A Framework for the study of Carrier Strategies in an Auction Based Transportation Marketplace

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Abstract

Online markets for transportation services, in the form of Internet sites that dynamically match shipments (shippers' demand) and transportation capacity (carriers' offer) through auction mechanisms are changing the traditional structure of transportation markets. A general framework for the study of carriers' strategies in a transportation auction marketplace is provided. The unique characteristics of these marketplaces and the sources of difficulty in analyzing the performance of these marketplaces under different carrier bidding strategies are discussed. A simulation framework is used to explore the complex engineering and economic processes and issues that arise in a transportation marketplace, which are difficult to explore using standard analytical or statistical tools. Some results and the overall simulation framework are also discussed.

KEYWORDS: Freight Transportation, Shipper and Carrrier Behavior, Game Theory, Dynamic Games, Carrier Management Strategies, Carrier Profitability, Information Technology, Electronic Commerce, Auctions

INTRODUCTION

It is well recognized that information and communication technologies (ICT) are changing many aspects of the way business is conducted (1). The implications for transportation and logistics systems structure and operations are continuing to unfold, sometimes in unpredictable ways. Discussion of these phenomena has been mostly limited to generalities and speculation, with few attempts to provide formal models or numerical results.

The changes that ICT could bring to companies' strategies and market structures have been examined from a broad perspective. As early as 1987, Malone et al. (2) predicted that reducing coordination costs (while holding other factors constant) should increase the proportion of economic activity coordinated by the markets. Factors that favor market or auction systems are the simplicity of the product description, the adoption of common standards, and access to multiple potential suppliers in the marketplace.

Other authors suggest the opposite, namely that widespread availability of ICT will reduce the number of suppliers and foster long-term cooperative partnerships (3). These two opposing views respectively lead to the market model or to the emergence of hierarchies. Intermediate views have also been suggested (4), whereby organizations gain the benefit of a controlled and known hierarchy while retaining an element of market competition. Beyond changes in market structure, the Internet and especially auctions have emerged as an effective catalyst to sell/buy through electronic marketplaces. Transaction time, cost and effort could be dramatically reduced, creating new markets and connecting buyers and sellers in ways that were not previously possible.

DEFINITION OF AUCTION MARKETPLACES

Many Internet-based sites have emerged to serve the transportation industry, offering a wide variety of services. These services range from load posting boards, cargo matching, and auctions to the procurement of transportation equipment, parts and systems for logistics and supply chain management (5). The focus of this paper is on the study of transportation marketplaces that enable the sale of cargo capacity based mainly on price, yet still satisfy customer level of service demands. The specific focus of the study is the reverse auction format, where shippers post loads and carriers compete over them (bidding).

McAffee and McMillan (6) define auctions as market institutions with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants. Auctions have been widely studied by economists, leading to recent advances in the theoretical understanding of different auction types and designs (7). Auctions as a device to match supply and demand provide a powerful mechanism to allocate resources, especially when the latter have uncertain or non-standard value.

Transportation auctions are a relatively recent phenomenon, characterized by rapid change and fast development. This type of market has not yet reach maturity as indicated by the significant number of start-ups, mergers, consolidations, and liquidations that took place in the past couple of years. The interested reader may find a list of transportation marketplaces in the Journal of Commerce (Review and Outlook Millennium Edition, January 18th, 2000) and check how many are still operating. Hence, this paper does not focus on describing a particular existing marketplace, but rather builds a general framework for the study of auction marketplaces. The auctions operate in real time, providing transparency in a many-to-many market. Transaction volumes and prices are barometers of the market and their variation should reflect the status of demand and supply, for a given level of service in its multiple dimensions: reliability, visibility of the product, speed, etc. Even if auctions are not the most utilized procurement tool for transportation services, they provide a useful and appropriate framework to:

- Gain insight into drivers of price in a dynamic real time market
- Study and develop real time yield management strategies
- Examine the implications of market conditions and carrier strategies on shippers' level of service
- Monitor system evolution and describe market conditions using price and other performance parameters as system indicators.

However, as detailed below, transportation marketplaces possess certain characteristics that preclude direct transferability of conclusions and applicability of models developed for other types of goods and services. This unique set of characteristics gives rise to challenging problem classes that must be formulated and solved in order to study the performance and properties of transportation marketplaces, along with their implications for shippers and carriers.

CHARACTERISTICS OF TRANSPORTATION AUCTIONS

Two types of assets could be traded in transportation marketplaces: (a) loads, or demands of shippers, being "sold" to the lowest bidder-- this would be the case of extra supply looking for scarce demands; and (b) capacity, i.e. the capacity to move goods, that have certain requirements, by a given mode from location A to location B, being sold to the highest bidder. The buyer of such capacity could be a shipper wishing to move a load, a carrier needing the extra capacity to move contracted loads, or a third party hoping to make a profit by reselling this capacity.

