Combinatorial Auctions in the Procurement of Transportation Services

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Abstract
Most shippers go through an annual auction process of procuring transportation services, leading to an annual contract. This paper argues that the use of combinatorial auctions in this procurement can unlock significant reductions in operating costs for shippers, while protecting carriers from “winning” the lanes that do not fit their network, thus improving carriers’ operations as well.

Combinatorial auctions account for carriers’ economies of scope, which, by many accounts, are more important than economies of scale in transportation operations. Any transportation procurement procedure, however, has also to account for level of service and other non-price variables. Such factors are just as important as price in determining which carrier should serve what lane. These considerations can be incorporated into the combinatorial auction framework easily and holistically.

The paper introduces the approach and its potential for creating win/win situations for carriers and shipper. After several years of using this approach it has become the preferred procurement mechanism for leading shippers, with several software providers offering the requisite software.
1. Introduction
Freight transportation provides the physical connection between shippers and, in many cases, the final consumer. (This paper refers to “shippers” as the beneficial owners of the freight - manufacturers, distributors, retailers, etc. - while the term “carriers” designates transportation companies - truck-lines, railroads, airlines, ocean transport providers, etc.) Freight transportation expenditures in 2001 in the US have been estimated at $713 Billion (Standard and Poor, 2001), or about 8% of the US GDP.

The focus of this paper is on trucking, which represents over 83% of the freight transportation expenditure in the US (Eno Foundation, 2001), and in particular on the truckload (“TL”) segment of this industry, which accounts for over half of it. In TL operations, the truck is generally dedicated to a single shipment moving between an origin and a destination, in contrast with less-than-truckload (“LTL”) and parcel carriers, which consolidate many smaller shipments on a single truck.

Thus, a cost reduction in TL, the largest segment of trucking, which in itself is the largest component of transportation expenditure, can have a large impact on total cost, and therefore the profitability of shippers’ operations.

To realize the potential profits locked in transportation, managers have to understand how to buy transportation services. This paper demonstrates how several leading shippers have taken advantage of combinatorial auctions to achieve transportation costs savings of 3% to 15%, while maintaining or increasing their service levels. (Usually service level is measured in terms of on-time performance’ equipment availability, extent of damage to the goods hauled, etc.) Just as important, the optimization framework inherent in determining the winners in these combinatorial auctions allowed these shippers to meet many other business requirements and corporate goals beyond minimizing transportation costs.

The author has participated in over 100 transportation auctions as the principal in a third party logistics provider, LogiCorp (between 1988 and 1997) and in software and procurement services providers – PTCG Inc. (in 1996) and Logistics.com Inc (between 2000 and 2002).1 Almost half of these were combinatorial auctions. Many of the observations in this paper are based on the author’s personal experience.2

2. Buying Transportation Services
Transportation services are bought by large firms through a Request for Proposals (RFP) process, leading to contract prices that are typically in effect for a period of one to two years.

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1 LogiCorp Inc. was acquired by Ryder Inc. in 1994; PTCG Inc. was acquired in 1996 by Sabre Decision Technologies, which was own by AMR Inc. (the parent company of American Airlines) at the time; and Logistics.com Inc. was acquired by Manhattan Associates Inc. in 2002.

2 Note, however, that the author has neither financial nor any other commercial interest in any of the companies mentioned in this paper.
The RFP process for transportation services shares many characteristics with the procurement of general goods and services. Some aspects of the transportation procurement process, however, are somewhat different. The most important of these aspects is that transportation costs are influenced to a greater extent by economies of scope than by economies of scale, as explained in the Section 3. In addition, transportation service includes many attributes beside price, and the framework discussed here allows for these attributes to be properly accounted for, as shown in Section 6.

These points are explained below in the context of shippers buying TL motor carrier services. This mode of transportation exhibits strong economies of scope and therefore most of the combinatorial auctions used for transportation procurement were applied to the TL segment of the industry. The same principles, however, are applicable and have been used by leading shippers in the procurement of other transportation services such as LTL trucking, ocean, rail, and air.

