improve the profitability of their existing network.

Model Robustness

Having explored several potential drivers of cost and package discount, we tested the robustness of these models by regressing each auction individually and comparing the results. Because most truckload prices are quoted on a per mile basis, we chose specifically to use the model calculating the package discount as a function of distance. (See appendix A for a summary of each regression).

```
Cost per Lane = β0 + β1(Distance) + β2(Discount per Mile)
```

We found that the model is not robust, but rather, because of variations within each auction, the cost function changes significantly between each data set. This again confirms the previously mentioned assertions by Jara-Diaz and Basso (2002) that each auction is influenced by factors of the shipper's physical network.

Table 4.12: Summary of Carrier Cost Function Regression

Source	Fixed Charge	Rate per Mile	Average Distance	Discrete Cost	Package Discount	Package Discount %	R-Sq(adj)
Vendor 1 Data 1	$79.72	$1.20	746	$975.13	-$0.06	4%	89.8%
Vendor 1 Data 2	$312.11	$1.00	808	$1,117.23	-$0.06	4%	64.6%
Vendor 1 Data 3	$134.85	$1.06	825	$1,010.81	-$0.03	3%	95.3%
Vendor 1 Data 4	$240.14	$1.10	1,594	$1,996.14	-$0.05	4%	92.3%
Vendor 1 Data 5	$36.61	$1.12	703	$821.19	-$0.02	2%	89.8%
Vendor 1 Data 6	$59.70	$1.25	1,032	$1,349.97	$0.00	0%	83.6%
Vendor 2 Data 1	$136.91	$1.07	873	$1,071.13	-$0.02	2%	85.9%
Vendor 2 Data 2	$194.18	$0.93	560	$714.98	-$0.02	2%	92.3%
Vendor 2 Data 3	$300.51	$1.19	1,384	$1,947.28	-$0.60	43%	84.1%
Vendor 3 Data 1	$610.75	$0.70	681	$1,087.64	-$0.01	1%	69.1%
Vendor 4 Data 1	$147.00	$0.95	1,034	$1,125.15	-$0.02	2%	75.7%
Vendor 4 Data 2	$188.07	$1.05	946	$1,177.06	-$0.03	2%	90.9%
Vendor 4 Data 3	-$8.20	$1.33	717	$942.66	-$0.04	3%	92.8%
Total	$108.00	$1.15	914	$1,159.10	-$0.32	25%	83.8%

Surprisingly however, we found that, with the exception of one data set, the package discount per mile for each auction was between $0.00 and $0.06. Excluding this outlier, we regressed all the lanes again found an expected discount of $0.03 per mile for all data sets.

```
Cost per Lane = 106 + 1.15(Distance) - 0.0277(Per Packaged Mile)

SE Coef        3.688        0.00380              0.003844
T              28.77        301.16               -7.20
P              0.000        0.000                0.000

S = 301.4      R-Sq(adj) = 85.98%
```

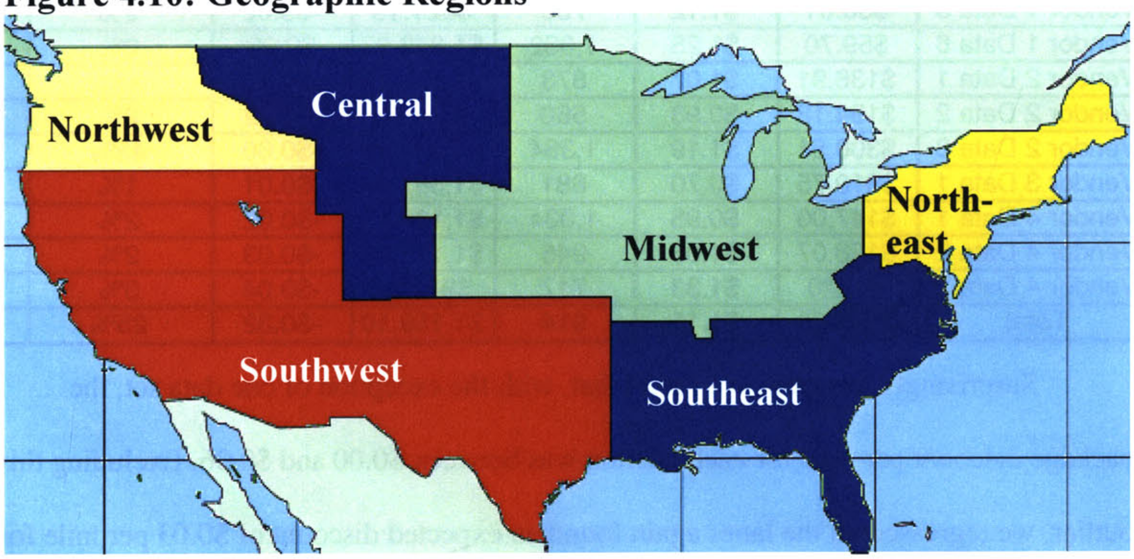
Given the proximity of this general model to the specific regressions for each data set, we conclude that, in general, between $0.00 and $0.06 per mile is a reasonable expectation of package discounts.

Regional Factors

As we've discussed frequently in this thesis, Jara-Diaz and Basso (2002) speculate that one of the major drivers of cost in a network is the physical location of the nodes. To test the significance of location on a carrier's cost function, we built a cost model incorporating a shipment's origin and destination region and defined the following regions, based on our interviews with truckload carriers:

1. Northeast;
2. Southeast;
3. Midwest;
4. Central;
5. Southwest; and
6. Northwest.

Figure 4.10: Geographic Regions



We classified each lane by its origin region (O1 - O6) and its destination region (D1 - D6) and used OLS regression to find the per mile package discount for each region.

```
Regression Analysis: Lane Cost v. Distance, Origin,
Destination

Lane Cost = 127 + 1.37 Distance - 0.0277 Package
          - 0.0795 O1 - 0.0039 O2 + 0.0754 O3
          - 0.0599 O4 + 0.0859 O5 - 0.0169 O6
          - 0.176 D1 - 0.261 D2 - 0.368 D3
          - 0.122 D4 - 0.284 D5 - 0.196 D6
```

