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Abstract

In this paper, we examine the for-hire truckload trucking industry in the U.S. and propose a new auction based carrier collaboration mechanism designed to facilitate economically efficient cooperation among functionally equivalent small and medium sized trucking companies based on a post market exchange. An architecture for such a system is proposed and its economic benefits are examined. Analysis shows that the system is a Pareto efficient one in which no participants are harmed and many are better off. The complex decision problems associated with subcontracting, bidding and bid selection in such a system are investigated.

Keywords

Contract procurement, auction, price discovery mechanisms, trucking operations

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Introduction

Today more than ever, the economy depends on the efficient movement of goods and the trucking industry, particularly for-hire truckload trucking, plays an increasingly important role in U.S. freight transportation. According to the latest data available from the Bureau of Transportation Statistics, nearly 70% of U.S. freight by volume and more than 70% by value is moved by truck (BTS, 1997). Since the deregulation of the industry over twenty years ago, trucking companies have faced fierce competition and very thin profit margins. A recent University of Michigan study shows that nearly fifty thousand carriers went out of business during the years 1980-99 and that typical operating ratios (operating expense * 100 / operating revenues) were in the mid to high 90 range (White, 2001).

In such a competitive market, trucking firms, especially small and medium sized firms, have to respond to the challenges of the market with innovative solutions. New technologies have been applied to trucking industry to reduce operation costs and facilitate the exchange of information. However, these new technologies either require significant investment capitol or inherently favor large carriers or both. These technologies are not always suitable for the problems faced by small and medium sized carriers.

Our paper proposes a framework for an auction based Collaborative Carrier Network. It is designed exclusively for small and medium sized carriers and harnesses the power of global optimization to deliver economically efficient solutions to every participant in the network. In addition, carriers incur much lower costs than traditional negotiation processes. As far as we know, this model has not been proposed to date, though there are several companies developing variations on collaborative logistics communities (see for example Nistevo and Leanlogistics). In our paper, we first review the current state of the trucking industry, particularly for-hire truckload trucking sector, and discuss the structure of existing trucking contract procurement. Next we analyze the problems faced by small and medium sized carriers and propose an auction based

collaborative carrier network in which a group of small carriers can conduct post-market negotiation and hence significantly improve their operational efficiency. Further we analyze the benefits of this system and discuss various decision problems including subcontracting, bid construction and bid selection.

Trucking Industry Overview

Since its deregulation in 1980s, the commercial trucking industry in the U.S. has become more dynamic and competitive than ever before. Shippers, typically large manufacturers and retailers, have increased their transportation requirements due to the adoption of innovative inventory practices and the increasing use of e-commerce. Combined with competition created by lower entry barriers to the market, this makes trucking a highly competitive industry with low profit margins. Trucking companies are responding to this challenge by adopting advanced information and communication technologies and by developing sophisticated routing and scheduling tools. These innovations improve the efficiencies of fleet operations; in addition, they facilitate the exchange of information and transactions between shippers and carriers and among carriers themselves. Shippers, on the other hand, sometimes with the help of the third party logistics providers, are developing various procurement methods to discover the "right" service providers at the "right" price in order to increase their profitability and improve service levels.

Williamson (1985) defined three basic types of governance structures used by buyers and sellers to ensure the successful exchange of transactions: competitive market forces, contractual agreements and administrative controls. All of these three types can be found in the trucking service procurement market(Caplice, 1996).

A spot market, in which a large number of shippers and carriers exchange additional loads and excessive capacity, is a type of competitive market force and is used by almost all shippers and carriers to some extent. Traditionally conducted by a broker through phone, fax and/or truck stop posting, spot markets have moved online during the