Foster and Strasser (1991) describe the traditional RFP process that was employed by most large shippers until the late 1990s and is still used by many shippers today. It typically begins with an estimate of the freight that will need to be shipped in the coming year. More often than not, this estimate is simply a compilation of the prior year’s movements. This information is transmitted to the carriers as a list of “lanes” on which the carriers are asked to bid. A lane is a one way movement from an origin to a destination with the associated set of shipments for the period covered by the RFP (see, for example, Jara Diaz, 1988). Carriers quote the prices they are willing to haul the loads for and transmit their bids back to the shipper. The shipper evaluates the bids on a lane-by-lane basis, using a single criterion - usually price - to select the winner. Thus, while this process is a simultaneous multiple unit auction (see, for example, Krishna, 2002), most shippers look at it as a set of individual auctions, one for each lane, ignoring lane interdependencies.

3. Economies of Scope

Shippers have to move freight between given origins and given destinations and thus evaluating each lane independently makes sense for them. Carriers’ economics, however, are not based on one-way movements since they have to maximize equipment utilization, as well as balance their equipment and driver needs. Thus, a carrier’s cost to serve a single lane is not independent of the other traffic moving throughout the carrier’s network.

To illustrate this point, assume that a carrier is transporting ten loads per week for a shipper from Atlanta to St. Louis. Suppose the shipper now approaches the carrier and wants it to haul ten more loads from Atlanta to St. Louis. Since it is doubling the carrier’s volume, the shipper expects a price concession. Many shippers are surprised when carriers sometimes decline to reduce their rates and in many cases require a higher price for the additional loads. This occurs because more business from Atlanta to St. Louis may only exacerbate an existing equipment balancing problem for the carrier. If, on the other hand, the shipper was to offer ten additional loads going in the opposite direction, from St. Louis to Atlanta, the new business may help the carrier balance the equipment and the drivers and may lead to a rate reduction.
This is an example of economies of scope; the cost of operations on one lane depends not only on the number of loads being transported on that lane (this would amount to economies of scale), but also on the number of loads carried on other, related lanes. The example given above - a back-and-forth movement - is simple. One can also imagine complicated multi-lane movements that help balance the transportation network. If the shipper in this example was to offer, say, ten loads from St. Louis to Dallas and ten loads from Dallas to Atlanta, the resulting “closed loop” would allow the carrier to increase utilization and achieve higher efficiency.

Carriers need balanced network for two reason. The first is that follow-on loads allow for better equipment utilization. The second is that balanced networks allow both for regular equipment maintenance at some fixed locations and for getting drivers back home frequently and predictably. “Getting home” is the most crucial factor of driver satisfaction in the TL industry, where many US companies report a driver turnover rate of over 100% per year. Costello (2003), reporting this turnover rate by trucking company type, also mentions that it costs a trucking company $9,000 on the average each time it has to find or replace a driver, representing significant costs to the carriers who must continuously recruit and train new drivers.

Since shippers evaluate each lane independently (comparing all competing bids for each lane and choosing a winning carrier), it is difficult for carriers to ensure that they win a set of balanced lanes. To illustrate the problem, consider the simple network shown in Figure 1. It includes shipments between Columbus, Ohio (“CMH”), Charlotte, North Carolina (“CLT”), and Nashville, Tennessee (“SHV”). Assume that each lane represents the same number of loads per week. Consider also two carriers, QUIK and FAST who are bidding on the business, as shown in Table 1.

Given the quotes shown in the table, QUIK will win lanes SHV→CMH, CLT→SHV and CLT→CMH, while FAST will win the lane CMH→CLT. As this example shows, there is nothing in the lane-by-lane process that will avoid this result in which neither carrier wins a balanced set of lanes. In other words, neither the three-lane loop: SHV→CMH→CLT→SHV, nor the two-lane loop: CMH→CLT→CMH will be awarded to one of the carriers.