Predictor	Coef	SE Coef	T	P
Constant	127.315	3.717	34.25	0.000
Distance	1.36689	0.03974	34.40	0.000
Package	-0.027686	0.003587	-7.72	0.000
O1	-0.07947	0.02908	-2.73	0.006
O2	-0.00392	0.02902	-0.14	0.892
O3	0.07539	0.02915	2.59	0.010
O4	-0.05991	0.03371	-1.78	0.076
O5	0.08591	0.02872	2.99	0.003
O6	-0.01694	0.03024	-0.56	0.575
D1	-0.17641	0.02772	-6.36	0.000
D2	-0.26073	0.02762	-9.44	0.000
D3	-0.36755	0.02757	-13.33	0.000
D4	-0.12187	0.03050	-4.00	0.000
D5	-0.28414	0.02735	-10.39	0.000
D6	-0.19581	0.02886	-6.78	0.000

S = 281.3   R-Sq = 87.8%   R-Sq(adj) = 87.7%

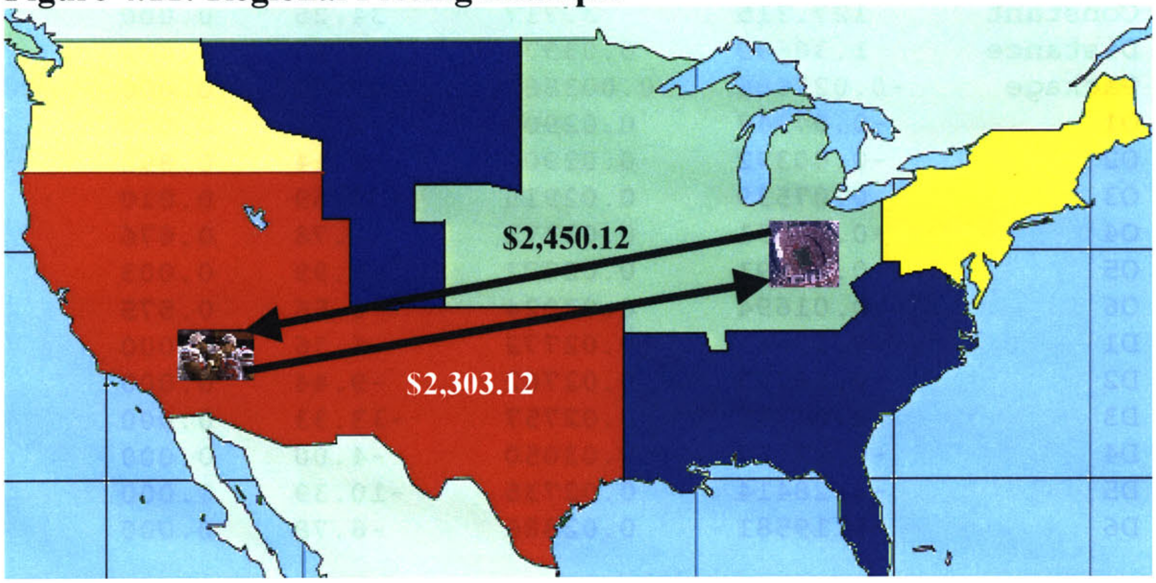
These data tell us that, in addition to distance and package effects, the regions within the country in which the freight originates and terminates also have strong affects on the cost of a lane.

A Simple Example

Columbus, Ohio, is approximately 2000 miles away from Tempe, Arizona. Given that Columbus is in the Midwest (region 3) and Tempe is in the Southwest (region 5), we know that, in addition to the base cost of $127.35 and a per mile cost of $1.37, the carrier will incorporate regional costs so that its head-haul price will be different from its back-haul price. Using this logic, we can estimate the costs of head-haul and back-haul lanes estimate as follows.

```
Head-haul: $127.32+ ($1.37 per mile * 2000 miles)
           + ($0.0754 per mile * 2000 miles) O3
           -($0.284 per mile * 2000 miles) D5
           = $2,450.12
Back-haul: $127.32+ ($1.37 per mile * 2000 miles)
           + ($0.0859 per mile * 2000 miles) O3
           -($0.368 per mile * 2000 miles) D5
           = $2,303.12
```

Figure 4.11: Regional Pricing Example



Carriers explain that each region of the country presents a different probability of getting a reload. To account for the probability that they may have to dead-head or wait for a load, carriers will increase their prices inbound to regions in which they expect they will have to wait for a reload or dead-head out.

Carrier Cost Function Conclusions

These findings suggest that Jara-Diaz and Basso (2002) were correct, and that the location of the nodes and lane demand structure within a carriers network is the most important factor in determining the cost to serve that network. From a carrier's perspective, the location of these nodes impacts what our models show to be the most significant drivers of cost; (1) location; and (2) length of haul.

The lane demand structure of a shippers network can be leveraged to create balance within a carriers network. Both our carrier interviews and the output of our models show that, through package bidding and discounts, carriers are able to reduce their costs of deadhead and dwell time and share their savings with shippers.

Chapter 5

Conclusions

This chapter presents our findings and conclusions from the literature, our interviews with truckload carriers, and our analysis of actual carrier bidding behaviors.

In addressing the economics of transportation we found that truckload carriers exhibit characteristics of Economies of Scope, Scale and Density. However, because the cost of serving a lane is significantly impacted by the probability of finding a follow-on load, the concept of Economies of Scope most closely represents the underlying dynamics of a Truckload Carrier's Operations.

In submitting bids, carrier's actual behavior reflects the predictions made by Song and Regan (2002) that a carrier seeks not to win as many lanes as possible, but rather only those lanes that make its current operation more profitable.

Given two separate truckload markets, as described by Rakowski, Souther, and Jarrell (1993), several levels of sophistication exist in the way carriers package lanes. The least sophisticate carriers are small, simple, privately held firms. Caplice (1996) showed that this group of carriers was profit-threshold oriented and provided a commodity service in a nearly perfectly competitive market. Not surprisingly, these simple carriers lack the time and resources to compile robust packages, and instead use conditional bids to balance single lanes within their network.

The next level of sophistication comes from progressive, medium-size carriers who seek to maximize profits by providing a differentiated service to a smaller market. These carriers use some software packages to identify freight lanes that can balance a single region within their network. Also unlike simple carriers, this group can afford to commit a moderate level of resources to creating balance.

The most sophisticated package bidders are the large, profit maximizing, advanced truckload carriers, who compete directly with the progressive, medium size carriers in providing differentiated services. Advanced truckload carriers devote considerable resources to creating balance within their network, and often use proprietary technologies to identify disparate lanes that can add balance to their entire network. Not surprisingly, these large, sophisticated carriers tend to package more lanes than either of their smaller counterparts

Using package or "conditional" bids in combinatorial auction, truckload carriers may be able to increase the scope of their operations. By creating package bids, carriers are better able to reflect their true cost structure in their pricing and as such, are able create balance within their networks, reducing the costs of deadhead and dwell time.