Auctions are typically used where products have no standard value (8), as opposed to situations where a fixed price can be posted for the products. In the case of transportation services, the price can be reasonably bounded by:

- What the shipper could pay in the regular market in an established relationship with a carrier minus the cost or fees of the auction (upper bound)
- What the carrier must pay for rerouting the vehicle, loading time, unloading time, driver extra compensation (lower bound)

However, these bounds can be greatly affected by the following unique characteristics of transportation auctions:

- The traded entity is a service
- Transportation services are perishable, non-storable commodities
- Penalties/costs associated with late deliveries or no delivery might be several times higher than the cost of transportation per se
- Demand and supply are geographically dispersed
- Uncertain demand/supply over time and space
- Present and future fleet utilization level

- Group Effect: value of traded item (shipment) may be strongly dependent upon the acquisition of other items (e.g. nearby shipments)
- Network Effect: value of a shipment is related to the current spatial and temporal deployment of the fleet
- There might be strong substitution/complementarity effects depending on the shipment attributes and the fleet status

Multiple Disciplinary Perspectives on Transportation Auction Marketplaces

By connecting shippers and carriers nationwide in real time, and increasing the size and scope of the market, transportation marketplaces move us closer to ideal perfect markets. At the same time, increased collaboration among shippers or carriers might be possible by allowing demand bundling or extended service offers and cost savings. Audience size and scope advantages give Internet auctions a major role in the emerging global economy (9, 10). However, the same enabling technologies may also facilitate anticompetitive behaviors. One danger of standard auctions is the possibility that buyers/sellers who repeatedly participate in the same types of auctions could engage in collusive behavior. This topic has been extensively study in the Economics literature, specifically in the field of Industrial Organization through game theoretical models of oligopoly and collusion. General references include the work of Tirole (11) and Martin (12).

A market environment that has few suppliers and many buyers is called an oligopoly. In such an environment, each buyer takes market conditions as given, but each seller is aware that his actions have significant impact upon his rival's payoffs, and vice-versa. Compared to a competitive firm or an uncontested monopoly, the typical oligopolist faces a considerable complicated decision problem, which stems mainly from the strategic interdependency among competitors (12). This interdependency lends itself to be modeled using game theory. Game theoretic models of oligopoly tend to be marked by precise treatments of the sequence of moves and specifications of the information that oligopolists are assumed to have at different times. The distinctive emphasis of these models is on the kinds of equilibria that could reasonably be expected to persist, and on beliefs needed to support such equilibria.

In an auction, profits are highly dependent on the quality of the bidding strategy. Game theoretical models of bidding provide important insights, mainly focused on symmetric risk-neutral agents bidding competitively for a unit of an item in a one shot (one period) auction. In a transportation auction marketplace, however, most auctions will involve oligopolistic sellers (a few carriers) with different fleet sizes, fleet assignment strategies, and fleet statuses (asymmetries), who meet repeatedly and determine their bid strategically in an effort to exploit market power opportunities.

The repeated interaction among oligopolistic carriers allows the possibility of learning about strategies, the environment, and competitors. This realistic assumption implies that carriers can analyze with different degrees of sophistication the history of play and estimate the possible future consequences of current actions. Therefore, carriers and shippers must be modeled as entities or intelligent agents that determine their interaction with other agents and with their environment on the basis of history (experience), learning, expectations about future consequences of current actions, and evolving strategies. A good introduction to the subject of learning in games is provided by Fudenberg and Levine (13).

The learning and repetition establishes an expected connection to a relatively new branch of Economics, Agent based Computational Economics (ACE) (14), which studies the economics of self-organization and evolution using the following:

1. Heterogeneous agents that interact among each other and with the environment on the basis of their behavior and experience
2. Agents co-evolve and continually adapt their behavior in response to agent-agent and agent-environment interactions
3. Agents engage in continual open-ended experimentation with new rules of behavior. That is, agents in the economic world co-evolve
4. Once initial conditions are set, all subsequent events can be initiated and driven by agent-agent and agent-environment interactions without further outside intervention

Previous work in ACE closely relates to this topic and covers auctions in the electric power marketplace (15). However, there appears to be no published work of a fundamental, scholarly or methodological nature specifically dealing with the unique characteristics of the interaction among shippers and carriers and the performance of transportation marketplaces.

Clearly, the market setting will establish the rules of the game determining an individual player's optimal decision strategy. In the transportation context, this includes not only the player's bidding process decisions, but also the associated vehicle fleet and load assignment decisions. A carrier's bidding decisions must be directly linked to the actual operational plan under which service will be provided. From a carrier standpoint, deciding whether to bid, assigning a given truck to a load, or buying capacity on a competitor's fleet at a given price must be integrated in a real-time decision framework for fleet operations.

Advances in ICT have also affected the way transportation fleets are operated and managed. More quality information about the current and future status of the fleet and demand can highly improve the efficiency of fleet operations (16). In a dynamic bidding environment the quality and accuracy of costing services is a key input to ensure the profitability of carrier operations and can provide a significant competitive edge. The revenue realized for each loaded movement is highly dependent on the availability and proximity of vehicles and drives to the load at the time it has to be moved or serviced. Different approaches to solve the dynamic vehicle routing problem include stochastic programming (17 and 18) variations of the probabilistic traveling salesman problem (19), and heuristics for real time applications (20).