### Table 1. Lane Bids

<table>
<thead>
<tr>
<th>Lane</th>
<th>QUIK</th>
<th>FAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHV→CMH</td>
<td>500</td>
<td>525</td>
</tr>
<tr>
<td>CMH→CLT</td>
<td>525</td>
<td>500</td>
</tr>
<tr>
<td>CLT→SHV</td>
<td>500</td>
<td>525</td>
</tr>
<tr>
<td>CLT→CMH</td>
<td>475</td>
<td>500</td>
</tr>
</tbody>
</table>
4. Combinatorial Auctions

Several large shippers and third-party-logistics (3PL) providers have turned to combinatorial auction mechanisms as a way to reduce their transportation costs during the procurement process. The idea is to entice carriers to bid more aggressively by ensuring that carriers can bid in a way that reduces their own costs -- offering service on lanes that will balance their networks. The practice is also known as “combinatorial bidding,” “combinatorial procurement,” and “conditional bidding.” These terms are used interchangeably in this paper.

In combinatorial auctions the shipper asks the bidding carriers to quote prices on groups or “packages” of lanes, in addition to individual lanes. The carriers are allowed to form their own packages based on their own specific economics, existing client base, driver domiciles, and underlying maintenance network. The idea is that carriers may form packages that, if granted, will allow them to operate at a lower cost on the group of lanes included in the package (such as closed loops and continuous moves). The lower costs will then be passed to the shipper in the form of lower bid prices. Carriers can also submit bids for individual lanes and partial packages so they can be protected against the shipper’s insistence on a low package price while awarding only a single lane or only a part of a package.

To understand the difference between a standard auction based on a set of individual bids and a combinatorial auction, consider the small example shown in Figure 1. In a standard auction, a carrier responding to an RFP for the lanes in this network would submit at most four bids -- one for each of the lanes, as shown in Table 1. In a combinatorial bid, a carrier may submit many more “packages.” For example, Figure 2 depicts nine bid packages that can be submitted for this network: the four individual lane bids (packages #1, #2, #3 and #4), three continuous move packages including two lanes each (#5, #6 and #7), and two closed loop tours: one including two lanes (#8) and the other three lanes (#9). Other combinations of lanes are also possible. And many more packages could be generated when the carriers can also specify the volume desired on each lane. In many practical cases, the carrier might, for example, specify one package bid with 100% of the lane volumes and another package bid with the same lanes, but at, say, 50% of the lane volume with a correspondingly different price. Different packages can also be associated with different level of service commitments. In this paper the focus is only on the use of lane combinations in order to simplify the presentation.
When bidding on packages, each carrier may end up submitting multiple quotes for the same lane, since each lane can be a part of many different packages. The result is that the shipper may receive many more bids than the number of lanes, with overlapping lane quotes, making the evaluation of these quotes significantly more difficult than the evaluation of individual lane quotes. The combinatorial nature of the number of bids is what gives the method of procurement its name.

De Vries and Vohra (2002) survey combinatorial auctions. They review applications of combinatorial auctions in several fields and focus on the winner determination problem – in other words on solving the auctioneer’s problem of determining the winning bidders using optimization formulations. In the context of transportation procurement this is the shipper’s problem once the bids are in -- it has to determine which carrier will haul the freight on each lane.

Caplice and Sheffi (2003) discuss several references to combinatorial auctions in the freight transportation context. Elmaghraby and Keskinocak (2002) also describe the use of a combinatorial auction to secure transportation services by Home Depot Inc. (using software from i2 Inc.) and by Wal-Mart Stores, Compaq Computer Co, Staples Inc., the Limited, and several other companies (using software from Logistics.com Inc.). De Vries and Vohra (2002) also mention the use of combinatorial auctions by Logistics.com Inc. in the context of that vendor’s work with K-mart and Ford Motor Company. They also mention Saitech Inc. as a company which has capabilities in this area. In addition, Manugistics Inc. offers combinatorial auction software for the procurement of transportation services, and Schneider Logistics, one of the leading 3PL companies, offers combinatorial procurement as part of its services. Moore et al (1991) describe an early application (during the early 1980s) of combinatorial auctions at Reynolds Metal Company and Porter et al (2002) describe a 1992 application of combinatorial auctions (which they referred to as combined value auction) by Sears Logistics Services. They report savings of 6% to 20%. 

