# OPTIMIZATION-BASED PROCUREMENT FOR TRANSPORTATION SERVICES

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Common carriage comprises over one-third of the $600 Billion annual trucking market in the United States (see American Trucking Association 2002). Since the deregulation of interstate trucking in 1980 and the intrastate movements in 1994, the predominate form of commercial relationship between shippers and common carriers has changed from a transactional to a contractual basis. These contracts typically hold for one to two years and sometimes longer. Shippers select which carriers to do business with on each lane (origin-destination pair) utilizing a competitive request-for-proposal (RFP) process, which is, in fact, an auction.

This paper takes a look at this RFP procurement process for transportation services. While bidding processes have been used to procure many products and services, transportation presents added complexities in terms of strong interdependencies (later referred to as economies of scope), large numbers of unique items, and inaccurate information. Truckload, ocean, air-cargo and most other transportation modes share these complex characteristics – especially interdependent costs. For the sake of brevity, this paper focuses on truckload (TL) transportation but the model can be, and has been, applied to other modes as well.

The primary research question addressed in the extended research is: How should shippers procure TL motor carrier transportation services? This paper presents one approach that is both grounded in theory and appears to have worked well in practice.

The generic transportation procurement process can be divided into three steps:

- **Bid Preparation** – where the shipper determines what is to be bid out, what carriers to invite, how to present or package the business to be bid, and what opportunities exist for different types of shipper-carrier relationships.[1]

- **Bid Execution** – where the shipper communicates the bid information to the carrier(s) and the carriers respond back with quotes. This exchange can differ in terms of bid visibility, number of rounds, and other more standard auction rules.
- **Bid Analysis and Assignment** – where the shipper analyzes the carriers' responses, considers the business needs, and assigns the business to specific carriers.

The majority of prior research has focused on the Bid Preparation step by applying generic purchasing strategies to transportation applications, such as reducing the number of carriers and applying certification programs. See, for example, Abshire and Premeaux (1991), Bardi, Bagchi, and Raghunathan (1989), Crum and Allen (1990), Foster and Strasser (1991), Gentry (1991), Gibson, Mundy, and Sink (1995), Gibson, Sink, and Mundy (1993), and Rinehart (1989). Even when procurement strategies have considered specific qualities of transportation, such as transit time or delivery reliability, the decisions have been applied on the macro-level. That is, the procurement strategy assesses whether a carrier, as a whole, should or should not be used by the shipper. While beneficial in many respects, these initiatives treat all of the individual products and services provided by a given carrier/supplier alike and, therefore, ignore the unique characteristics of transportation. In other words, level of service, for the most part, is used in the bid preparation stage to decide who is qualified rather than in the bid analysis stage to look at individual lanes and explicitly trade-off cost vs. service.

More recently, there has been increased interest in both practice and academia on the Bid Execution step of the procurement process. The Internet has dramatically reduced the cost of connectivity between business partners. This has allowed shippers and carriers to more easily communicate by posting information and quotes directly onto a website. One result of this has been an increase in the frequency of bidding events. Commercial services are now widely available that enable the bid execution stage of the process through providing an auction-like, real-time, open bidding forum. The most successful example is *www.freemarkets.com*, which has been used for procuring transportation services. As argued by Lucking-Reiley (1999), the benefits of using the Internet versus traditional methods in the Bid Execution step include increased convenience for both "auctioneer" and bidders, asynchronous bidding, access to greater numbers of bidders, and lower participation and transaction costs for both.

The focus of this paper is the Bid Analysis step of the procurement process. The TL procurement problem is approached from a different, more operational perspective, to determine not just the best set of carriers to use, but also the optimal *assignment* of carriers to lanes within the network through the use of optimization techniques. By examining the specific economics of the carriers (rather than just assuming economies of scale, as do most generic policies), this research identifies opportunities to reduce the carriers' costs, which, in turn, can potentially lower the shipper's costs. Recognizing that TL carriers are influenced more by economies of scope than by economies of scale, it is shown how a shipper can *positively* influence a TL carrier's cost structure – other than by simply allocating greater volume (which in many cases can increase the carrier's costs). Essentially, the research examines the use of optimization-based procurement techniques to shape the way in which shippers and carriers interact in order to remove costs from the transportation process.

Several researchers have recently looked at a more comprehensive approach to procurement and auctions in general. Klemperer (1999) presents a comprehensive review of current approaches in auction theory and design. There is also a burgeoning field of research in combinatorial auctions that require the use of optimization techniques. De Vries and Vohra (2002) present a comprehensive survey of both techniques and applications of combinatorial auctions. They report on the use of optimization-based auctions in the FCC spectrum rights as well as numerous other fields. There are several companies that specialize in offering combinatorial auctions for use in non-transportation settings – these include *www.emportis.com* and *www.combinenet.com*.