Each combinatorial auction is unique and dependent upon the specific underlying shipper's physical network and lane demand structure. Carriers need detailed information about the location of the shippers facilities and annual shipment volumes in each lane to create competitive package bids.

Within a given auction, only about 30% of carriers submit package bids and, of those carriers that do submit package bids, most submitted between only 2 - 7 packages containing only 2 - 4 lanes each. Surprisingly, lanes with higher annual shipment volumes are not significantly more likely to be packaged than lanes with low volumes. In fact, most packaged lanes contained relatively low annual shipment volumes and were bid on by only 1 or 2 carriers, confirming that carriers package the lanes that complement their specific networks.

In examining carrier bidding strategies, we found four common patterns of package bidding to be present in most auctions.

- Round Trip Packages;
- Destination Packages;
- Origin Packages; and
- Disparate Lane Packages.

Round trip, or "closed loop" packages, which allow carriers to balance a single lane, are the simplest form of package bids and seem to be most frequently by small, simple truckload carriers.

Destination and Origin packages, or "Inbound" and "Outbound" packages respectively, allow a carrier to leverage cost advantages within a single lane to create balance within a region of that carrier's network. In chapter 4, we used the example of a carrier which leveraged freight outbound from Montgomery, Alabama, to offer significant discounts on 9 inbound lanes. Origin and Destination packages seem to be used by both progressive, medium-sized carriers and large, advanced truckload carriers.

Going one step farther, disparate lane packages bundle unrelated lanes to create balance within an advanced truckload carrier's specific network.

When submitting packages, a carrier most frequently will not change its prices between a discrete bid and a packaged bid. When a carrier does change its price for a packaged lane, most package discounts fall within a relatively small range, between – 5% and 15%, with the average discount around 5% of the value of that lane.

To offer package discounts, carriers leverage existing freight in their networks to create packages that improve asset utilization through reduced deadhead and dwell time.

A carrier may price some lanes higher than its discrete bid to more accurately reflect the cost of serving those lanes. Knowing that packages are awarded based on total discounts, carriers sometimes bundle these higher priced lanes with those lanes in which they have a cost advantage to create balance within their networks.

In speaking with carriers, we found that progressive and advanced carriers will often bundle lanes in which they have a cost advantage, and thus can bid a lower price than the general market, with lanes in which they can charge a market premium. This bundling allows a carrier to increase the balance within their network while offering a discount to the shipper.

Depending on the length of haul and the origin and destination of the shipments, package discounts generally range from $0.01 to $0.06 per mile. Surprisingly, annual shipment volume within a lane is relatively insignificant in carrier's pricing decision. Length of haul is significant in determining package discounts in that a certain amount of deadhead and dwell time are to be expected in even the best situations and, as such, carriers try to spread those costs across more revenue-generating miles

Because different regions of the country hold different probabilities of getting a follow-on load, and different expectations of deadhead and dwell time, carriers also adjust their prices for each region.

The number of carriers included in an auction has little impact on the number or level of package bids submitted; suggesting that carriers submit packages based the relative value of the shipper's lanes to that carrier's network rather than competition.

Despite what appears to be a huge potential for savings, package bids generally are not executed for three reasons. First, given a large number of small, simple, profit-threshold seeking carriers submitting low cost discrete bids to balance a single lane, more sophisticated package bids represent the lowest cost in a given lane between only 10% and 30% of cases.

Even when a package bid is the lowest cost within a single lane, it may not win. One reason is that shippers often impose business rules / constraints that exclude some portion of a package, and thus eliminate that entire package.

Another reason why the low cost package bid may not win is that, in many cases, shippers lack the IT capabilities to tender package bids.

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Appendix A

Auction Lane Cost Regressions

Vendor 1 Data 1 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 116 + 1.28 Distance - 134 Package

Predictor	Coef	SE Coef	T	P
Constant	115.566	7.886	14.66	0.000
Distance	1.28161	0.00838	152.85	0.000
Package	-133.65	14.08	-9.49	0.000

S = 227.7   R-Sq = 86.1%   R-Sq(adj) = 86.1%

Lane Cost versus Distance, Volume, Package

Lane Cost = 131 + 1.28 Distance - 0.190 Volume - 130 Package

Predictor	Coef	SE Coef	T	P
Constant	130.621	9.147	14.28	0.000
Distance	1.27814	0.00844	151.39	0.000
Volume	-0.18978	0.05865	-3.24	0.001
Package	-129.97	14.11	-9.21	0.000

S = 227.4   R-Sq = 86.2%   R-Sq(adj) = 86.2%

Lane Cost versus Distance, Package

Lane Cost = 79.7 + 1.20 Distance - 0.0558 Package

Predictor	Coef	SE Coef	T	P
Constant	79.72	14.22	5.60	0.000
Distance	1.20500	0.01877	64.20	0.000
Package	-0.05580	0.01446	-3.86	0.000

S = 136.2   R-Sq = 89.9%   R-Sq(adj) = 89.8%

Vendor 1 Data 2 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 364 + 1.01 Distance - 99.1 Package

Predictor	Coef	SE Coef	T	P
Constant	364.34	10.77	33.84	0.000
Distance	1.01105	0.00860	117.59	0.000
Package	-99.13	14.24	-6.96	0.000

S = 363.5   R-Sq = 77.8%   R-Sq(adj) = 77.8%

Lane Cost versus Distance, Volume, Package

Lane Cost = 388 + 1.01 Distance - 0.116 Volume - 95.6 Package

Predictor	Coef	SE Coef	T	P
Constant	387.76	12.95	29.95	0.000
Distance	1.00658	0.00870	115.73	0.000
Volume	-0.11568	0.03561	-3.25	0.001
Package	-95.57	14.27	-6.70	0.000

S = 363.1 R-Sq = 77.8% R-Sq(adj) = 77.8%

Lane Cost versus Distance, Package

Lane Cost = 312 + 0.997 Distance - 0.0560 Package

Predictor	Coef	SE Coef	T	P
Constant	312.11	17.68	17.65	0.000
Distance	0.99672	0.01956	50.96	0.000
Package	-0.05596	0.02182	-2.56	0.010

S = 525.3 R-Sq = 64.7% R-Sq(adj) = 64.6%

Vendor 1 Data 3 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 171 + 1.14 Distance - 137 Package