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**Fig. 2 A Network Example with Nine Bid Packages**

<table>
<thead>
<tr>
<th>The Network:</th>
<th>Some Possible Packages:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMH</td>
<td>#1 CMH</td>
</tr>
<tr>
<td>SHV</td>
<td>#2 CMH</td>
</tr>
<tr>
<td>CLT</td>
<td>#3 SHV</td>
</tr>
<tr>
<td>CMH</td>
<td>#4 CLT</td>
</tr>
<tr>
<td>SHV</td>
<td>#5 CMH</td>
</tr>
<tr>
<td>CLT</td>
<td>#6 CMH</td>
</tr>
<tr>
<td>CMH</td>
<td>#7 SHV</td>
</tr>
<tr>
<td>CLT</td>
<td>#8 CMH</td>
</tr>
<tr>
<td>CMH</td>
<td>#9 SHV</td>
</tr>
<tr>
<td>CLT</td>
<td></td>
</tr>
</tbody>
</table>
5. Determining the Lane Allocation through Formal Optimization

To determine the winning bid for each lane, the shipper has to solve an optimization problem. The objective of this optimization is to minimize the total transportation expenditure, subject to the constraints that each lane is to be served by one carrier. Fortunately, this is a standard problem in operations research, known as the “set-covering problem.” Several mathematical programming formulations are suggested by De Vries and Vohra (2002), who also discuss solution methods. A formulation in the transportation context is given by Caplice (1996) and Caplice and Sheffi (2003), with a discussion of solution methods.

To get a general notion of how this optimization problem can be tackled, assume that each of the two carriers in the example submits a bid that includes the nine packages shown in Figure 2. These bids are depicted in Table 2. In this matrix each row represents a lane (identified in the first column on the left) and each column represents a bid package from a given carrier (identified in the top two rows). A “1” in a column indicates that the corresponding lane is part of the package represented by that column. The bottom cell in each column is the price that the corresponding carrier bids on that package of lanes.

Table 2. Package Bids

<table>
<thead>
<tr>
<th></th>
<th>Carrier “QUIK”</th>
<th>Carrier “FAST”</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 SHV→CMH</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>#2 CMH→CLT</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>#3 CLT→SHV</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>#4 CLT→CMH</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>#5 Bid</td>
<td>$500</td>
<td>$525</td>
</tr>
<tr>
<td>#6 $500</td>
<td>$525</td>
<td>$475</td>
</tr>
<tr>
<td>#7 $475</td>
<td>$975</td>
<td>$900</td>
</tr>
<tr>
<td>#8 $975</td>
<td>$1225</td>
<td>$525</td>
</tr>
<tr>
<td>#9 $900</td>
<td>$1325</td>
<td>$925</td>
</tr>
</tbody>
</table>

With this formulation, the optimization problem reduces to choosing a combination of columns from this matrix, such that the sum of the bid prices of the chosen columns (the bottom cells) is a minimum. This minimization is subject to the constraint that the sum of each row, counting only the chosen columns, equals “1.” In other words, the problem is to minimize the total transportation expenditure, while assuring that each lane is served by one carrier. In this particular example, the optimal solution is to use Carrier “QUIK” exclusively, combining its bid package # 9 (SHV→CMH→CLT→SHV), with its package #4, which is a simple bid on lane CLT→CMH, for a total of $1325 + $475 = $1800.