There has also been increased interest in applying advanced procurement approaches specifically to the transportation field. Moore, Warmke, and Gorban (1991) describe the formulation of an optimization-based bidding approach for Reynolds Metals. Unfortunately, the model was not fully implemented in practice due to limited computer capabilities available at the time. Ledyard et al. (2000) describe their use of a "combined value" auction for securing transportation services for Sears Logistics Services in the early 1990s. They applied a limited optimization-based approach and claimed to have reduced total spending of the procured services by 13% or $165 million. Elmaghraby and Keskinocak (2002) discuss how Home Depot utilized i2 Inc.'s combinatorial bidding system (TBC or Transportation Bid Collaboration) for securing transportation services, but do not disclose dollar figures saved. Additionally, they point out that several other companies (to include Wal-Mart Stores, Compaq Computer Co., Staples Inc., the Limited Inc., and others) used Logistics.com Inc.'s optimization-based procurement tool (OptiBid) to procure transportation services and cite The Limited alone as saving over $1.24 million. Strategic transportation procurement tools, whether sophisticated or quite simple, have become a part of most all supply chain solution suites. For example, Manugistics Group, Inc. acquired Digital Freight Exchange in May 2002 in order to add an online bidding tool to its SRM suite. Invensys Software Systems' subsidiary, CAPS Logistics, is on its third release of its transportation procurement tool called BidPro. Schneider Logistics introduced their Combined Value Auction (CVA) module in June 2002. The authors themselves have been involved both in developing the theory of combinatorial procurement in the transportation sector (see Caplice 1996) and in applying optimization-based techniques to more than 50 companies for the procurement of truckload, less-than-truckload, ocean, rail, inter-modal, and air transportation services. These procurement efforts involved more than $8 billion in transportation services and have documented combined savings to the shippers in excess of $500 million.

Rather than describe the specifics of a particular software product or the technical details of the optimization models used, however, this paper focuses on two topics: (1) the theoretical underpinning of the approach – explaining why optimization-based procurement makes sense and is gaining traction, and (2) the business applications and implications of using optimization-based procurement for transportation. The first part is based on academic research, while the second is based on the application of these techniques in practice over the last several years.

The remainder of the paper is organized as follows. First, because the major theme of the research is that the underlying economics of the supplier should guide the procurement strategy used by the buyer, the paper briefly reviews transportation carrier economics – particularly the concept of economies of scope. Second, the paper examines how and why carriers use hedging in order to cope with the uncertainty inherent in a competitive bid. The bidding method used by shippers is shown to determine the extent to which carriers will hedge their bids due to various forms of uncertainty. Third, the paper presents the details of the Bid Analysis step of the procurement process to include the use of combinatorial optimization models to solve the resulting assignment problem and to incorporate level of service explicitly in the analysis. Finally, lessons learned from implementing optimization-based procurement solutions are discussed.

## TRANSPORTATION CARRIER ECONOMICS

Transportation systems can be loosely classified as being either "direct" or "consolidated." Truckload (TL) carriers, operating over irregular routes and moving from origin to destination without any intermediate stops for load consolidation, are a direct mode. Consolidated carriers, such as less-than-truckload (LTL) and package delivery carriers, require the use of terminals and scheduled routes to collect smaller shipments and consolidate them into larger loads.

This paper focuses on the economics of direct transportation services. The majority of the costs for direct modes can be divided into two activities: line-haul movement and connection to a follow-on load. Line-haul movement costs are mainly variable with distance (fuel, tires, operator's wages), are well understood, and are mostly controllable by the carrier. The costs associated with connecting to follow-on loads consist of deadheading (movement of an empty truck from its current position to the location of a new load) and dwell time (time the driver has to stay at a location waiting for a follow-on load to be identified). Dwell time can also include the cost of waiting for loading and unloading at a facility. The cost of making a connection is never known with certainty by a carrier due to short tendering lead times and the overall spatial and temporal variability of shipper demand.

This uncertainty in connection costs creates lane interdependencies where the cost of hauling on one lane is affected by the other lanes that a carrier is serving. A backhaul lane is the most obvious example of this interdependency. The cost to haul from A to B will be lower if the truck has a high probability of outbound loads from B or inbound loads to A. This is an example of economies of scope – the cost to serve one lane depends not on the volume on that lane (which would be an example of economies of scale) but on whether another lane is served. Economies of scope are present if the total cost of a single carrier to serve a given set of lanes is lower than the cost of multiple carriers serving these same lanes. TL operations exhibit significant economies of scope, especially on lanes with high levels of reliable and consistent traffic volume. The inability to accurately estimate the connection costs can also lead to hedging – further inflating a TL carrier's price.

Once the underlying economics are understood, it is important to investigate how a shipper can influence a carrier's internal cost structure during the procurement process.[2] In most vendor-buyer relationships, the only influence the buyer has over the vendor's economics at the time of procurement is the volume of the business offered. The reason for this is that the production of most products and services can be described quite accurately as single output processes with both fixed and variable costs. Increased volume spreads the fixed costs over a larger number of transactions. Transportation, however, produces a multi-dimensional output that varies for different origins, destinations, commodities, and time of day, week, and year (Jara Diaz 1982, 1983, 1988). Because the timing and commodities are fixed by the production schedule, promotion patterns or other factors beyond the control of the shipper's logistics department, the transportation buyer really can control two things at the time of procurement: (1) the *total* volume of traffic it offers to each carrier, and (2) the *placement* of the traffic on the network that it offers to each carrier.