As seen above, the study of auction marketplaces cuts across a wide range of disciplines including Industrial Organization, Game Theory, Learning and Cognitive Science, Experimental Economics, Agent Based Computational Economics, and Fleet Management. The encompassing scope of the mentioned fields indicates the nature of the complexity of the study of transportation marketplaces, which is the topic of the next section.

COMPLEXITY OF TRANSPORTATION AUCTIONS

Transportation auctions present opportunities to improve the efficiency of the overall transportation system, but they also introduce a considerable challenge to the participants (shippers and carriers). More information and data are available for decision-making, but the complexity of the problem increases substantially. Shippers and carriers have to keep in mind the marginal cost and desired profit from a particular transaction. In real time situations this is often difficult. Furthermore, this is an increasingly difficult when optimal decision-making entails the solution of NP hard problems (problems where computational time to reach an optimal solution grow exponentially as problem size increases linearly). The sources of complexity include:

1. Multiple interacting agents with multiple conflicting objectives.
2. Uncertainties about a shipment's value, the shipper's reservation price and cost of serving the shipment for the carrier. This is particularly difficult for carriers if they want to incorporate the effect of accepting this shipment on the cost of serving future shipments.
3. Fleet management complexities (vehicle routing problem, with time windows, penalties, etc). This is a NP hard kind of problem. For real world fleet sizes these problems cannot be solved optimally.
4. Fast responses are needed. Information is received and updated in real time. Responses to requests and changes in initial conditions have to be dealt with before the arrival of new requests or changes in the initial conditions take place.
5. Demand: spatial and temporal stochasticity preclude the use of naïve or unsophisticated bidding and fleet management techniques.
6. The problem becomes even more complicated if combinatorial bidding (bidding on bundles) is allowed

Online transportation marketplace characteristics deeply challenge "traditional" models of equilibrium, decision-making, and analysis. As mentioned earlier, a new cross-disciplinary approach is required to model and study the problems that the online business environment poses to shippers, carriers, policy makers, and researchers.

SIMULATION MOTIVATION AND DESIGN

Given that closed analytical solutions for these complex dynamic systems would require many simplifications that could compromise the validity of the results, computational experiments and simulation can enhance and extend the theoretical investigation of these dynamic games. Furthermore, simulation enables the computational study of interactions among market agents by means of controlled and replicable experiments. It is also possible to explore and systematically test changes in key market parameter values, e.g., number of carriers, arrival rates, auction types, etc. in a wide spectrum of scenarios allowed by the many potential market settings. Table 1 provides a categorized list of parameters that are possible to study in the context of an auction marketplace.

A market simulation framework was therefore developed to start gaining insight into the overall market behavior, its efficiency and resulting shipper service levels under different market settings and when carriers follow different individual strategies in a non-cooperative decision environment with varying degrees of information sharing and market settings. An object-oriented discrete-event simulation code was written to test carrier strategies and study overall market behavior and performance. The simulation program provides a framework to study important questions and a test bed for defining and investigating bidding and operational strategies for fleet management.

Marketplace Agents

Our framework accommodates three basic and distinct types of agents: the marketplace, carriers, and shippers. The marketplace creates an environment with well-defined rules and settings that allow the exchange of information and completion of transactions between carriers and shippers. Carriers are the sellers of transportation services. Carriers' behavior is given by their internal state, strategy, endowment, and external stimulus (demand stream). Carriers adapt their behaviors in response to interactions with other carriers and their environment in an attempt to maximize profits or gain market power. Besides, they act according to the physical feasibility constraints given by their assignment strategies and pool of awarded shipments. Past decisions are binding and limit the future actions of carriers, therefore behavioral rules are state-conditioned and the carriers co-adapt their behavior as the marketplace evolves over time. The number of carriers is an important parameter. In an oligopolistic market (relatively few carriers) a present carrier's action may influence competitors' future behavior and significantly affect its own future profit. On the other hand, with a relatively high number of carriers, individual carrier actions would not significantly alter its future rewards by modifying other players' behavior.

Each carrier is modeled as an autonomous agent with internalized social norms (market settings or protocol), internally stored bid outcomes data, stored state information, and internal behavioral rules. Although each carrier has the same internal structure, trader types can differ from each other in terms of their specific fleet management techniques, beliefs about the shippers or other carriers, and original endowments (fleet size or initial fleet status). Each carrier acquires different state information and evolves different behavioral rules over time on the basis of its own unique past experiences.

Shippers are buyers of transportation services. Shippers are developed as agents that generate a stream of shipments and their corresponding attributes according to predetermined probability distributions. They are rational agents because they know the exact value of the reservation price of their shipments as a function of its attributes (origin-destination, commodity type, stock out costs, time window, etc.). Furthermore, shippers maximize profits by setting the right reservation price; the highest price a shipper is willing to pay a carrier for servicing a given shipment. The shipper achieves a profit (saving) when paying less than the reservation price. A rational shipper rejects transportation services exceeding the reservation price (the shipper does not incur loss). Table 2 summarizes the functions performed by each agent type in our simulation framework.