Predictor	Coef	SE Coef	T	P
Constant	170.922	4.377	39.05	0.000
Distance	1.13825	0.00461	246.66	0.000
Package	-137.04	10.46	-13.10	0.000

S = 234.0 R-Sq = 87.3% R-Sq(adj) = 87.3%

Lane Cost versus Distance, Volume, Package

Lane Cost = 181 + 1.14 Distance - 0.0684 Volume - 134 Package

Predictor	Coef	SE Coef	T	P
Constant	181.030	4.744	38.16	0.000
Distance	1.13725	0.00461	246.66	0.000
Volume	-0.06837	0.01248	-5.48	0.000
Package	-134.48	10.45	-12.87	0.000

S = 233.6 R-Sq = 87.4% R-Sq(adj) = 87.4%

Lane Cost versus Distance, Package

Lane Cost = 135 + 1.06 Distance - 0.0334 Package

Predictor	Coef	SE Coef	T	P
Constant	134.853	8.213	16.42	0.000
Distance	1.06142	0.00926	114.57	0.000
Package	-0.033385	0.009583	-3.48	0.001

S = 145.5 R-Sq = 95.3% R-Sq(adj) = 95.3%

Vendor 1 Data 4 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 405 + 1.07 Distance - 231 Package

Predictor	Coef	SE Coef	T	P
Constant	404.689	7.288	55.53	0.000
Distance	1.07348	0.00426	251.91	0.000
Package	-231.162	7.094	-32.59	0.000

S = 250.1 R-Sq = 87.7% R-Sq(adj) = 87.7%

Lane Cost versus Distance, Volume, Package

Lane Cost = 406 + 1.07 Distance - 0.0110 Volume - 229 Discrete / Package

Predictor	Coef	SE Coef	T	P
Constant	406.320	7.784	52.20	0.000
Distance	1.07310	0.00431	249.18	0.000
Volume	-0.01097	0.01840	-0.60	0.551
Package	-228.695	8.212	-27.85	0.000

S = 250.1 R-Sq = 87.7% R-Sq(adj) = 87.7%

Lane Cost versus Distance, Package

Lane Cost = 240 + 1.10 Distance - 0.0467 Package

Predictor	Coef	SE Coef	T	P
Constant	240.14	10.36	23.18	0.000
Distance	1.10167	0.00645	170.77	0.000
Package	-0.046656	0.004243	-11.00	0.000

S = 184.8 R-Sq = 92.3% R-Sq(adj) = 92.3%

Vendor 1 Data 5 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 133 + 1.16 Distance - 128 Package

Predictor	Coef	SE Coef	T	P
Constant	132.805	3.711	35.78	0.000
Distance	1.16136	0.00481	241.57	0.000
Package	-128.203	4.773	-26.86	0.000

S = 199.9 R-Sq = 81.2% R-Sq(adj) = 81.2%

Lane Cost versus Distance, Volume, Package

Lane Cost = 128 + 1.16 Distance + 0.0415 Volume - 130 Discrete / Package

Predictor	Coef	SE Coef	T	P
Constant	128.465	3.871	33.18	0.000
Distance	1.16348	0.00484	240.62	0.000
Volume	0.04154	0.01060	3.92	0.000
Package	-129.800	4.787	-27.11	0.000

S = 199.8 R-Sq = 81.2% R-Sq(adj) = 81.2%

Lane Cost versus Distance, Package

Lane Cost = 36.6 + 1.12 Distance - 0.0239 Package

Predictor	Coef	SE Coef	T	P
Constant	36.605	4.513	8.11	0.000
Distance	1.11604	0.00624	178.91	0.000
Package	-0.023912	0.005449	-4.39	0.000

S = 145.4   R-Sq = 89.8%   R-Sq(adj) = 89.8%

Vendor 1 Data 6 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 6.5 + 1.29 Distance - 12.4 Package

Predictor	Coef	SE Coef	T	P
Constant	6.45	10.49	0.62	0.538
Distance	1.28981	0.00773	166.90	0.000
Package	-12.41	11.19	-1.11	0.267

S = 348.0   R-Sq = 86.3%   R-Sq(adj) = 86.3%

Lane Cost versus Distance, Volume, Package

Lane Cost = 12.9 + 1.29 Distance - 0.0212 Volume - 11.5 Package

Predictor	Coef	SE Coef	T	P
Constant	12.91	12.52	1.03	0.303
Distance	1.28708	0.00825	156.01	0.000
Volume	-0.02124	0.02250	-0.94	0.345
Package	-11.52	11.23	-1.03	0.305

S = 348.0   R-Sq = 86.3%   R-Sq(adj) = 86.3%

Lane Cost versus Distance, Package

Lane Cost = 59.7 + 1.25 Distance + 0.00089 Package

Predictor	Coef	SE Coef	T	P
Constant	59.70	10.52	5.68	0.000
Distance	1.24851	0.00964	129.57	0.000
Package	0.000894	0.009533	0.09	0.925

S = 395.8   R-Sq = 83.6%   R-Sq(adj) = 83.6%

Vendor 2 Data 1 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 175 + 0.992 Distance + 11.5 Package

Predictor	Coef	SE Coef	T	P
Constant	175.40	15.05	11.65	0.000
Distance	0.99207	0.01208	82.12	0.000
Package	11.48	24.65	0.47	0.641

S = 345.8   R-Sq = 78.3%   R-Sq(adj) = 78.3%

Lane Cost versus Distance, Package

Lane Cost = 137 + 1.07 Distance - 0.0247 Package

Predictor	Coef	SE Coef	T	P
Constant	136.91	22.29	6.14	0.000
Distance	1.06804	0.02397	44.55	0.000
Package	-0.02471	0.02481	-1.00	0.320

S = 280.9   R-Sq = 86.0%   R-Sq(adj) = 85.9%

Vendor 2 Data 2 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 225 + 0.999 Distance - 75.5 Package

Predictor	Coef	SE Coef	T	P
Constant	225.195	1.720	130.91	0.000
Distance	0.998776	0.002059	484.99	0.000
Package	-75.512	4.702	-16.06	0.000

S = 173.1   R-Sq = 91.4%   R-Sq(adj) = 91.4%

Lane Cost versus Distance, Volume, Package

Lane Cost = 226 + 0.999 Distance - 0.00244 Volume - 75.4 Package

Predictor	Coef	SE Coef	T	P
Constant	225.609	1.816	124.25	0.000
Distance	0.998622	0.002071	482.25	0.000
Volume	-0.002444	0.003434	-0.71	0.477
Package	-75.432	4.703	-16.04	0.000