## HEDGING AND UNCERTAINTY IN BIDDING

The objective of a competitive TL bid is to find the "best" assignment of carriers to traffic lanes within the shipper's distribution network. This paper assumes that "best" is the minimum adjusted cost (to the shipper), where the fees charged by the carrier are adjusted to reflect the service level for each carrier on each lane.

It is in the shipper's best interest to assign to their network carriers that have the best internal cost structure. Unfortunately, the shipper does not know these internal cost functions for the different carriers. Instead, the shipper has to use the bids submitted by each carrier as proxies for their internal cost structure.

The manner in which the shipper asks for and receives the bids from the carriers affects both the prices received and the complexity of the problem the shipper must solve. In the traditional TL bidding processes carriers bid on each lane separately in a single-round auction. The winning carrier on each lane is found by sorting all the offers for each lane and selecting the lowest bid.

### Problems with Traditional Bidding Methods

There are three major problems with using the traditional bidding and award method. First, there is an *incentive compatibility* problem. Because the bid rates submitted by carriers are used as the basis for choosing the least-cost assignment, the solution is only as good as the bid rates submitted. Simply asking carriers for their true valuations of each lane ("reservation value")[3] does not mean that they will actually provide them. In fact, carriers have an incentive to hedge, or artificially increase, their bids based on uncertainty in the information provided to them, competition on the lanes offered, and numerous other factors.

Second, there is an *interdependency* problem due to economies of scope in TL trucking. While in traditional bids a carrier would bid on each lane individually, the actual internal cost for a carrier to serve a lane depends on the other lanes being served. This dependency makes it difficult, and sometimes impossible, to obtain an efficient allocation using lane-by-lane bids. In an efficient allocation, the items being auctioned are awarded to those bidders that value them the most. For the TL bidding problem, this means assigning traffic lanes to the carrier with the lowest internal cost structure for that *combination* of lanes.

Third, there is the *system constraint* problem. Lane-by-lane bid analysis cannot account for requirements that involve more than one lane at a time, such as needing a minimum number of carriers serving a location or ensuring that a carrier is awarded at least a certain level of business.

The incentive and interdependency problems can be reduced by careful design of the auction. One method that can create an efficient allocation is allowing carriers to submit *conditional bids* on sets of lanes where the carrier's bid rate is conditional on being awarded the entire set of lanes at the specified volume level. As it turns out, however, this bidding method requires that the shipper use a formal optimization mechanism to make the carrier assignment. Additionally, optimization can be used to solve rigorously the system constraint problem. So, in effect, using optimization in the Bid Analysis stage minimizes all three of the problems associated with traditional bidding.

The more efficient a carrier's operations are, the lower its bids can be. Thus, shippers have an interest in designing the bidding process in a way that enhances each carrier's efficiency. Properly designed TL bids should assist carriers in recognizing their own *reservation values* for their lanes and encourage them to bid their true reservation values. These are not necessarily the same goals – the former is concerned with enabling carriers to determine the true reservation values for themselves, while the latter is concerned with having them actually use these values in the bidding process. This is not to say that the lanes will be awarded at the reservation value prices or that a carrier is guaranteed to win every lane for which it submits its reservation value.

**Sources of Uncertainty in Competitive TL Bids**

The main obstacle for shippers to achieve efficient allocations is each carrier's hedging. Carriers tend to hedge, or increase, their bids when there is a significant level of uncertainty present. The two primary sources of uncertainty in TL auctions that the shipper has direct control over are: (1) quality of the information, and (2) network imbalance.

*Quality of information*

Each carrier must make its bid based on information provided by the shipper. For example, given an annual number of loads per year over a lane, a carrier can assume, at one extreme, that the loads are distributed uniformly across the entire year or, at the other extreme, that all loads move in, say, a single month. The former assumption is overly optimistic and can lead to underbidding (i.e., prices that are too low given the actual requirements), while the second assumption can lead to an overbid with the carrier not winning the lane at all, even though it may be able to serve it efficiently and profitably at a lower price. Often times, the carriers that are most unfamiliar with a shipper's operations will make overly optimistic assumptions and end up winning a lane, but incurring a loss. In auction theory literature, this is referred to as the "winner's curse." Introduced by Capen, Clapp, and Campbell (1971), the concept of a winner's curse in this paper refers to the situation where the carrier that wins the business on a lane is the one that most underestimated the cost of serving it.

It is not in the shipper's best interest to have carriers bid below their reservation prices and operate at a loss. Having carriers serving at a loss will almost certainly lead to a lack of priority by the carrier, future service problems, and even more costly service defaults. An interesting observation in practice is where incumbent carriers "lose the bid but win the business." That is, the incumbent carriers lose the official assignment of business to carriers that are unfamiliar with the shipper's actual requirements and correspondingly made overly optimistic assumptions. But, after the new carrier defaults, the incumbent is brought back in – oftentimes at a higher rate!

*Network imbalance*

The second form of carrier hedging is caused by uncertainty in achieving network balance. Actually, there are two issues here: being awarded lanes that complement each other during the bid and then actually being tendered loads on these lanes during daily execution. The latter issue is known as the real-time routing guide adherence or "maverick buying" issue. While reducing maverick buying is a very important topic, this paper is focused on the strategic aspects of procurement and will address the former issue only. (The issues associated with real time execution of strategic contracts are discussed in an upcoming paper by the authors.)