past several years. In the simplest case these are simply bulletin board services in which shippers and carriers can post and view loads and capacity. Some adopt an online procurement auction method in which a shipper posts a request for quote for transportation services and carriers bid for that contract. More sophisticated spot markets provide advanced search capabilities and automatic notification of matching capacity and loads. Examples of third party logistics companies providing spot market services include Transcore Commercial Services (previously DAT), NTE (formerly the National Transportation Exchange) and Transplace. Spot markets facilitate the exchange of information, lower the search and transaction cost, increase convenience, and provide both shippers and carriers access to larger markets. However, as discussed by Lucking-Reiley (1999), the Internet auction based procurement method suffers from fraud and lack of credibility. Since there are virtually no entry requirements for participants to spot markets, any shipper or carrier can use these services in a public marketplace. Hence shippers still need additional efforts to evaluate and screen carriers' performance such as financial stability and service levels. Carriers also concern with the price-driven property of spot markets and fear the adverse competition encouraged by spot markets. This has limited the use of spot markets primarily to excessive demand or capacity and irregular loads. In addition, the model in which both shippers and carriers can post demand and capacity only provides matching opportunities and it requires shippers and carriers conduct post-market negotiations to achieve an agreement. Song and Regan (2001) provided a review of the practice of online logistics providers including these spot markets.

Another extreme is the use of private fleets in which shippers have exclusive and direct control of operations with all or partial of ownership of equipment and drivers. Private fleets can be perceived as a form of administrative control governance structure. Though being the largest segment of the overall trucking industry, private fleets typically have less efficient operations than for-hire carriers. Even before deregulation, when for-hire fleets were considerably less efficient, empty miles for private fleets were reportedly fifty percent higher than those of for-hire fleets (ICC, 1977). The focus of this paper is the for-hire trucking industry.

Situated between private fleets and spot markets is the contractual agreement structure that is popular in the trucking industry. A contractual agreement takes place between shippers and carriers and includes a formal document specifying price, contract length, commitments and penalties. These relationships are stable and are often long-term. Many shippers have a core carrier program in which a large shipper forms partnerships with a few large carriers with an intent both to reduce its carrier base and to maintain or increase the level of service provided. A few online logistics companies provide this service to shippers or large carriers, these include but are not limited to: the "Preferred Trading Partners" program in Transcore Commercial Services, the "Private Marketplace" in FreightMatrix and the "Private Transportation Marketplace" in LeanLogistics. Traditionally shippers follow a carrier screening, request-for-quote and negotiation procedure to form long term contracts with carriers. In recent years, some are starting to use auctions to procure transportation services and even more sophisticated models such as combinatorial auctions are being introduced into trucking contract procurement market (Ledyard et al., 2002, Elmaghraby and Keskinocak, 2002). Companies like Manugistics, Logistics.com, Caps Logistics and i2 have all acquired or developed bidding software to aid large shippers to set up auctions or combinatorial auction based procurement practice. A recent review of the industry, albeit by the original developers of such software, makes some compelling arguments in favor of its increased use (Caplice and Sheffi, 2003). Compared to traditional negotiation methods, auctions, especially online auctions and combinatorial auctions, facilitate information exchange, significantly reduce transaction times and are able to achieve economic efficiencies if they are properly designed.

More efficient implementation of traditional contracting services and web based contracting can improve transportation service procurement by making processes more transparent, efficient and cost effective. However, these methods favor large carriers and ignore post market problems and opportunities. For example, its often the case that the carrier who loses the first contracting opportunity will later be provided an opportunity to move the freight anyway because the bidder with the lowest cost is unable to provide either the capacity or the service level required by the shipper. Large carriers, with

national coverage and tens of thousands of power units (tractors), have large and stable customer bases and are able to afford investments in advanced technologies and sophisticated bidding software to improve their operational efficiencies. This also gives them a better negotiation situation in the spot markets. Large companies also have many more opportunities than small ones to optimize their operation and reduce their empty movements.

While the truckload segment of the industry is often viewed as homogeneous, it is differentiated by size. Rakowski, Sourthern and Jarrell (1993) suggest that the truckload trucking industry appears to be dichotomous with a small number of large carriers at one end and a very large number of small carriers at the other. These small carriers act like a perfectly competitive market – competing almost solely based on price. In fact, in 1998, more than 70% of trucking companies operating in the U.S. in 1998 had fewer than seven trucks (White, 2001). These are either owner operators with one or two trucks or small fleets serving a few local customers around which their service network is centered. These companies typically lack the capacity or capability to be a core carrier and either temporarily lease to large carriers or use freight brokers or spot markets to find customers, mostly small shippers. Fluctuating demand often makes their operations less concentrated and limited access to customers turns them into a pure price taker. As a result, this group of small carriers have a much higher empty miles than large trucking companies.(Caplice, 1996) A post market and optimization based collaboration mechanism between these small and medium sized carriers, especially among those who have overlapping geographical service coverage, might be able to leverage the power of global optimization and improve their efficiencies significantly with relatively small costs.