S = 173.1   R-Sq = 91.4%   R-Sq(adj) = 91.4%

Lane Cost versus Distance, Package

Lane Cost = 194 + 0.930 Distance - 0.0198 Package

Predictor	Coef	SE Coef	T	P
Constant	194.180	3.940	49.28	0.000
Distance	0.930240	0.006197	150.12	0.000
Package	-0.019810	0.007027	-2.82	0.005

S = 141.7   R-Sq = 92.3%   R-Sq(adj) = 92.3%

Vendor 2 Data 3 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 323 + 0.937 Distance - 314 Package

Predictor	Coef	SE Coef	T	P
Constant	323.179	9.163	35.27	0.000
Distance	0.936697	0.006666	140.52	0.000
Package	-314.40	29.65	-10.61	0.000

S = 308.3   R-Sq = 85.9%   R-Sq(adj) = 85.8%

Lane Cost versus Distance, Volume, Package

Lane Cost = 357 + 0.925 Distance - 0.0706 Volume - 316 Package

Predictor	Coef	SE Coef	T	P
Constant	356.94	10.40	34.33	0.000
Distance	0.924525	0.006865	134.67	0.000
Volume	-0.07059	0.01051	-6.72	0.000
Package	-316.06	29.45	-10.73	0.000

S = 306.2   R-Sq = 86.0%   R-Sq(adj) = 86.0%

Lane Cost versus Distance, Package

Lane Cost = 301 + 1.19 Distance - 0.602 Package

Predictor	Coef	SE Coef	T	P
Constant	300.51	64.20	4.68	0.000
Distance	1.19353	0.04500	26.52	0.000
Package	-0.60212	0.03980	-15.13	0.000

S = 369.2   R-Sq = 84.4%   R-Sq(adj) = 84.1%

Vendor 3 Data 1 Regression Analysis:

Lane Cost versus Distance, Package

Lane Cost = 362 + 0.700 Distance - 9.0 Package

Predictor	Coef	SE Coef	T	P
Constant	361.88	17.20	21.04	0.000
Distance	0.69953	0.02124	32.94	0.000
Package	-9.01	13.16	-0.68	0.494

S = 143.9   R-Sq = 69.6%   R-Sq(adj) = 69.4%

Lane Cost versus Distance, Volume, Package

Lane Cost = 361 + 0.708 Distance - 0.00377 Volume - 9.0 Package

Predictor	Coef	SE Coef	T	P
Constant	360.56	17.22	20.94	0.000
Distance	0.70802	0.02226	31.81	0.000
Volume	-0.003772	0.002981	-1.27	0.206
Package	-9.01	13.15	-0.69	0.494

S = 143.8   R-Sq = 69.7%   R-Sq(adj) = 69.5%

Lane Cost versus Distance, Package

Lane Cost = 361 + 0.700 Distance - 0.0093 Package

Predictor	Coef	SE Coef	T	P
Constant	360.75	15.97	22.59	0.000
Distance	0.70032	0.02304	30.39	0.000
Package	-0.00933	0.01755	-0.53	0.595

S = 143.6   R-Sq = 69.3%   R-Sq(adj) = 69.1%

Vendor 4 Data 1 Regression Analysis:

Lane Cost v. Distance, Package

Lane Cost = - 54.0 + 1.22 Distance - 106 Package

Predictor	Coef	SE Coef	T	P
Constant	-54.03	17.25	-3.13	0.002
Distance	1.21811	0.01476	82.53	0.000
Package	-105.61	25.35	-4.17	0.000

S = 304.7   R-Sq = 70.9%   R-Sq(adj) = 70.8%

Lane Cost versus Distance, Volume, Package

Lane Cost = - 73.0 + 1.22 Distance + 0.164 Volume - 107 Package

Predictor	Coef	SE Coef	T	P
Constant	-73.00	19.89	-3.67	0.000
Distance	1.22397	0.01507	81.23	0.000
Volume	0.16433	0.08592	1.91	0.056
Package	-106.97	25.34	-4.22	0.000

S = 304.5   R-Sq = 70.9%   R-Sq(adj) = 70.9%

Regression Analysis: Lane Cost versus Distance, Package

Lane Cost = 147 + 0.946 Distance - 0.0234 Package

Predictor	Coef	SE Coef	T	P
Constant	146.86	32.70	4.49	0.000
Distance	0.94599	0.03152	30.02	0.000
Package	-0.02344	0.01743	-1.34	0.180

S = 164.6   R-Sq = 75.9%   R-Sq(adj) = 75.7%

Vendor 4 Data 2 Regression Analysis:

Lane Cost v. Distance, Package

Lane Cost = 241 + 1.06 Distance - 97.4 Package

Predictor	Coef	SE Coef	T	P
Constant	241.218	6.920	34.86	0.000
Distance	1.06333	0.00490	216.79	0.000
Package	-97.44	22.44	-4.34	0.000

S = 434.4   R-Sq = 73.2%   R-Sq(adj) = 73.2%

Lane Cost versus Distance, Volume, Package

Lane Cost = 260 + 1.07 Distance - 0.284 Volume - 87.2 Package

Predictor	Coef	SE Coef	T	P
Constant	260.480	7.137	36.50	0.000
Distance	1.06613	0.00490	217.73	0.000
Volume	-0.28404	0.02703	-10.51	0.000
Package	-87.20	22.39	-3.89	0.000

S = 433.0   R-Sq = 73.4%   R-Sq(adj) = 73.4%

Lane Cost versus Distance, Package

Lane Cost = 188 + 1.05 Distance - 0.0308 Package

Predictor	Coef	SE Coef	T	P
Constant	188.07	13.80	13.63	0.000
Distance	1.04547	0.01408	74.26	0.000
Package	-0.03077	0.01284	-2.40	0.017

S = 183.6 R-Sq = 91.0% R-Sq(adj) = 90.9%

Vendor 4 Data 3 Regression Analysis:

Lane Cost v. Distance, Package

Lane Cost = 132 + 1.23 Distance - 98.7 Package

Predictor	Coef	SE Coef	T	P
Constant	131.500	9.096	14.46	0.000
Distance	1.22544	0.01083	113.17	0.000
Package	-98.71	34.48	-2.86	0.004