A very common form of TL auction selects the lowest priced carrier on a lane-by-lane basis and the carriers are asked to bid on each lane as an independent entity. In this case, each carrier has to make assumptions as to whether it will win other lanes that interact with the lane under consideration. In other words, it has to estimate the probability of achieving economies of scope. Economies of scope are not limited to closed loop tours or immediate reloads at a facility. A balanced network, where the inbound volume is in sync with the outbound volume at the regional level, is an example of achieving economies of scope. Unless a set of lanes can be guaranteed as a whole, a carrier will need to hedge its bid to cover for uncertainties in the connection costs associated with each lane. To minimize this hedging, shippers need to provide additional guarantees to the carriers to be enforced by contractual agreements.

## BID ANALYSIS STAGE

The Bid Analysis stage of the procurement process begins with receiving all of the carriers' bids and ends with an assignment of carriers to specific lanes within the shipper's network. The mathematical model used to complete this stage is sometimes called a carrier assignment model.

### Carrier Assignment Models

The generalized carrier assignment model can be formulated as [GCA] shown in Figure 1. The objective is to minimize the total cost (to the shipper) of having carriers serve the expected traffic volumes. Constraint (1) ensures that each lane is served by sufficient capacity. Constraints (2) specify that the allocated lanes and respective volumes are feasible to both the carrier and the shipper. The cost function, Ck(xk), and the set of feasible assignments, *X*, are determined by the shipper based on the carriers' responses. The form of the cost function dictates the type of problem being solved.

**FIGURE 1**

**GENERAL CARRIER ASSIGNMENT MODEL**

$$\min_x \sum_k C^k(x^k)$$

*Subject to* **[GCA]**

(1) $\sum_k x^k = D$

(2) $x^k \in X \qquad \forall k$

Where:

$x^k$: Vector of volume for each lane (or segment) assigned to carrier *k*, measured in trailer-full units

$C^k(x^k)$: Cost function for carrier *k* to serve the vector of lanes (segments) $x^k$,

D: Vector of expected volume demanded on each lane (segment) measured in trailer-full units, and

X: The set of all feasible volume allocations and lane (segment) assignments.

A properly specified cost function, $C^k(x^k)$, would represent a carrier's cost of serving an additional load on each lane as a function of all other loads being served on every other lane in their system. Such a function, which would specify the full relationship between bid rates, lanes, and volumes is unlikely to be known in theory, much less found in practice. Furthermore, even if this were quantifiable, it would be non-linear and extremely difficult to solve. See Caplice (1996) for additional discussions of this formulation.

### Carrier Assignment Model with Conditional Bids

A better, more practical method of capturing the lane cost interdependencies through the use of conditional bids is proposed. A conditional bid is an offer by a carrier to serve some portion of traffic (a partial lane[4], a single lane, or a set of lanes) only if certain conditions are met.

For example:

- A bid is valid only if that carrier is awarded a minimum volume level. [Volume Conditions]
- A bid for a set of tours is only valid if the shipper pays for the empty mileage. [Tour Bids]
- Bids on a set of lanes are only valid if the carrier is awarded each lane in the set at the capacity levels specified. [Package Bids]

Package bids capture the salient aspects of *economies of scope* that drive a carrier's economics but are not highly dependent on the details of the network volume estimates. Rather than trying to capture the effects of every lane on every other lane's cost structure through an involved non-linear cost function, conditional package bids let the *carrier* specify the relationships between costs, volumes, and lane assignments. A carrier submitting a conditional bid for a lane package essentially makes the cost of serving each of these lanes non-separable and thereby incorporates economies of scope. Note that carriers can submit overlapping bids. In other words, the same lane can appear in several package bids submitted by a carrier, potentially creating a very complicated assignment problem for the shipper.

Using a linear formulation (since the bids are given by the carriers), the basic optimization problem that needs to be solved by the shipper for carrier assignment is given by [CACB] in Figure 2. The objective of [CACB] is to minimize the total estimated annual freight bill. Constraints (1) ensure that every lane is covered by exactly one primary carrier and (2) state that all variables are binary. Note that relaxing the integrality of the decision variables will capture partial lane assignments (i.e., when carriers bid on some but not all the volume on a lane), if desired.

**FIGURE 2**

**CARRIER ASSIGNMENT MODEL WITH CONDITIONAL BIDS**

$$\min \sum_k \sum_p c_p^k x_p^k$$

subject to :

**[CACB]**

$$(1) \quad \sum_k \sum_p \delta_{ij}^{pk} x_p^k = 1 \ \forall \ ij$$

$$(2) \quad x_p^k = [0,1]$$

where:

*Indices:*

| | |
|---|---|
| *i*: | Shipping location origin |
| *j*: | Shipping location destination |
| *p*: | Package of lanes in a conditional bid |
| *k*: | Carrier identification |

*Decision Variables:*

| | |
|---|---|
| $x_p^k$: | = 1 if carrier *k* is assigned all lanes in package *p*, = 0 otherwise |