In this framework, carriers' beliefs and experiences evolve jointly over time, and their strategies at a given moment are contingent on interactions that have occurred in a path-dependent time line. Similarly, the shippers' behavior can be affected by the evolution of the system. However, if a large population of shippers (much larger than the number of carriers) is considered, the individual effect of a shipper in the system's outcome is negligible. The reservation prices are derived mostly from individual shipper characteristics rather than from strategic or learning considerations.

Figure 1 presents a schematic overview of how a transportation marketplace works. A shipper's decision to post a shipment in the auction market initiates an auction. Events in the market are the arrival of shipments, the subsequent bidding process, and bid resolutions. Carriers' internal events are the assignment, pickup, and delivery of loads. Carriers repeatedly engage in bidding interactions modeled as noncooperative games, fleet assignment decisions, and update of its own beliefs to take into account bidding outcomes and service costs.

A common characteristic among agents is that they are all capable of collecting and processing the performance measures necessary to evaluate a given marketplace setting. A sample of performance measures by agent type follows:

a) Marketplace level: total system welfare, number of inefficient outcomes (shipment reservation price is higher than the cost of serving a shipment, but bids are over the reservation price and, consequently, the shipment is not served), lost welfare (lost wealth originated by inefficient outcomes)

b) Shipper: consumer surplus, service time, percentage of served loads.

c) Carrier: profit, fleet utilization, ratio loaded/empty distance, empty distance, loaded distance, number of shipments in the carriers system, and market share.

EXPERIMENTAL DESIGN AND RESULTS

The experimental design considered is intended to provide a starting point for examining marketplaces. It includes strategic interaction among carries, uncertainties over time, space, and prices, yet keeps the complexity of carriers' behaviors at a low level.

A Vickrey or second price auction is used. This is a one shot (or period) auction where each carrier submits a single sealed bid and the shipment is awarded to the carrier with the lowest bid, but the winning bidder gets paid the second-lowest bid and the other bidders do not get or pay anything (21). A Vickrey auction guarantees that the shipment will always be awarded to the carrier with the lowest service cost for that shipment (assuming rational carriers that are profit maximizers at each bid instance, with no look ahead, i.e. ignoring the future) regardless of the beliefs of the participants about the shippers or about other carriers. This is a consequence of a simple and remarkable result: the optimal strategy in a Vickrey auction is for each carrier to bid his or her true cost value for the shipment. The intuition and proof behind this result are detailed by Varian (22) and Vickrey (21).

These characteristics of the Vickrey auction allow for a simple and elegant treatment of carrier strategies since they render the tracking or updating of carrier beliefs about the shippers or competitors essentially irrelevant. It allows all this in a simple one-shot sealed bid auction avoiding bid iteration over time. When using a Vickrey auction it is possible to concentrate on the effect that arrival rate and numbers of competing carriers have on market performance without having to estimate the impact of carrier beliefs or the search for optimal bidding strategies. This is what makes a Vickrey auction a good starting point in the study of transportation marketplaces. The focus is on "transportation" variables rather than on learning or rationality levels of the agents.

For added simplicity in the current implementation, it is assumed that all carriers are identically implemented (in the simulation). Furthermore, it is assumed that carriers' fleet assignment strategy is a simple heuristic that estimates the cost of serving a shipment with the smallest cost of appending it to the shipment queue of each carrier's truck (but checking for feasibility, service must take place during the shipment time window).

Other market setting characteristics include:

- Geographic Area : 1 by 1 unit square area
- Shipments Origin and Destination ≈ Uniformly distributed
- Shipment Type: Truckload movements only
- Shipments Reservation Price ≈ Uniformly distributed (0.5, 1.0)
- Shipment Time Window Length: 4 units of time + uniform (0.0, 4.0)
- Earliest Delivery Time = arrival time
- Latest Delivery Time = arrival time + Time window length
- Truck Speed : 1 (unit of distance/unit of time)
- Fleet size: 10 vehicles (constant) serving the market

As stated earlier, these are simple and stylized market settings and yet provide the necessary features that capture the most important stochastic elements of the problem:

stochasticity of reservation prices, origin and destinations, time windows, and competitors' bids and costs.