We propose a framework for an auction based Collaborative Carrier Network. It is designed exclusively for small and medium sized carriers and uses global optimization and an auction to deliver economically efficient solutions to every participant in the network.

Collaborative Carrier Network

We consider a group of small and medium-sized truckload carriers, each providing equivalent trucking services in terms of quality in their local or regional areas which can be geographically identical, overlapping or adjacent. Each day when new demand become available either from spot markets or sub-contracts from large carriers, these carriers need to examine their current loads and determine the best way to assign these new loads to their fleets. For an individual carrier, there may be some new loads that cannot be efficiently integrated into the carrier's operation. For example, a one-way delivery to an area beyond this carrier's service region might incur some initial setup cost in addition to the backhaul empty cost. An option for this carrier would be to collaborate with its partner trucking companies, which may have the resources to efficiently integrate these inefficient loads. Alternatively, carriers could also trade this contract in a spot market. However, contracting on a spot market can be time-consuming and risks deterioration of service performance. Managers and dispatchers must make decisions in a short time period. As a matter of fact, none of these three typical contract governance structures can satisfy this particular demand efficiently as the collaborative carrier network we propose.

We propose an auction based Collaborative Carrier Network (CCN) in which a group of small and medium-sized truckload carriers collaborate based on mutual agreement on performance and payment, either through a central portal or purely operating by themselves through a CCN platform. See figure 1 for example.

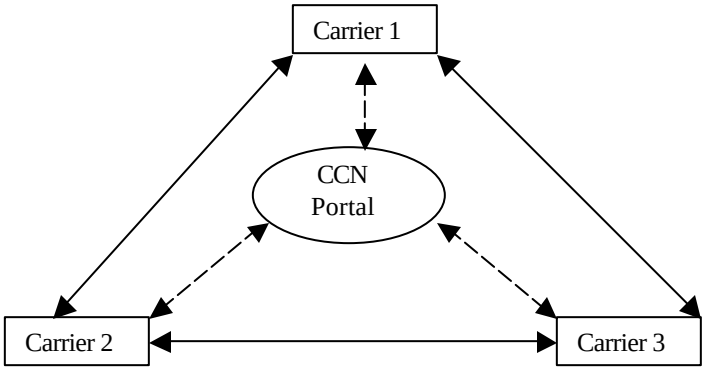

Figure 1. Collaborative Carrier Network

Each time a carrier obtains a new load, it calls a set of optimization routines to determine whether this load is efficient or inefficient for its fleet to operate. If it is not cost-effective, the carrier calculates a reservation price for this load and notifies its peer carriers in the CCN network for subcontracting. The other carriers use the same optimization rules to evaluate this new load's contribution to their networks and bid on the load if it is profitable for them. After they submit bids to the carrier who called for the auction, that carrier compares the bids to its reservation price and awards the load to the lowest bidder if appropriate. If no appropriate bids are placed, it will simply withdraw from the auction. This process can be completed with a simple electronic transaction and incurs relatively little negotiation or transaction cost. Most small carriers today have access to the Internet and are equipped with some kind of information and communication technologies (Golob and Regan, 2002). With a relatively low setup costs, Internet-based systems can dramatically reduce the cost of connectivity between business partners.

In this network, each carrier can be both a contractor and a sub-contractor in different auctions. We assume that each carrier will launch at most one auction at a time, and that if new loads come in during the previous auction round, they will be simply held and wait for the next round. Further, contractors can do a re-evaluation in bid awarding step and determine whether it needs to change its subcontracting decision. This system naturally leads to a set of questions: What benefits do participants gain from this system?

How should a carrier make its subcontracting decisions? How should a carrier award bids? What is the best bidding strategy for a sub contractor? We address each of these in the following sections.