*Data:*

| | |
|---|---|
| $\delta_{ij}^{pk}$: | = 1 if carrier *k*'s bid package *p* contains lane *i* to *j*, = 0 otherwise |
| $c_p^k$: | Total annual cost for carrier *k* to service lane package *p* |

Note that the decision variable here is whether to allocate a package of lanes to a given carrier (the variable $\delta_{ij}^{pk}$ sets the content of each package and the variable $c_p^k$ is the cost of the package). This formulation not only accommodates conditional bid package, but one can easily add a variety of side constraints to account for various business rules. The model [CACB] is a well-known mixed-integer-programming (MIP) structure – set covering formulation – for which known solution approaches exist. See, for example, Nemhauser and Wolsey 1999. So, by utilizing package bids, an intractable general problem can be readily solved by most off-the-shelf MIP solvers.

As discussed in the introduction, there has been increased interest in and use of combinatorial auctions for transportation procurement. While becoming more common, there are still significant differences. The approach taken in the seminal work in Moore, Warmke, and Gorban recommended a MIP to determine which carriers to select, but did not allow for any conditional bids and therefore did not capture economies of scope. The methodology followed in Ledyard et al. (2000) at Sears allowed for package bids, but did not capture capacity limitations, performance factors, or any other non-price based considerations. Both i2's and *Logistics.com's* commercial products utilize package or bundled bids but differ in their inclusion of additional business considerations.

While model [CACB] is the basic carrier assignment model, in practice the model is usually enriched to include a variety of other business considerations such as:

- Minimum/Maximum Number of Carriers – A shipper could require that no more than or no less than a certain number of carriers can win freight – at the lane, facility, or system wide levels. This is very often utilized to determine the optimal size of a core carrier group.
- Favoring of Incumbents – Most shippers recognize that there is an additional cost of bringing in a new carrier to service a facility. To compensate, the shipper can apply a penalty to non-incumbents (or, conversely, a reward to incumbents) to capture the total cost of switching vendors. In practice, incumbents are often favored by 3% to 5% – especially on service-critical lanes to key customers or time-sensitive plants.
- Back Up Carrier Bids – A shipper could require bids from carriers for both primary and alternate or back-up positions. Additional constraints are required to ensure that the primary carrier on a lane is not also assigned as back up.
- Minimum/Maximum Coverage – A shipper may want to ensure that the amount of traffic that a carrier wins across the system, on a lane, or within a region is within certain bounds.
- Threshold Volumes – A shipper can specify that if a carrier wins any freight (on a lane, from or to a facility, or system wide) that it is of either a certain minimum threshold amount, or they win nothing at all. This is typically used at the facility level to ensure that a carrier wins enough business to support a pool operation.
- Service Requirement for Alternates – A shipper can require that all carriers act as both primaries and alternates over different segments of the system.

- Restricting Carriers – A shipper might want to ensure that certain carriers, or groups of carriers, are restricted from serving certain portions of the network. Conversely, the shipper might want to ensure that a group of core carriers wins a target level of traffic across the system. Some shippers use such constraints to ensure that a certain percentage of their business is given, for example, to minority-owned carriers.
- Complete Regional Coverage – A shipper can require every carrier be able to cover all lanes from a certain location. This reduces the problem to a shipper-defined package for all traffic from that location.
- Performance Factors – The level of service provided by a carrier can be incorporated into the decision by modifying the cost coefficients by either a multiplicative or an additive factor. By allowing multiple attributes (such as on-time percentage, claims performance, refusal rate, EDI, etc.) to be considered in the Bid Analysis step, the shipper can make service-price tradeoffs. Additionally, and more importantly, it allows for the de-commoditization of transportation services.

## LESSONS FROM PRACTICE

Over the past 15 years, the authors have been involved in over 100 procurement events for companies in the automotive, retail, manufacturing, distribution, industrial, and high-tech industries. Many, but not all, of these engagements involved applying optimization-based procurement concepts. This experience has shown that the underlying theory for optimization-based bidding is directly relevant and valuable to practice in most cases. The practice led, however, to some unexpected results in terms of where the added value of the process lies and which tasks are trivial versus which are important. The next section of the paper discusses some of the issues that came to light when applying optimization-based bidding concepts in practice.

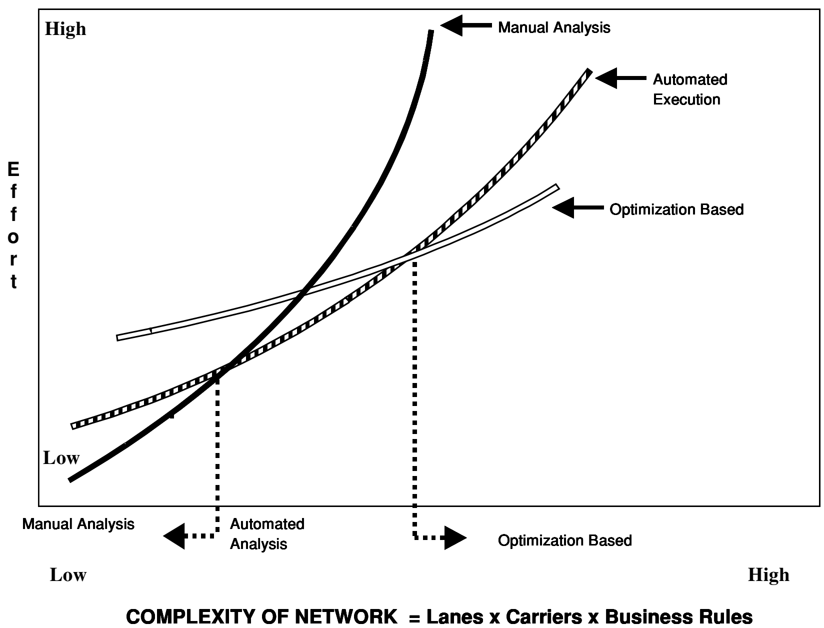
### When Does it Make Sense to Use Optimization-Based Procurement?