The problem shown in Table 2 can be solved using a spreadsheet. Real size problems, which may include thousands of lanes, dozens or even hundreds of carriers and millions of combination bids, are more challenging and require special code. While the theory is not new, the solution algorithms involve decomposition and require iterative procedures to solve. In fact, solving arbitrary cases of such problems is not trivial. The four largest
auctions software and services providers in the marketplace - i2 Inc., Manugistics Inc., Manhattan Associates Inc. and Schneider National Inc. - all seem to be using very similar decomposition methods. They typically imbed significant domain knowledge in the problem formulation and in the rules designed to “price out” various solutions, so they can solve efficiently the actual winner determination problems encountered in practice.

6. Accounting for Level of Service

In practice, the winning carrier for every lane is typically not determined solely on the transportation price. Shippers take into account both lane service attributes and system constraints. This section explains what lane service attributes are and how they can be incorporated in the winner-determination optimization problem, while the next section looks at system constraints.

Lane attributes include characteristics of the transportation service beyond price and can be associated with each lane independent of other lanes. Typical lane attributes important to shippers include:

- on-time performance (both transportation time and response time),
- familiarity with the shipper’s operations,
- correct equipment availability,
- accessorioal services and charges (these are added fees that carriers append to their rates to cover non-transportation activities, such as collecting payment, delivery beyond the dock, mid-route stop-offs, etc.),
- pick-up performance (i.e., the percentage of loads accepted by the carriers),
- ease of doing business - including billing accuracy, electronic data interchange (EDI) capability, tracking and visibility systems availability.

Many of these characteristics are carrier-specific and therefore can be simply accounted for on every bid that a carrier is quoting. More commonly, however, these characteristics vary among the lanes that each carrier serves due to regional differences in the carrier’s network.

To account for lane attributes, and in particular level of service, the traditional approach among shippers is to decide a-priori how many carriers should be allowed to participate in the auction, creating a “core carrier” group. The criteria for becoming a core carrier are based on meeting some threshold of lane attributes. The auction is then conducted only among the core carriers (see, for example, Gibson et al, 1995).
For example, in 1994, MicroAge Computer Centers, Inc. invited 300 carriers to bid on its business, giving them 18 key attributes to quote on (Thomas, 1994). MicroAge then focused on 47 respondents, normalizing their responses by assigning each attribute in the response a score of 1 to 10 (for example, they used “10” for on-time performance above 97% and “0” for performance below 89%). Each service attribute also got a relative weight, as shown in Table 3. These weights were then normalized and each carrier was assigned a score based on the normalized, weighted sum of the attributes. The top eight carriers were then considered “core” and invited to participate in the actual bidding process, where price was the major determinant.

This example is typical of the process used by many shippers (see, for example, Bradley, 1998). The drawback of this process is that it does not allow for continuous trade-offs between price and level of service. Carriers whose service is above some cutoff level are invited to participate in the bidding process while others are not. For example, a carrier may not be invited to participate because its billing process is not very accurate. Such inaccuracies increase the shipper’s costs in terms of freight bill audit and payment processing. But if that carrier’s transportation rates were low enough, they might compensate for the increased audit expense. If, however, the carrier is not invited to participate in the bidding process, this trade-off will never be made, to the detriment of the shipper.

One formal way of using the optimization framework mentioned above, while accounting for non-price considerations, is to let all carriers bid on the shipper’s business. In order to manage the large amount of data in a consistent fashion, the level of service and other lane attributes can be used to modify the actual bidding price of each carrier and the optimization program is then solved with the modified prices. This is the process that has been used practice in conjunction with combinatorial auctions.

To see how this works, assume for example that the shipper is facing bids from two carriers on a given lane: $500 from carrier I, and $475 from carrier II. Furthermore, assume that the only relevant non-price attribute is ‘on time’ performance and Carrier I provides 98% service while carrier II is only 95% on time.