S = 270.2 R-Sq = 83.8% R-Sq(adj) = 83.8%

Lane Cost versus Distance, Volume, Package

Lane Cost = 157 + 1.22 Distance - 0.118 Volume - 99.7 Package

Predictor	Coef	SE Coef	T	P
Constant	156.69	12.48	12.56	0.000
Distance	1.22391	0.01082	113.08	0.000
Volume	-0.11821	0.04016	-2.94	0.003
Package	-99.73	34.43	-2.90	0.004

S = 269.8 R-Sq = 83.8% R-Sq(adj) = 83.8%

Lane Cost versus Distance, Package

Lane Cost = - 8.2 + 1.33 Distance - 0.0420 Package

Predictor	Coef	SE Coef	T	P
Constant	-8.20	26.55	-0.31	0.758
Distance	1.32617	0.03603	36.80	0.000
Package	-0.04203	0.03121	-1.35	0.181

S = 143.2 R-Sq = 92.9% R-Sq(adj) = 92.8%

Master (ex Vendor 3 Data 3) Regression Analysis: Lane Cost versus Distance, Package

Lane Cost = 106 + 1.15 Distance - 0.0277 Package

Predictor	Coef	SE Coef	T	P
Constant	106.078	3.688	28.77	0.000
Distance	1.14553	0.00380	301.16	0.000
Package	-0.027686	0.003844	-7.20	0.000

S = 301.4 R-Sq = 85.9% R-Sq(adj) = 85.9%

Appendix B

Statistical Analysis

To be "normal," a distribution must meet four criteria:

- Bell shaped and symmetrical;
- Identical measures of central tendency;
- An interquartile range equal to 1.33 standard deviations; and
- An approximately infinite range (equal to 6 standard deviations).

We can see from the above table and histogram that the distribution is neither bell shaped nor symmetrical and the measures of central tendency (mean, median, mode), though close, are not identical.

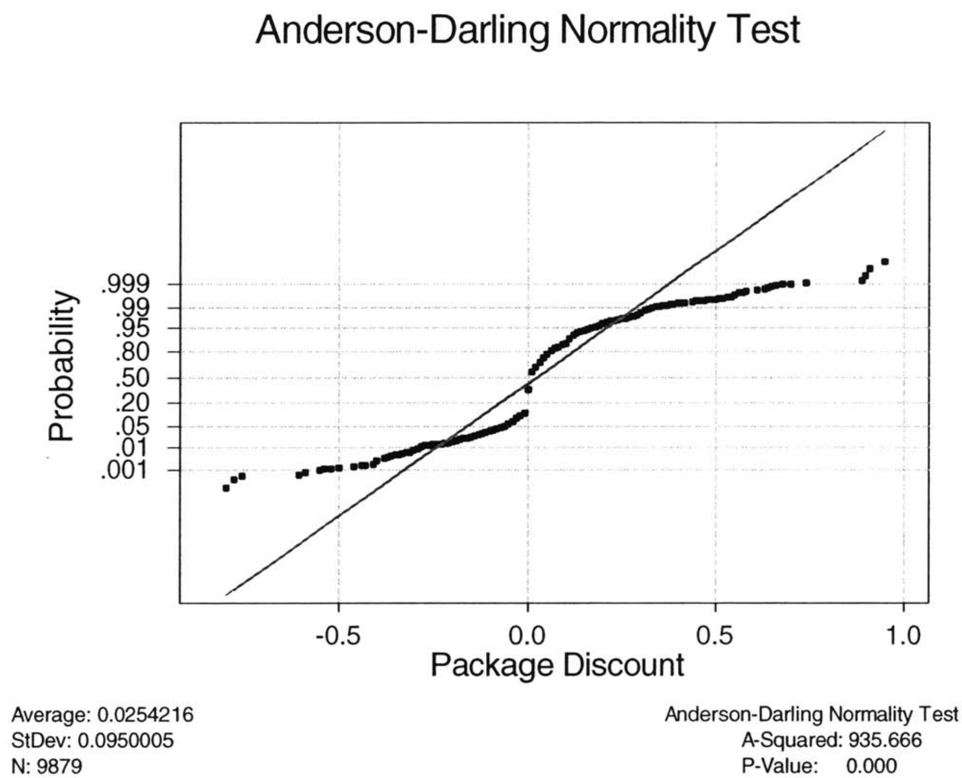
The following table however, shows that the interquartile and overall ranges for several of the auctions meet the criteria for being "normal."

Table B.1: Tests of Normality

Source	Std Dev	Range	6 Std Dev	Interquartile Range	1.33 Std Dev
Vendor 1 Data 1	10.7%	106.7%	63.9%	6.0%	14.2%
Vendor 1 Data 2	9.2%	139.8%	55.0%	11.0%	12.2%
Vendor 1 Data 3	13.0%	104.5%	77.9%	9.0%	17.3%
Vendor 1 Data 4	9.1%	105.7%	54.9%	8.5%	12.2%
Vendor 1 Data 5	9.1%	79.6%	54.3%	4.0%	12.0%
Vendor 1 Data 6	5.4%	130.8%	32.4%	0.0%	7.2%
Vendor 2 Data 1	9.4%	79.0%	56.2%	6.0%	12.5%
Vendor 2 Data 2	10.7%	168.7%	64.2%	3.0%	14.2%
Vendor 2 Data 3	25.8%	142.1%	154.6%	41.5%	34.3%
Vendor 3 Data 1	13.6%	135.0%	81.5%	2.0%	18.1%
Vendor 4 Data 1	1.9%	13.0%	11.5%	2.0%	2.5%
Vendor 4 Data 2	4.4%	25.2%	26.2%	3.0%	5.8%
Vendor 4 Data 3	3.2%	16.7%	19.0%	5.0%	4.2%

We resolved any question however, and proved that these data are not normally distributed by generating the following normal probability plot. When a data set is normally distributed, we can expect the points to lie on or close to the diagonal. However, for these data, the probability points are only near the diagonal towards the center of the distribution.

Figure B.1: Normal Probability Plot



This graph reflects what we saw in the histogram above and tells us that 98% of our results occur within $\pm$ 3% of 0. The symmetric shape of the probability plot, coupled with flattening out of the curve at both ends tells us that the vast majority of the results are concentrated near the exact center of the distribution. This means that almost no tails exist on this distribution and that these data are not normally distributed.