There is, of course, a fixed cost with conducting an optimization-based procurement event. This is primarily due to the added amount of data required to set up and run an optimization model. In some cases, it might not make sense to use optimization-based techniques in the Bid Analysis step. Figure 3, below, illustrates schematically the different effort curves involved in applying manual, automated, and optimization-based analysis approaches. Essentially, straightforward rate collection does not require optimization-based procurement. As business constraints become more important to shaping the final assignment, the value of an optimization-based approach increases.

Manual analysis consists of a simple sorting of lowest rates on a lane-by-lane basis using a spreadsheet or database application. This is the most common method used by shippers running bids in-house. Automated analysis adds to this by including multiple attribute rating (such as performance) and automatically favoring or disfavoring certain bids. This is the most common method used by Internet providers. Optimization-based analysis adds on constraint-based rules as described in the first part of the paper.

**FIGURE 3**

**EFFORT CURVES FOR MANUAL, AUTOMATED, AND OPTIMIZATION-BASEDAPPROACHES**




The complexity of the procurement drives the analysis type. Complexity is a vague metric that seems to be impacted by the size of the network, the number of carriers involved, and the number and types of business rules considered. Shippers that are securing transportation services for less than a dozen lanes from fewer than twenty carriers are best served by a manual or automated process. However, if the size of the network or number of potential carriers increases dramatically, then performing manual analysis becomes onerous and automated or optimization-based techniques become more attractive.

Table 1 shows the range in network size, carrier base, savings, and duration of optimization-based procurement events that the authors have run in practice. The trend over time appears to be towards more frequent, smaller procurement events, but with more business rules applied.

**TABLE 1**

**STATISTICS FROM OPTIMIZATION-BASED PROCUREMENT EVENTS IN PRACTICE**

| | Minimum | Average | Maximum |
|---|---|---|---|
| Number of Lanes | 136 | 1,800 | 10,000+ |
| Number of Annual Loads | ~6,000 | ~200,000 | 1,500,000+ |
| Number of Carriers Invited | 15 | 120 | 500 |
| Number of Carriers Assigned | 8 | 64 | 300 |
| Reduction in Size of Core Carrier Base | 17% | 52% | 88% |
| Base Reduction in Transportation Costs (without considering service factors) | 3% | 13% | 24% |
| Final Reduction in Transportation Costs (considering service factors) | 0% | 6% | 17% |
| Duration of Procurement Event (Months) | <1 | 3 | 6+ |

**Who Should Create Package Bids – The Shipper or the Carriers?**

In most auction theory, it was thought that the seller (shipper) is best qualified to determine the efficient aggregations (or packages) that a bidder (carrier) should consider. Art, antique, and other "collection-like" auctions follow this practice. Additionally, most Internet based procurement solutions offer this approach by allowing the seller to create "lots" that the carrier must bid on as a whole. However, shipper specified package bids have been found to be less than successful for transportation. Shippers have a difficult time determining which lanes to bundle; they have different methodologies than the carriers, and even with large networks, only a small subset of useful combinations is actually found in practice. Instead, we have found that carriers are better at identifying packages based on their own individual perspectives and networks. Some examples of carrier created packages include:

- Creating a package bid consisting of all lanes into or out of a region in order to better balance the new traffic with existing business,
- Creating a package bid with a set volume of traffic in a new region ensuring that if the carrier is awarded any traffic in a new market that it has a large enough presence to sustain service levels,
- Creating a series of package bids with lanes set up so that the carrier may win any one of the potential packages, but not all of them (essentially an "either-or" conditional bid), and
- Creating packages based on the carrier's existing network in conjunction with the lanes in the bid process.

The market for sell-side bid management or yield management systems that assist carriers in forming these packages is relatively untapped at this time and could be the source of significant future research efforts.

**How Should a Transportation Auction be Designed?**

Because shippers manage their transportation requirements differently, there is no single "best" form of auction or one-size-fits-all solution. Management preferences tend to dictate the ultimate auction form. The three most pressing areas for auction flexibility involve deciding whether to: (1) single source or split lanes; (2) hold a single round or multiple rounds bid; and (3) provide real-time rate visibility (open auction).