<table>
<thead>
<tr>
<th>Table 3. Example of Attributes and Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attribute</strong></td>
</tr>
<tr>
<td>On time Percentage</td>
</tr>
<tr>
<td>Equipment availability</td>
</tr>
<tr>
<td>Direct service points</td>
</tr>
<tr>
<td>Full state coverage</td>
</tr>
<tr>
<td>Discount percentage</td>
</tr>
<tr>
<td>FAK class rate</td>
</tr>
<tr>
<td>Claims ratio</td>
</tr>
<tr>
<td>Claims payment</td>
</tr>
<tr>
<td>Cargo insurance</td>
</tr>
</tbody>
</table>
Prior to the auction, the shipper goes through a formal process (typically facilitated by the software provider) to determine how much each percent of on-time performance on each lane is “worth.” Assume, for example, that it determined that each 1% of on-time performance on the lane under consideration is “worth” $10. Using a single level of service as a benchmark, the bid prices are modified. In this example, assume that the benchmark service level is 95% and thus the bid of Carrier II should not be modified. The price of Carrier I is modified to be: $500 - $30 = $470. The winner determination optimization will then compare the modified price of $470 to the $475 submitted by Carrier II, and Carrier I will be chosen. The situation is summarized in Table 4.\textsuperscript{4} Note that the shipper will still pay carrier I $500 to carry loads on that lane; the carrier with the lowest actual rate will not be chosen in this example due to service considerations.

The challenge in this situation is to specify explicitly the monetary value of service attributes. This process is conducted prior to running the auction, using standard utility theory tools, but it is not a trivial process since it forces an organization to agree on its value system, which may be neither uniform across an organization nor static over time. Indeed, in many cases, shippers have commented that the most significant value that they got out of the entire auction process is the formal determination of the price/service trade-off, which has forced group consensus on the value of non-price attributes.

Naturally, such a one-step process (inviting all the carriers to participate in the bid and choosing based on the modified bid price) can be implemented whether or not a combinatorial auction is used. When using a combinatorial auction with a formal optimization to determine the winners, however, it becomes more naturally part of the entire approach. It also typically involve a third party (a software provider or third party auction manager) who can effectively run a sometimes contentious intra-company process.

### Table 4. Price/Service Trade-off

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Raw Bid</th>
<th>Service</th>
<th>Service modification</th>
<th>Modified Bid</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$500</td>
<td>98%</td>
<td>-$30</td>
<td>$470</td>
</tr>
<tr>
<td>II</td>
<td>$475</td>
<td>95%</td>
<td>0</td>
<td>$475</td>
</tr>
</tbody>
</table>

7. **System Constraints**

In addition to lane attributes, many RFP processes involve constraints representing business rules that are placed on a group of lanes. These may include, for example, requirements on all lanes in and out of a facility or a region (for example, having at least three carriers and at most five serving a given plant); having a minimum or maximum volume of business for a carrier (for example, ensure that a given carrier wins at least a given amount of business); carrier-initiated constraints (for example, a carrier may indicate that while it is bidding on a large volume of business, it cannot carry more than a given capacity); or system-wide constraints (for example, ensuring that a certain percentage of the expenditure goes to minority-owned carriers). To determine the winners consistently in the presence of such constraints, the winner determination problem requires an optimization formulation whether or not one uses combinatorial bidding.

\textsuperscript{4} When the level-of-service adjusting mechanisms are linear, as they are in practice, it does not matter which level of service is used as a benchmark.
When using combinatorial bidding, however, one can simply add additional constraints to the winner determination problem in order to handle these system-level requirements.