The parameters to be varied include:

- Number of Carriers: 1, 2, 5, or 10 with fleet sizes of 10, 5, 2, and 1, respectively
- Poisson Arrival Rate: from 8 to 20 shipments per unit of time (very uncongested to extremely congested conditions)

Results and Insights

Though these numerical results depend on the experimental design parameters considered, they also provide initial insight into the performance of these kinds of marketplaces. The results were obtained from 30 simulations including 10,000 shipments each. As expected, the number of carriers has an important effect on the consumer surplus of shippers (Figure 2). Clearly, competition affects consumer surplus at a decreasing rate. Keeping a constant total fleet size of 10 vehicles, the consumer surplus (calculated as the accumulated reservation price minus the price paid to the winning carrier) begins to taper between 2-4 carriers. Carrier profit decreases as the number of carriers increases, and similarly to consumer surplus, it also tapers out. Consumer surplus and carrier profit will even out at around the same point, 2-4 carriers, because with a Vickrey auction carrier profits and consumer surplus are complementary; in other words, holding all parameters constant but varying the number of carriers, the sum of carriers' profits and consumer surplus is a constant. The consumer surplus for the case of one carrier corresponds to the case when shippers can set a ceiling to the amount to be paid to the carrier. Obviously there is a degeneracy problem since there is no second bid (to determine what the winner gets paid). The sum of the consumer surplus and carrier profits must add up to a known number, but each value cannot be determined without further assumptions.

The price of bids won remains consistent regardless of the number of carriers (Figure 3). However, there is a variation in the price of bids lost. When more carriers enter the system, it is on average for the second lowest cost carrier more costly to pick up an additional shipment since the fleets are smaller and hence the price higher.

Carrier profit will reach a peak near full fleet utilization. This occurs at an arrival rate near 15 for the system being examined (Figure 4). The number of won bids for the carries evens out and the number of infeasible shipments increases exponentially for arrival rates higher than 15 (Figure 5).

Figure 6 shows how consumer surplus and total welfare also tapers as the system approaches capacity. The slight increase in total welfare is due to an increase in carrier profits; as the arrival rate increases, it is easier to find feasible shipments that can be added to the end of the existing queues of shipments for each truck (Figure 7). Most of the surplus goes to the carrier, given that the second price will be very high or non-existing. This results from the infeasibility of the competitors when the market is under high arrival rates.

Higher insertion costs also explain why empty distance and the price of the winning bid increase with the arrival rate (Figures 8 and 9). However the average loaded distance decreases because there is a higher probability of appending shorter shipments at the end of the trucks' shipment queues (while maintaining feasibility).

CONCLUSIONS

The complex interaction of shippers and carriers through auction marketplaces (virtual hubs) may alter logistic networks in the medium term, and the way infrastructure and equipment are used and operated in the long term. A simulation framework was used to explore the complex engineering and economic processes that arise in a transportation marketplace, which are difficult to explore using standard analytical or statistical tools. Four different levels of analysis were explored: interaction patterns, interaction behaviors, welfare outcomes, and service levels. This framework blends concepts and tools from fleet management, evolutionary economics, game theory, and learning and cognitive science, in a manner that enables:

(a) Development of a test bed for the testing, refinement, and extension of dynamic pricing, bidding, and fleet assignment strategies;

(b) Study of the performance and evolution of different market settings; and

(c) Understanding of the connections relating structure, behavior, and welfare outcomes in markets comprised of boundedly-rational agents who learn imperfectly from the past

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1.	Commodities Traded • Shipments • Cargo capacity • Spot / Long term market • Swapping / reselling / speculation
2.	Decision Making Process / Bidding Resolution • Centralized • Decentralized • Hybrid
3.	Information Sharing Policies • About competitors' past bids • About competitors' fleet status • About fulfilled shipments or bids processes (resolute shipments) • Number of competitors watching or bidding • About shipments reservation price. • About carriers endowments: fleet and crew size • Ex-ante vs. ex-post availability of information • Perfect Public Information • About competitors' fleet management and bidding strategies • About competitors' beliefs
4.	Auction Design • First Price Sealed Bid Auction • Second Price Sealed Bid Auction • English Auction • Dutch Auction • Double Auctions • Combinatorial Auctions
5.	Commitment of players • Firm commitment at all times for any submitted bid • Bidding with given commitment duration • Bidding is allowed (Not allowed) while the results of previous bids are still unknown • Flexible commitment (shippers-carriers) • Bid firm for a small time window Conditional bidding (Shipment bundling or combinatorial auctions)
6.	Modal / Geographic Setting • TL, LTL Services • Ocean, Rail, Air Services • Intermodal • Urban, Intercity, International Freight • Geographic Shape, origin-destination areas • Arrival rates

Table 1 Market Settings and Dimensions

Agent	Function
Market Agent	1. Linkage and communication between carriers and shippers 2. Bidding processing 3. Bid Awarding 4. Track statistics of performance data
Carrier	1. Gathering, storing and processing information 2. Updating beliefs a. about shippers b. about carriers c. about my service costs and fleet management 3. Estimating expected utilities 4. Bidding submission 5. Fleet management 6. Track statistics of performance data
Shipper	1. Generate stream of arrivals and shipment attributes 2. Track statistics of performance data