*Single sourcing versus split lanes*

Some shippers assign a single carrier to each lane or even to an entire region. Reasons for this include simplifying carrier selection at the operational (tendering) stage and giving "ownership" of a lane to a single carrier that will provide coverage during a demand surge. Other shippers assign more than one carrier to a lane on which surges are expected in order to alleviate the burden on a single carrier. A surge of ten loads can be more easily covered by two carriers supplying five trailers each, rather than a single carrier having to cover the full requirement of ten. The model [CACB], as shown, can only assign a single carrier to each lane. In practice, this constraint has usually been relaxed to allow carriers to specify capacity at the lane, origin, destination, and system wide levels, thus ensuring that they will not be assigned more freight than what they are willing to handle.

*Single versus multiple rounds*

There is continuing debate over the benefit of having multiple rounds when conducting a bid. Ledyard et al. (2000) based their entire approach at Sears on using multiple rounds and providing visibility to rates to carriers between rounds. Elmaghraby and Keskinocak note that Home Depot, using i2's CBO tool, favored a single round bid in order to reduce the probability of a "damaging price war between carriers" that would result in lower overall service levels. The authors' experience falls in between with approximately 80% of the shippers favoring single round bids. Shippers preferring single rounds state that this lets the carriers give their most accurate prices "without playing games." Other shippers (and surprisingly some carriers) prefer multiple rounds because they provide the opportunity for the carriers to get the most accurate sense of the market. A carrier can start off trying to bid fully allocated costs on certain lanes and, if the competition is fierce, can adjust its rates in the next round to, say, only covering variable costs. With single round auctions, the thought goes, the carrier must make these decisions ahead of time. Of course, other shippers employ multiple rounds simply to apply more pressure to the carriers. The model [CACB] can be used for both multiple and single round auctions. The only additional issues raised by multiple rounds are how to handle the non-winning bids in subsequent rounds and what information to provide carriers in between rounds.[5] These, however, are business decisions and do not affect the model formulation or use.

*Real-time rate visibility*

Providing real-time rate visibility in reverse auctions has become common for the procurement of many commodities. First pioneered by the FCC in its Narrowband PCS Frequency Spectrum Auctions of 1993, the use of interconnected computers to run sequential rounds or continuous bidding has been commercialized and is now available from a number of software vendors utilizing the Internet. When used to procure transportation services, these systems do reduce the initial prices paid – typically by significant margins. However, it does increase the incidence of winner's curse (resulting in having to re-source a large portion of the network), cannot handle conditional bidding (missing opportunities for collaborative cost savings with carriers), and ignores performance factors (these are typically only price-based auctions). Depending on the circumstances and management approach, these risks are perfectly acceptable to many shippers. Acceptance from the carriers varies from mode to mode. Ocean and LTL carriers, for example, have not responded well to this practice and have in some cases refused to participate in engagements where real-time rate visibility was allowed.

**What Business Constraints Should Shippers Consider?**

While the initial research by the authors in the early 1990s allowed for the insertion of constraints into the model, it was felt that they would not be widely used in practice. The initial model in Ledyard et al. (2000) for Sears also did not consider any business constraints. The common thought was that there would be minimal use of these side constraints because the model would select the "optimal" assignment. In the authors' experience, this was found to be dead wrong. Being able to include business constraints directly in the optimization model was seen as one of the strongest added values of the whole process. Shippers used the optimization model to price out various "what if" scenarios to answer questions such as:

- What if I single source a region?
- What if I reduce the number of carriers serving facility X?
- What if I assign only incumbents and do not allow new carriers?
- What if I encourage (through soft, dual-based constraints) the balance of loads for a carrier for inbound and outbound at a facility?
- What if I restrict brokers from servicing my customers directly?
- What if I restrict the inter-modal assignment on any particular lane to 50%?
- What if I remove all national (or regional) carriers from the assignment?
- What if I give the set of core carriers a minimum total volume over the system as a whole?

It is not uncommon in an engagement to run several dozen scenarios, each of which features hundreds of specific business constraints. Shippers, once enabled with this type of decision support, typically spend a considerable amount of time exploring various assignments to maximize the fit to their business needs rather than just looking for low cost. This "what-if" analysis or scenario management capability is frequently used as a tool to drive consensus among different factions within a shipper (or among shippers in a multi-company engagement) where the consequences of different business decisions are weighted against each other. The power of these "what if" analyses is that they are conducted with actual relevant and operational bids, not with historical costs.

**What Performance Factors Should a Shipper Use?**

In theory, the incorporation of carrier performance is trivial to implement in an optimization model – the cost coefficients are simply modified. In practice, however, shippers find this capability both extremely valuable and exceedingly difficult to implement. The value comes from being able to actually make rigorous cost-service trade-offs. In fact, being able to include many performance attributes (such as transit time, on-time performance, equipment type, response time, billing accuracy, surge capacity, or whatever) in the assignment decision is a major attraction to this whole process, by both shippers and carriers. The difficulty lies in selecting what metrics to capture, determining how much to value each facet of performance, and collecting the actual data. An interesting area of future research is to benchmark how different shippers perceive and weight different performance indicators.

**What is the Purpose of the Auction?**

A fine point in practice that was not recognized during the initial model development is that shippers use auctions for very different business reasons. The type of relationship the shipper has with its carriers, for example, can play a significant role in the type of auction used. Apparently, TL competitive bids can be classified into two categories: screening and realignment.