Benefit Analysis

Now assume a carrier has a quasi-linear utility function $u(v,c)$. If it is awarded a contract, its utility is equal to the difference between the payment for this contract v and its cost to serve this contract c, that is, $u = v - c$; Otherwise, its utility is zero. Now denote x as the amount of the contract that this carrier decides not to subcontract to other carriers in the CCN and to hold for itself. In our system, x is a binary variable and a contract is either subcontracted or held. If we denote carrier 1 as the contractor and carrier 2 as the bidder with lowest bid price (the winner), then their expected utility is as the following, respectively. (The other bidders are not considered since they lose the bid and gain / pay nothing in the auction.)

$$\overline{u_1} = (v_1 - c_1)x + (v_1 - v_2)(1-x)$$
$$\overline{u_2} = 0 \cdot x + (v_2 - c_2)(1-x)$$

All carriers are assumed to be rational. As a result, carrier 2, who is the bidder for this contract, always submits a bid with a price $v_2 \geq c_2$. Carrier 1, who is the contractor, will accept this bid only if the bidding price is less than its own cost. That is, $x = 0$ when $v_1 - c_1 < v_1 - v_2$, i.e., $c_1 > v_2$. Under such a decision rule, the total surplus for all firms can be maximized according to:

$$\begin{aligned} max. \ & \sum_i u_i \\ & = (v_1 - c_1)x + (v_1 - v_2)(1-x) + (v_2 - c_2)(1-x) \\ & = (v_1 - c_1)x + (v_1 - c_2)(1-x) \end{aligned}$$

Note under the above decision rule, the subcontract trade will be accepted by both parties when $c_1 > v_2 \geq c_2$. Indeed, anytime carrier 2's cost c_2 is less than carrier 1's cost c_1, the total surplus in this system will be maximized at $v_1 - c_2$ with a decision to subcontract, that is, $x = 0$. In summary, under Bertrand competition on bid prices, the bidder with the lowest cost will win the auction at an equilibrium bidding price equal to the second lowest cost. (In a Bertrand model, firms compete on prices rather than production quantities, in a Nash equilibrium of the Bertrand model, all sales take place at a price equal to cost, see Mas-Colell, Whinston and Green, 1995 for example.) Therefore, the total surplus is maximized at $v_1 - min\{c_j\}$; while in the spot market, the total surplus is just $v_1 - c_1 \leq v_1 - min\{c_j\}$.

Also note with this allocation scheme, compared to the case in which firms do not collaborate, all participants in this network are either better off or remain same as before. For those who lost their bids or chose not to bid, their utility did not change. The bidder who won obviously gained a utility of $v_2 - c_2 \geq 0$ and is better off. The contractor also increases his profit from $v_1 - c_1$ to $v_1 - v_2$. Hence, it is a Pareto efficient allocation which makes some participants better off without making others worse off and maximizes the total surplus of trucking firms. As a result, we have the following lemma:

Lemma: The post-market negotiation mechanism, CCN, is a Pareto efficient allocation when each participating trucking firm is rational and has a quasi-linear utility function, hence the sum of all participants' expected utilities is maximized.

With this win-win property, the collaborative carrier network is an attractive model compared to not sharing information in terms of system-wide optimization. It is not unusual to see the need for this post market negotiation, particularly for those small carriers whose service is geographically centered in a local area but have some loads to transport to adjacent areas. However, this system involves some complex decisions for both contractors and subcontractors.

Sub-Contracting Decisions

Whether a carrier with new loads should subcontract or not is a complex decision that depends on the carrier's capacity, current demand, historical demand, risk-taking behavior and anticipation of new service requests. First of all, a carrier has to determine the optimal operating cost with and without the new loads. This problem is typically modeled as a truckload pickup and delivery problem that requires the solution of variants of multiple traveling salesman problems. Here we assume that each carrier has access to an optimization routine that can calculate the optimal routes and cost in reasonable time or, that its network is so small that its dispatch managers can develop near optimal solutions quickly. With a small or medium sized fleet, these problems should be solved optimally in a very short time. These optimization routines are widely available in commercial software. We define the difference between carriers' optimal costs by adding a new load as the marginal cost, correspondingly we have marginal empty cost which is the difference between carriers' minimum empty costs with and without adding the new load and we denote a set of loads as L. Further, we have following notation:

R: a carrier's revenue from the set of new loads which is the original contract price;
C: a carrier's total optimal cost serving any set of loads L;
LC: a carrier's direct cost traversing loaded links in L;
EC: a carrier's empty haul cost for repositioning and linking purpose;
MC: a carrier's marginal cost serving a set of new loads;
MEC: a carrier's marginal empty cost serving a set of new loads;
ΔLC: a carrier's direct cost traversing a set of new loads;

Now a carrier's optimal cost before taking the set of new loads and after serving those new loads would be the following, respectively:

$$C_1 = LC_1 + EC_1$$
$$C_2 = LC_1 + \Delta LC + EC_2$$

Note that these conditions always hold in an optimal solution since a truck will never travel more empty miles than loaded miles:

$$EC_1 \le LC_1;$$
$$EC_2 \le \Delta LC + LC_1$$

Also note EC_1 may not be equal to EC_2. Now the marginal cost to serve this set of new loads is:

$$MC = C_2 - C_1 = \Delta LC + (EC_2 - EC_1) = \Delta LC + MEC$$

Without loss of generality, we assume costs are proportional to distance, that is, a fully loaded vehicle will have the same costs as an empty truck traveling the same distance. Then the following situation could occur to this marginal cost. (Note this marginal cost can never be less than zero, that is, adding a new load will not reduce a carrier's operating cost.)

1. $MC = 0$

   In this situation, we have $MEC < 0$ since ΔLC is always positive, that is, adding a set of new lanes will actually complement a carrier's current operation and reduce the carrier's empty hauling cost. That makes this set of new lanes highly profitable and the carrier definitely should hold it for itself to fulfill it.

2. $MC > 0$

   This could lead to following situations:

   1) $MEC = 0$

      In this case, a carrier's empty cost remains same when a new load is assigned to its fleet. An example would be that the set of new lanes consists of a routing plan by themselves. This is also highly profitable for carriers and hence these loads should be held for carrier itself.

2) $MEC > 0$

An example would be adding a single lane without backhaul trip. Since it does not integrate with carrier's network, serving this load would need additional capacity and incur a higher cost. Hence, this set of loads should be subcontracted as bng as the bid price is lower than this carrier's own marginal cost. A carrier might have other business rules applied to subcontracting decisions, for example, a lane critical to its business might not be subcontracted even if it incurs a higher cost. These rules can be incorporated into carrier's decision system.

3) $MEC < 0$

This situation normally should be considered lucrative and the carrier should not subcontract. For example, in Figure 2, that new lane $\overrightarrow{BC}$ should not be subcontracted since it complements this carrier's current lane $\underline{AB}$ with a total empty cost of CA. However, when multiple new lanes (delivery routes) are called for auction simultaneously, these require careful examination. In Figure 3, the new lane $\overrightarrow{BA}$ should be held for carrier itself since it complements with the current lane $\underline{AB}$ while the other new lane $\overrightarrow{CB}$ should be subcontracted since it requires additional capacity. In a word, when multiple new lanes are considered at one time, the routing plan generated by optimization routines should be examined in detail to exclude those new lanes with higher cost.

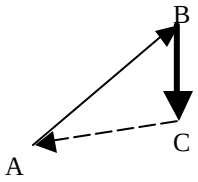

Figure 2

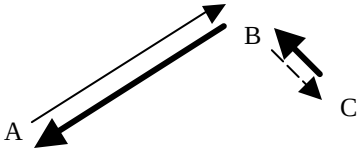

Figure 3

(In the above figures, the solid lines represent current lanes on which a carrier has current loads to move for pre-committed contracts; the bold lines represent new lanes on which the loads are new demands; and the dashed lines represent empty movements under optimal operations.)

In summary, a carrier's subcontracting decision depends not only on its optimal marginal cost, but on its optimal marginal empty cost. When more than one new lane are considered simultaneously, the optimal routing plan should be examined in detail. In a more sophisticated case, carriers might also consider the future demand. For example, a new lane whose origin and destination are both within a carrier's local service area should be reserved for the carrier itself and not subcontracted anyway even if it incurs higher operation cost according to the above scheme since chance to get a backhaul for this lane is high. Simply stated, carriers should not subcontract lanes that are critical to their core business.