To see the effect of a system constraint, assume that in the example depicted in Table 2, the shipper had a constraint specifying that there should be at least two carriers serving the network. In other words, for reasons of risk mitigation, flexibility, future capacity needs, or whatever, the shipper wants to ensure that it is not in a situation in which it is dependent on a single carrier. Such a constraint can be easily included in the optimization program by making sure that there is at least one column chosen from the first group of nine lane packages (see table 2) and at least one from the second. The results of such an optimization are depicted in Figure 3 (where the solid lines represent carrier QUIK and the dashed lines represent carrier FAST). In other words, the shipper will choose package #8 (lanes CMH→CLT and CLT→CMH) from QUIK and package #7 (lanes SHV→CMH and CLT→SHV) from FAST for a total of $900 + $925 = $1825. The difference between the original solution value ($1,800) and the new solution value ($1,825) is the price that the shipper will have to pay for imposing the requirement that no one carrier will serve the entire network. This provides a threshold value for the shipper to cross in order to justify imposing the business rule represented by that constraint.

8. Example - Core Carrier Program

To demonstrate the advantages of optimization-based bidding in a specific context, consider the traditional practice, mentioned above, of using a “core carrier” group in the bid process – it involves an *a priori* determination of the size of the core group, whose members are the only ones to participate in the formal auction. One of the main issues with the core carrier approach is the size of the group: how many carriers should be included? Most shippers do not make this decision based on any analytical trade-off but rather fix the number arbitrarily before the auction. To see how this number can be determined, or at least analyzed, with optimization-based bidding, assume that a shipper has orchestrated an RFP process with many carriers. Instead of running the winner determination optimization only once - to allocate the lane awards, it can be run multiple times - each time with a constraint that there will be only a certain number of overall winners.

Figure 4 depicts a graph of annual transportation expenditure as a function of the number of carriers that the shipper contemplates doing business with. The data was taken from a large “Tier 1” automotive supplier who conducted a transportation services auction in 1998. The expenditure includes the total payments to carriers for hauling the freight over a period of one year. Each point on the graph represents one run of the winner
determination problem. The corresponding value on the horizontal axis is the constraint on the maximum number of carriers in that computer run and the vertical axis represents the resulting annual expenditure.

Several observations are evident from the figure: (i) the annual transportation expenditure falls as more carriers participate in the shipper’s business, (ii) there is a minimum number of carriers needed to haul the freight (in this example it is 12), (iii) beyond a certain number of winning carriers (25 in this example), the annual expenditure is not affected by constraining the number of carriers.

The results are typical of any constrained optimization problem: at the point where the constraints are too strict there is no feasible solution; as constraints are relaxed the solution improves; and after enough constraints have been relaxed, further relaxations are irrelevant.

Naturally, the transportation expenditure does not include all the relevant shipper’s costs. The shipper has certain costs associated with dealing with each incremental carrier. Examples include:

- setting all the communications links between the shipper’s and the carrier’s systems,
- familiarizing the carrier’s drivers with the shipper’s business and its facilities, and
- charting the carrier’s performance and conducting quarterly performance reviews.

Thus, the conclusion of this analysis should not be that shippers should always use a large number of carriers. Instead, the analysis should be used to determine the consequences, in terms of annual expenditure, of restricting the number of carriers. If the annual administrative costs of dealing with an incremental carrier are known, the optimal number of carriers in the core group can be determined; it is the point in Figure 5 where
this administrative cost equals the reduction in the annual freight bill from using one more carrier.

For example, if the cost of dealing with an additional carrier is in the range of $1 million per year, the shipper depicted in Figure 4 should use 15 – 20 carriers. If the cost is higher it should use a smaller number of carriers and vice versa. Interestingly, most shippers claim that the costs of using an additional carrier are much smaller.

9. Process Administration

The procurement of transportation services is inherently complex. Since shippers want to concentrate their buying power, utilize economies of scope, and impose system constraints, all lanes are bid out simultaneously. Thus even medium-size bids involve thousands of different, non-independent items.

Furthermore, the opportunity to take advantage of economies of scope suggests that shippers not only aggregate their transportation needs across all their divisions and plants, but aggregate even across enterprises. Some shippers invite non-competing enterprises to participate in a single RFP process. In many cases it makes sense to have both suppliers and customers working together since their freight lanes are likely to be complementary, thus creating stronger economies of scope. Interestingly, the process of several companies bidding together is also encouraged by the carriers; it gives them an opportunity to consider a larger volume of freight simultaneously, increasing the number of opportunities for forming packages and for matching their current network. In addition, it tends to reduce the problems accruing when a carrier makes a commitment to one shipper only to find a short time later that the freight put out for bid by another shipper provides better opportunities for network-building.