Table 2 Overview of Agents Functions

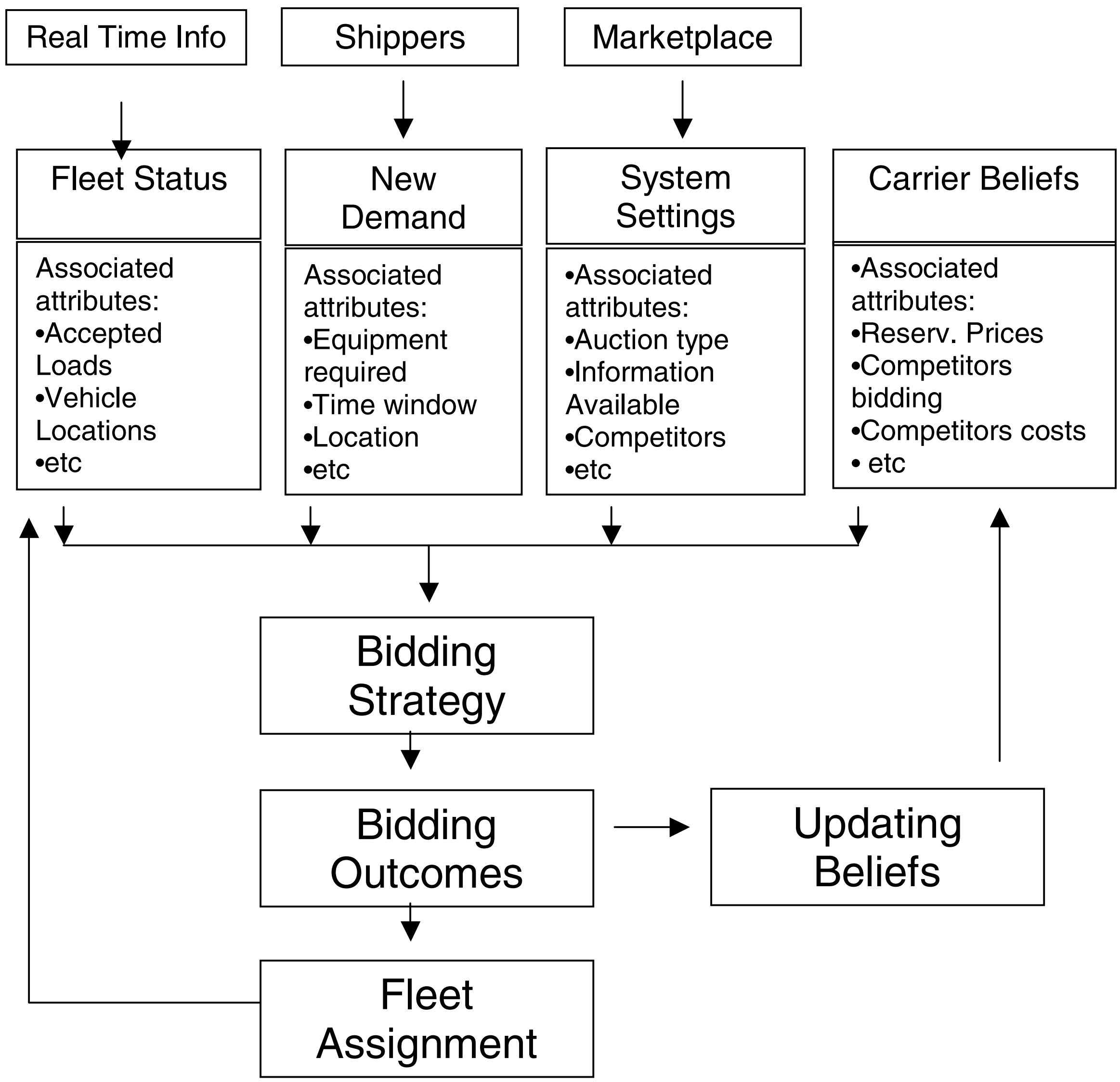

Figure 1 Overview of an auction marketplace

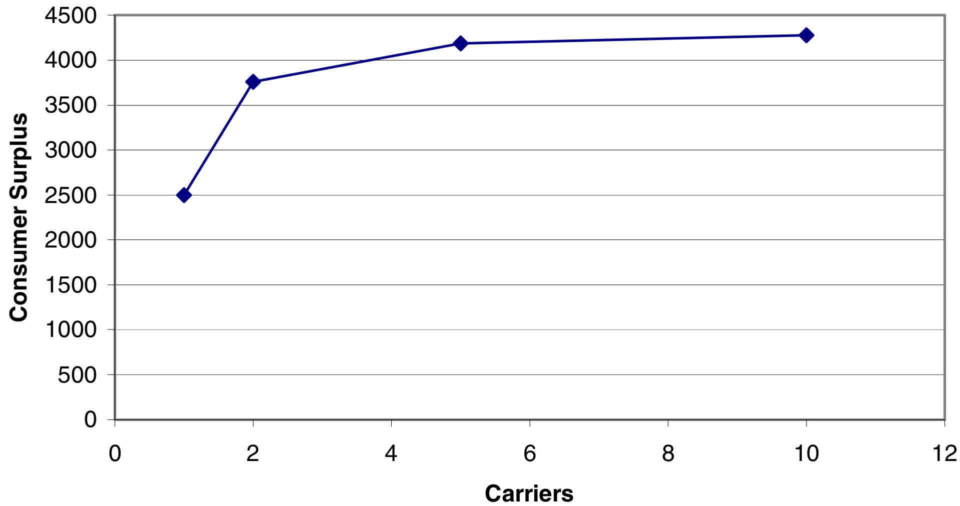

Figure 2 Consumer Surplus vs. Number of Carriers

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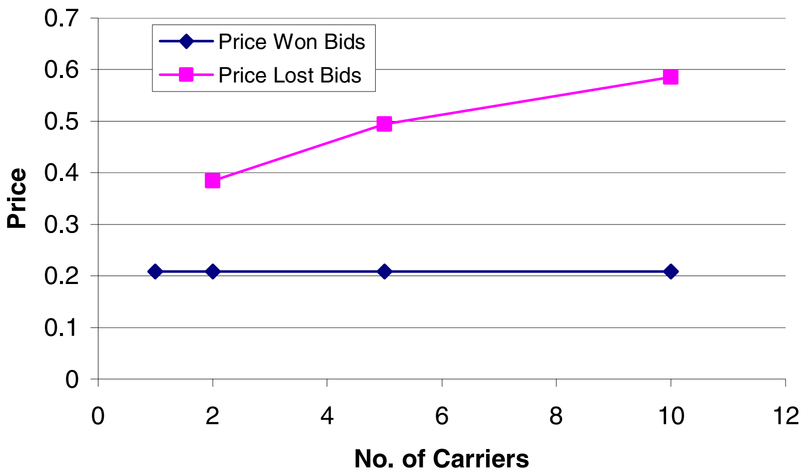