Similarity of Distributions: The Impact of Shippers Networks

Understanding that, as a whole, the data is very concentrated around 0%, we set out to understand whether each of the individual data sets came from that same distribution. We used hypothesis testing to determine whether the distributions of each auction were similar, and found that they were not. As we will show in the following analysis, although several common distributions emerged, no single common distribution was found, suggesting that the specific shipper's network represented had an impact on the distribution of package discounts.

We defined our hypotheses as follows:

***H_0:** The distribution of package discounts is independent of the software package used to collect those bids. (i.e. the median and proportion of package discounts in each auction is approximately the same)*

***H_1:** One or more of the populations come from a different distribution.*

Using the Mood Median test and the Kruskal-Wallis test, we found that both the median and the proportion of each level of package discounts varied significantly among the different auctions and thus rejected the null hypothesis.

Both the Mood Median test and the Kruskal-Wallis test are non-parametric hypothesis tests that examine the differences in population distributions. While the Mood Median test is more robust against outliers, the Kruskal-Wallis test has a narrower confidence interval, making it more powerful for analyzing data from many distributions

The Mood Median Test

The Mood Median Test is essentially a compilation of a Chi-Square test, and a comparison of medians, interquartile ranges, and confidence intervals. Given its greater tolerance of outliers, we chose to use this test first. In the case of the Mood Median test, we can define our hypotheses as:

$$H_0 : p_1 = p_2 = p_3 = p_4 = p_5 = p_6 = p_7 = p_8 = p_9 = p_{10} = p_{11} = p_{12} = p_{13}$$

H_1 : not all p_i are equal

where p_i = proportion of package discounts in data set i

Mood Median Test: Package Discount versus Source

```
Chi-Square = 2112.67    DF = 12    P = 0.000

                                                Individual 95.0% CIs
Source        N<=     N>    Median     Q3-Q1  +---------+---------+---------+------
V 1 D 1       71      192    0.020      0.060    (-+
V 1 D 2       403     574    0.030      0.110       +)
V 1 D 3       92      338    0.040      0.090        (+
V 1 D 4       342     971    0.030      0.085       +)
V 1 D 5       1349    854    0.000      0.040   +
V 1 D 6       1956    229    0.000      0.000   +
V 2 D 1       89      128    0.020      0.060    (-+)
V 2 D 2       785     647    0.000      0.030   +
V 2 D 3       7       61     0.195      0.415                    (---+---------)
V 3 D 1       157     81     0.000      0.020   +
V 4 D 1       22      131    0.020      0.020      +)
V 4 D 2       185     152    0.000      0.030   +)
V 4 D 3       10      53     0.040      0.050       (+)
                                                +---------+---------+---------+------
                                                0.000     0.080     0.160     0.240
Overall median = 0.000
```

Interquartile Ranges (Q_3-Q_1)

Interquartile ranges gauge the amount of variation within the 25% of results above and 25% of results below the median. In this case, we see that most interquartile ranges are relatively small. However, a few of the data sets have interquartile ranges that may not be representative of the entire population. Therefore, given the large interquartile ranges and the small p-value in this test, we suspect that each auction represents a slightly different distribution.

Confidence Intervals

Confidence intervals tell us the range in which the population median could lie with a certain level of confidence. In this situation, given a 95% level of confidence, we see that, though many of the sample means and confidence intervals are relatively close, only a few overlap. This tells us that, although the sample and population means are similar, they do come from slightly different distributions.

An interesting observation is that not only do few of the medians and confidence intervals overlap, but even samples from the same source do not over lap. This would suggest that each auction is drawn from a slightly different distribution based on some factors of the underlying shipper's network.

Furthermore, we can see that several auctions from different software vendors share distributions, suggesting that the distribution of package discounts is dependent on the shipper's network rather than the auction software method used. We will prove this a later section of this paper.

Chi Square Test

The Chi-Square Test looks for similar frequencies in multiple different samples and tests the null hypothesis that all observations come from a single distribution. Technically, the Chi-Square test divides the squared difference between the observed frequency and an expected frequency by the number of observations. The Chi-Square distribution then tells us how likely, with a given level of confidence, a series of observations are to come from a single distribution. If the Chi-Square Value falls below some critical value of the Chi-Squared distribution, dependant upon its degrees of freedom and its confidence level, we accept the null hypothesis (Lowry, *Chi-Square* 3) .

Here, the Chi-Square is looking for similar frequencies of package discounts within each auction. Given 12 degrees of freedom and assuming a confidence level of 95%, the critical Chi-Square value is 21.026. Given that the Chi-Square value of this test is approximately 100 times that figure, we can be relatively confident in rejecting the null hypothesis.

The Kruskal-Wallis Test

To further gauge whether each auction comes from a similar distribution, we used the Kruskal-Wallis test. Like the Mood Median test used above, the Kruskal-Wallis test looks for differences in distributions. Unlike the previous test, however, the Kruskal-Wallis test identifies distributions by the rank of each observation rather than by the frequency of occurrences. The Kruskal-Wallis tests the null hypothesis that the mean rank of several distributions will not differ substantially (Lowry, *Kruskal-Wallis* 5):

$H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7 = \mu_8 = \mu_9 = \mu_{10} = \mu_{11} = \mu_{12} = \mu_{13}$
H_1 : not all μ are equal
where μ_i = mean rank of data set i

The key measures of the Kruskal-Wallis test are the H statistic and the Z score. The H statistic gauges variance in ranks relative to the number of degrees of freedom. Again referring to the Chi-Square distribution, we can estimate the likelihood of each auction coming from the same distribution.

The Z score represents the closeness of one data set to the entire population. Those auctions with the lowest Z-scores have distributions closest to that of the entire data set, whereas those with high Z-scores have distributions significantly different from the entire data set.

Kruskal-Wallis Test: Package Discount versus Data Source

Kruskal-Wallis Test on Package Discount

Data Source	N	Median	Ave Rank	Z
V 1 Data 1	263	1.56E-02	5851.4	5.24
V 1 Data 2	979	2.94E-02	5844.9	10.42
V 1 Data 3	430	3.82E-02	6548.4	11.93
V 1 Data 4	1313	3.48E-02	6183.6	16.92
V 1 Data 5	2203	0.00E+00	4822.0	-2.25
V 1 Data 6	2186	0.00E+00	3475.9	-27.23
V 2 Data 1	218	1.69E-02	5963.0	5.34
V 2 Data 2	1432	0.00E+00	4533.3	-5.87
V 2 Data 3	68	1.93E-01	8422.1	10.09

```
V 3 Data 1  239  0.00E+00      4471.9     -2.58
V 4 Data 1  153  2.22E-02      6168.3      5.36
V 4 Data 2  337  0.00E+00      4837.7     -0.69
V 4 Data 3   63  4.00E-02      6784.0      5.14
Overall     9884                4942.5

H = 1310.51  DF = 12  P = 0.000
H = 1420.36  DF = 12  P = 0.000 (adjusted for ties)
```

As with the Mood Median test, the Kruskal-Wallis test tells us that a significant amount of difference exists within the distributions of the auctions. Given the wide variance in Z scores, an H value well above the acceptable 21.026 and a P value of 0.000, the Kruskal-Wallis test confirms that we should reject the null hypothesis.