In addition to involving a large number of overlapping items being auctioned off simultaneously, transportation procurement processes may involve hundreds of vendors, each with its own characteristics, service levels, equipment availability, communications capabilities, etc. And many of these characteristics vary with the lanes served even by the same carrier.

The main consequence of this administrative complexity, and the inclusion of systems constraints in the bidding process, is that shippers are not inclined to perform multiple-round bidding processes. In fact, most shippers go through a single round, sealed-bid auction process. Thus, the need for combinatorial bidding is even more pronounced in an environment where carriers cannot hope to build their network through successive bidding rounds. (Multiple rounds can be used by some bidders to signal to other bidders which lanes they are interested in, thus helping them win the ones they really desire. Using such successive bidding rounds carriers may converge on a desired network. A flagrant use of such approach has been observed in several spectrum auctions, as documented by Klemperer, 2002).
10. **Bottom Line Results**

Over the last several years, the use of combinatorial procurement has become standard practice among large shippers. Software for conducting combinatorial auctions for transportation services is available from several providers, as mentioned in section 4 above. From 1999 to 2002, the author was involved with and had unrestricted access to dozens of such auctions, involving billions of dollars in freight expenditures. The savings vary widely by company since some shippers were focused on cost savings while others were focused on non-monetary objectives.

Nevertheless, the final savings in such auctions are typically in the range of 3% to 15%. It is difficult to ascertain what fraction of the savings would have been achieved with any auction mechanism and how much of the savings are due to the use of combinatorial auctions. Clearly, most well-run auctions are likely to generate savings. Combinatorial auctions, however, are typically conducted by large, sophisticated shippers that are likely to have low transportation rates even before the auction. For such shippers the combinatorial aspect may have generated significant additional savings.

It is important to note that almost all of these shippers did not use the straight-forward cost minimizing solution in practice. Instead, they have tested and implemented many system constraints. This meant that they ended up with carrier assignments that cost more than the cost-minimizing solution. In practice, carriers usually “gave up” about half the potential savings in order to comply with the systems constraints.

Interestingly, the number of lanes which carriers have put together in lane packages is not very large. Less than 10% of the total number of lanes in typical combinatorial auctions are parts of packages (with wide variation, however). This may be the result of many lanes not offering any bundling opportunities, or carriers not trusting the shippers to follow through during operations. Anecdotal evidence suggests that carrier sophistication is not a hurdle as leading carriers understand and embrace the process. It allows them not only to put together packages based on a specific shipper’s offerings, but to combine the newly offered business with their existing business to create favorable network-wide traffic patterns.

As important as these savings are, many shippers have been using combinatorial bids not only to achieve lower transportation costs, but also to select carriers who promise, and have a track record of better level of service, in addition to meeting the corporate goals imbedded in the system constraints.

11. **Summary and Conclusions**

Recognizing that transportation procurement is different from general procurement, most companies empower their transportation professionals to conduct specialized RFP and negotiation processes, rather than their procurement professionals. Combinatorial bidding allows both shippers and carriers to exploit the economies of scope inherent in TL operations. The use of optimization in the winner determination process has an added benefit of dealing effectively with non-price attributes and system constraints.
Leading companies, including Procter and Gamble, Wal-Mart, Sears, Colgate-Palmolive, Nestle, Lucent Technologies, Compaq Computers, Quaker Oats, International Paper, Ford Motor Company, Home Depot, and dozens of others, have used the approach outlined in this paper to achieve lower transportation rates and higher transportation level of service. Some shippers have gone further and joined up with others in conducting combined RFP processes in order to accentuate the benefits of combinatorial procurement.

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