Figure 3 Average Prices of Bids (per carrier) vs. No. of Carrier

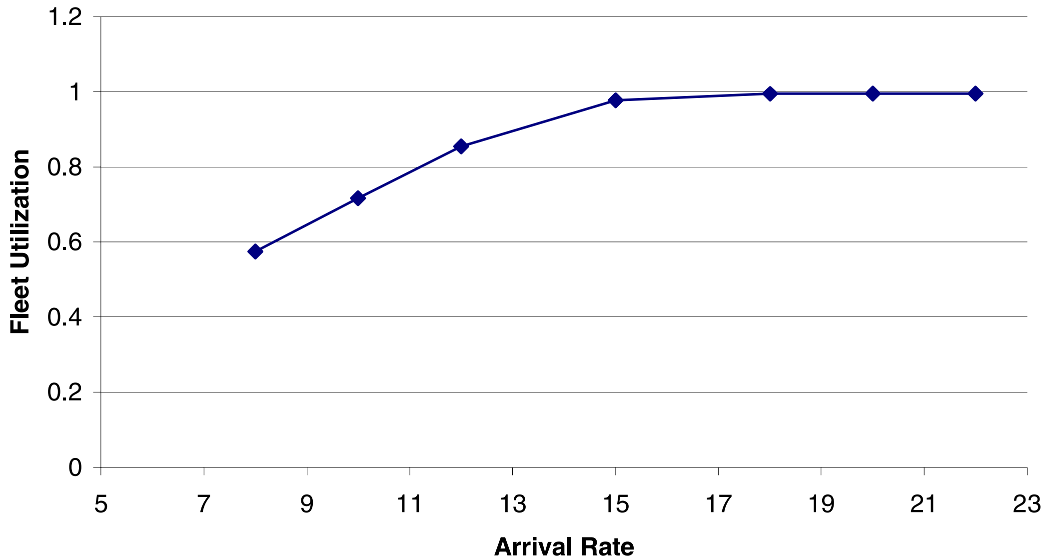

Figure 4 Average Fleet Utilization vs. Arrival Rate

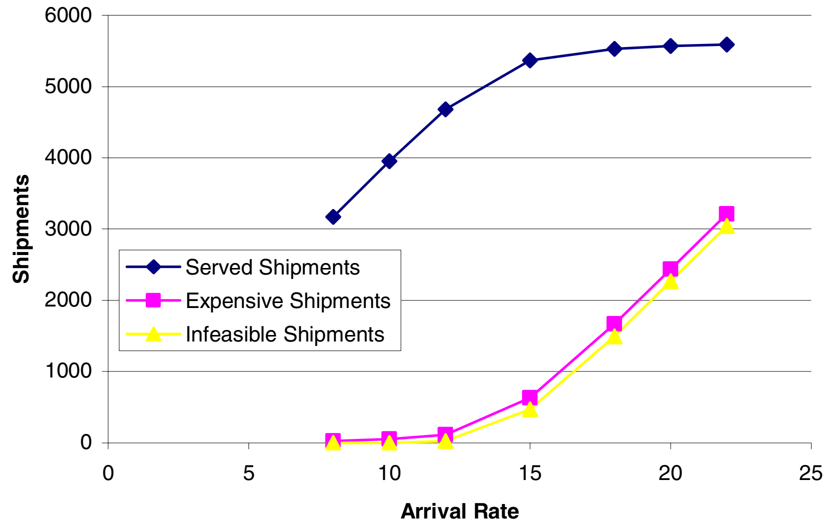

Figure 5 Shipments Served vs. Arrival Rate