Bidding and Bid Selection

Carriers who are the contractor and auctioneer should award the bid to the lowest bidder as long as that bidder's asking price is less than its reservation price. In addition, its reservation price is equal to the marginal cost by adding that new load into its current network as described in last section. That is, as long as the lowest bid price p_B and its reservation price $c = MC$ satisfy $p_B < c$, this carrier should award the contract to that

bidder. However, this carrier could recalculate its optimal cost if new demands arrive during the current auction round and may decide to change its subcontracting decision, in which case it simply awards the new load to no one.

Another issue in bid selection is the use of combinatorial auctions versus simple auctions when multiple new lanes are put for bid simultaneously. Combinatorial auctions have received increasing and significant attention in recent years due to their potential economic efficiencies. In such an auction, multiple loads are put out for bid simultaneously and bidders are allowed to bid on combinations of loads and to make conditional bids. For example, a bidder could say "I want load AB and CD both for a total price of \$X". If combinatorial auctions are used in a collaborative carrier network, the bid awarding has to be made by solving a winner determination problem which has been a hot topic of research in recent years (see for example a recent review by de Vries and Vohra, 2001). Also as long as the total bidding price from the optimal solution of a winner determination problem is less than a carrier's reservation price, these loads should be awarded to those winners respectively. Though it is computationally difficult, a winner determination problem would not be a hurdle in our collaborative carrier network since the number of new loads will typically be small and the resulting problems will be computationally tractable.

The carrier bidding strategy is essentially the same problem. In general, a carrier as a bidder should always ask for a price equal to or higher than its marginal cost to serve that new load, and if possible, should also add a reasonable profit margin. That is, $p_B \geq MC' + PM$ where PM is its desired profit margin. The optimal bidding price that a bidder should select in order to compete with other carriers is determined by the auction design and its equilibrium solution and is beyond our research scope in this paper. In addition, if a combinatorial auction is called by contractors, a complex bid making decision occurs, that is, how carriers should construct their bids. In this case, a bid construction strategy such as those described in Song and Regan (2002) should be used to deliberate carriers' bids. Similarly, with a small number of new loads at a single auction, computational difficulty should not be a serious problem for bidders.

Conclusion

In this paper, we examined the for-hire truckload trucking industry in the U.S. and proposed a new auction based collaborative carrier network to encourage economically efficient collaborations among functionally equivalent small and medium sized carriers based on a post market exchange. An architecture for such a system was proposed and economic benefits were examined. Our analysis showed that this system is a Pareto efficient one in which each participant is either no worse off or better off. The complex decision problems associated with subcontracting, bidding and bid selection were also investigated.

The for-hire truckload trucking industry in the U.S. exhibits a dichotomous structure in which a few mega carriers and thousands of small trucking firms operating in a very competitive market. We find that current procurement methods including spot markets and long-term contractual agreements are either of limited efficiency or they favor large carriers over small ones. Currently, there is a lack of mechanisms to allow post-market collaborations between small and medium sized carriers so as to coordinate their operations and achieve system-wide optimization and economic efficiency. In this paper, we made an effort to analyze this problem and propose such a system in which small and medium sized carriers can exchange their inefficient lanes in a low-cost auction and balance their networks.

The main purpose of this paper is to examine the feasibility of such an auction based carrier collaborative network and its economic benefits to participating trucking firms. We fully realize that in order to implement such a system in the real world, more delicate consideration should be made regarding many aspects ranging from system design to individual decision rules. Many subtle decision problems are simplified in this paper. We expect to examine them in detail in the future. Of particular interest is the following: When transactions between carriers are frequent and possibilities of initiating multiple auctions increase, how should a collaborative carrier network coordinate or

synchronize these auctions? In addition, we mentioned the use of combinatorial auctions when multiple lanes are called for bid simultaneously. For carriers to benefit from such auctions they must be able to quickly and efficiently separate profitable opportunities from unprofitable ones.

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