Similarity of Distributions: The Impact of Software Vendors

Having shown that for each auction, the distribution of package discounts is different, we then found that the software vendor used had little significant impact on the distribution of package discounts. For each software package, our hypotheses are:

***H_0*: the proportion of each level of discount and the median discount for each auction from a single software vendor will be comparable; and**

***H_1*: the proportion of each level of discount and/or the median discount for each auction from a single software vendor is not comparable**

Again using both the Mood Median test and Kruskal-Wallis test we found that for each software vendor, most auctions showed significantly different distributions, allowing us to reject the null hypothesis in each case. This confirmed that the distribution of package discounts is not dependent upon the software vendor used.

Vendor 1 Mood Median Test: Package Discount Percent versus Source

```
Chi-Square = 819.66   DF = 5   P = 0.000
                                         Individual 95.0% CIs
Source      N<=     N>   Median     Q3-Q1  +---------+---------+---------+------
Data 1       63    177   0.0157    0.0637            +------)
Data 2      194    132   0.0000    0.0286  +
Data 3       83    303   0.0370    0.0920                      (------+---)
Data 4      304    771   0.0303    0.0811                    (--+---)
Data 5      952    748   0.0000    0.0465  +
Data 6      752    150   0.0000    0.0000  +
                                           +---------+---------+---------+------
                                         0.000     0.012     0.024     0.036
Overall median = 0.0000
```

For a test with 5 degrees of freedom, the critical Chi-Square value is 11.071. Given a P value of 0.000 and a Chi Square value of 819, we were relatively confident in rejecting the null hypothesis.

Vendor 1 Kruskal-Wallis Test: Package Discount Percent v. Source

Source	N	Median	Ave Rank	Z
Data 1	240	1.57E-02	2646.7	3.95
Data 2	326	0.00E+00	2033.7	-3.94
Data 3	386	3.70E-02	2974.0	10.12
Data 4	1075	3.03E-02	2717.0	11.26
Data 5	1700	0.00E+00	2292.8	-0.86
Data 6	902	0.00E+00	1609.1	-17.68
Overall	4629		2315.0	

```
H = 472.53  DF = 5  P = 0.000
H = 497.99  DF = 5  P = 0.000 (adjusted for ties)
```

Given another extraordinarily high H statistic, a P score of 0.000 and a high degree of variance in the Z values, we rejected the null hypothesis for vendor 1. Thus, because of considerable variation within both the proportion of discounts and the median discount, no common distribution existed within the auctions this software collected.

Vendor 2 Mood Median Test: Package Discount Percent versus Source

```
Chi-Square = 48.31    DF = 2    P = 0.000
                                          Individual 95.0% CIs
Source      N<=     N>    Median    Q3-Q1  +---------+---------+---------+------
Data 1       75     91     0.016    0.058  (-+)
Data 2      666    596     0.000    0.036  +)
Data 3       61     0.192    0.411                       (---+---------)
                                           +---------+---------+---------+------
                                       0.000     0.080     0.160     0.240
Overall median = 0.009
```

Vendor 2 Kruskal-Wallis Test: Package Discount Percent v. Source

Source	N	Median	Ave Rank	Z
Data 1	166	1.56E-02	854.8	3.36
Data 2	1262	0.00E+00	706.5	-8.72
Data 3	68	1.92E-01	1267.6	10.14
Overall	1496		748.5	

```
H = 120.16  DF = 2  P = 0.000
H = 123.57  DF = 2  P = 0.000 (adjusted for ties)
```

Again we found that considerable variance existed within the auctions from this software package. Given two P values of 0.000, a Chi Square value of 48 and an H statistic of 120when the critical value is 7.815 and a wide range of Z scores, we were confident in rejecting the null hypothesis for software vendor 2.

Vendor 3 Mood Median Test: Package Discount Percent versus Source

```
Chi-Square = 70.53   DF = 2   P = 0.000
                                          Individual 95.0% CIs
Source     N<=     N>   Median     Q3-Q1  +---------+---------+---------+------
Data 1      35     96   0.0190    0.0265                 +-----)
Data 2     202    112   0.0000    0.0250  +
Data 3      10     38   0.0292    0.0390                   (------+---------)
                                          +---------+---------+---------+------
                                      0.000     0.012     0.024     0.036
Overall median = 0.0116
```

Vendor 3 Kruskal-Wallis Test: Package Discount Percent v. Source

```
Source       N     Median    Ave Rank         Z
Data 1     131   1.90E-02       301.8      5.14
Data 2     314   0.00E+00       210.6     -7.50
Data 3      48   2.92E-02       335.2      4.51
Overall    493                  247.0

H = 58.24  DF = 2  P = 0.000
H = 62.03  DF = 2  P = 0.000 (adjusted for ties)
```

As with the previous two vendors, we again rejected the null hypothesis, because of P values of 0.000, high Chi Square and H statistic values and variance of Z scores.

Thus, found that the distribution of package savings is not dependent upon the software package used to collect bids, but rather is determined by the characteristics of the underlying network of shipments.

Conclusions

Within Chapter 4 we analyzed 9880 package and discrete bids submitted by 178 truckload carriers in 13 unique auctions. More than anything, the impact of these "other factors" seem to underscore the idea that truckload carrier pricing and discount strategies are influenced by a wide variety of factors that seem to differ for each carrier and each auction.

From the above statistical tests, we learned that the package discounts in each lane are neither normally distributed nor the same between auctions. This tells us that, as suggested by Jara-Diza and Basso (2002), each auction is unique, based on the underlying shipper's network.

We also found that, because several auctions from the same software vendor follow different distributions, the distributions of package discounts are not dependent on the software used to collect the bids.

Finally, we learned that most packages do not win because relatively smaller, privately held, profit-threshold-seeking carriers drive the price of a single lane low enough that a relatively larger, profit-maximizing carrier cannot meet its required return.