*Screening auctions*

Screening auctions, "separating the wheat from the chaff," are run by shippers that have used hundreds of carriers in the past and are looking to reduce their carrier base. With hundreds of carriers being considered, the performance data are usually absent or quite weak because the majority of the carriers are not incumbents. Thus, the focus is on the carriers' rates and stated capacities. The objective of a screening auction is to reduce the transportation cost while simultaneously increasing the control over the carrier base.

*Realignment auctions*

For realignment auctions, the shipper has a stable set of core carriers to select from in the new assignment. The performance data quality is typically quite good and the majority of the carriers are incumbents. The objective is to determine where each carrier can best fit into the shipper's network. In this case the use of performance factors is extensive, the information is highly utilized, the carriers are essentially playing "musical chairs" with their commitments to a valued shipper in accordance with how the shipper's network as well as their own network have changed over the last year or so. Also, these bids are smaller and are run more frequently.

**What about the Limitations of a Shipper's Real-time Execution System?**

One of the biggest surprises in applying optimization-based bidding in practice is the lack of flexibility within most commercially available tendering/rating systems. While the literature has stressed the need for continuous moves, specialized menu pricing, and other innovative arrangements between shippers and carriers – the tendering, rating, auditing, and pricing systems available today are sorely inadequate. For example, many shippers cannot include more than one rate from a carrier on a single lane even if they are for different modes (intermodal versus dry van). Similarly, it is rare that a tendering system allows a carrier to submit different rates for varying trailer lengths. To allow an expedited transit time, most systems require classifying the rate as a totally different mode. Continuous moves and prices based on weekly volumes assigned are even less likely to be able to be handled within current systems. Most transportation management systems today cannot execute upon the strategic plans that an optimization-based procurement process creates – this can lead to lost opportunities for savings and collaboration as well as increased costs due to maverick buying. In practice, the very first step of any procurement engagement is to discuss what the shipper can actually achieve in execution. This usually defines the bounds within which the strategic procurement event must operate.

**How can Bidding be Used to Collaborate Across Shippers?**

Having shippers collaborate strategically has been gaining some recent attention in both the literature and in practice. For example, companies such as Nistevo and Elogex have made shipper-to-shipper collaboration of transportation assets a cornerstone of their solutions. This is actually not a new practice, J.B. Hunt Logistics and other 3PLs have run shared dedicated fleets since the mid-1980s. The Internet, however, has made these collaborative opportunities much easier to implement and monitor. In practice, cross-company procurement engagements can be very successful. The greatest difficulties lie in: (1) the real-time tendering system handling cross-company moves; (2) shippers coming to agreeable terms for payment and cost sharing; and (3) the capability of a freight payment and audit system to handle cross-company moves. In practice, collaboration for procurement with shippers of a common supply chain works better than shippers in "independent" supply chains. The only exception to this may be the case of individual "power lanes" over which a dedicated fleet can operate.

## CONCLUSION

This paper discussed how shippers can use optimization-based techniques for procuring transportation services. It presented a theoretical underpinning to explain why conditional bidding and optimization-based procurement make sense for transportation due to the strong presence of economies of scope. Lessons learned in practice were also presented and discussed.

The key take-away of this research for shippers and other buyers of transportation services, is that all negotiations should take the carrier's economics into account. The vast majority of any shipper's transportation budget is the direct cost paid to carriers. Therefore, it is in the shipper's best interest to lower its carriers' cost of doing business. Optimization-based procurement is one approach that: (1) allows carriers to capture economies of scope; and (2) enables shippers to quantify and compare level of service with carrier rates. Shippers should consider working with their carrier base on other methods of reducing their total transportation cost, such as minimizing detention time, increasing visibility, and linking operational systems.

Carriers should take away the same key point. Additionally, the onus is on the carrier to educate the shipper on the importance of finding joint approaches to reducing operational costs. Optimization-based procurement is actually a method for carriers to provide shippers with quantifiable justifications for higher service levels. The analytical approach outlined in this paper can be used as a marketing tool by the carriers to help their shipper clients better understand how to place value on their specific service offerings.

Transportation procurement is still a relatively untapped research topic. This research only addressed one aspect of the process. Additional topics that need to be addressed include the extension of this approach to a more generalized (non-linear) cost structure, the role of variability in the procurement practice, and the synergies between strategic planning and operational execution.

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**NOTES**

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[1]Shippers and carriers can form a number of different types of relationships based on different characteristics of the network. These range from tightly defined dedicated fleets to more loosely coupled spot or "haul if capacity is available" backups. Readers interested in how these relationships can be formed should see Williamson (1985).

[2]For this paper, we are ignoring those practices that a shipper can take that would lower the operational costs of a carrier, such as decreasing loading time, minimizing dwell time, utilizing advance ship notices, etc. While these are important, this paper is focused solely on the strategic procurement process.

[3]Reservation value is the lowest price that a carrier will be willing to offer for a lane.

[4]A partial lane means that the carrier serves only a portion of the traffic on a lane.

[5]Carriers can be given information on the winning bid on every lane, they can be shown a partial or complete distribution of the bids on each lane, etc.