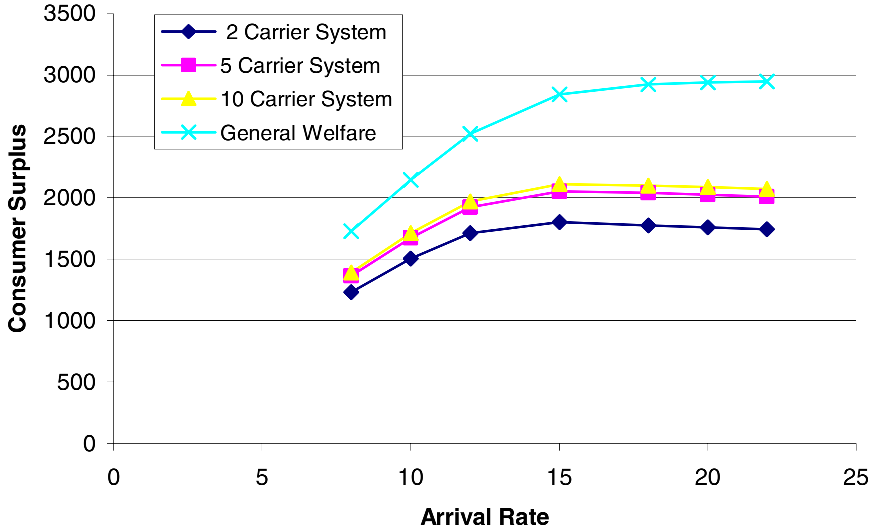

Figure 6 Consumer Surplus and General Welfare vs. Arrival Rate

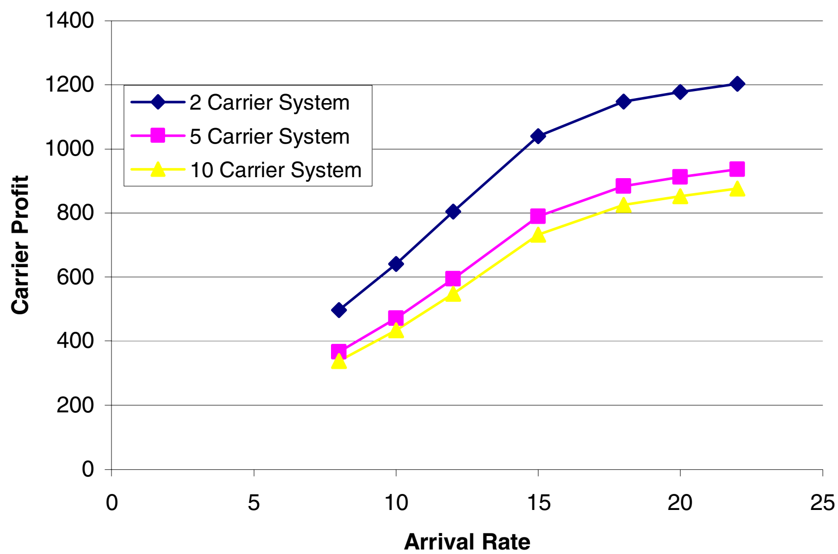

Figure 7 Carrier Profit vs. Arrival Rate

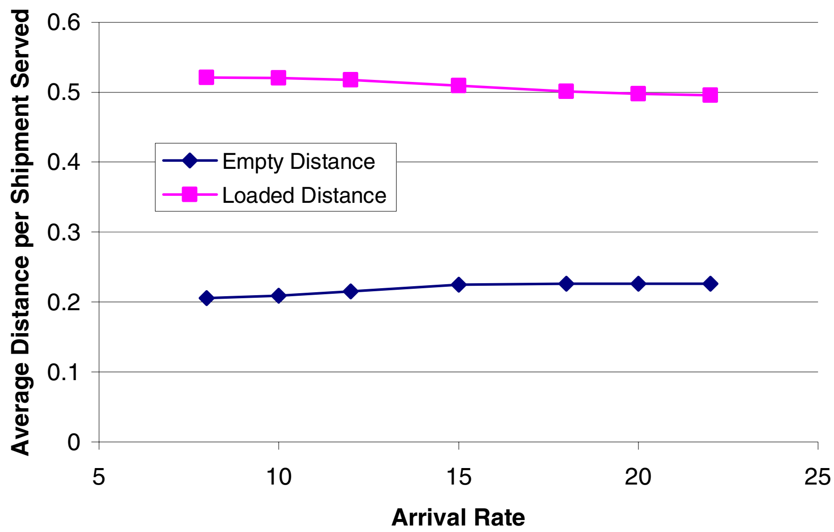

Figure 8 Empty and Loaded Distance vs. Arrival Rate

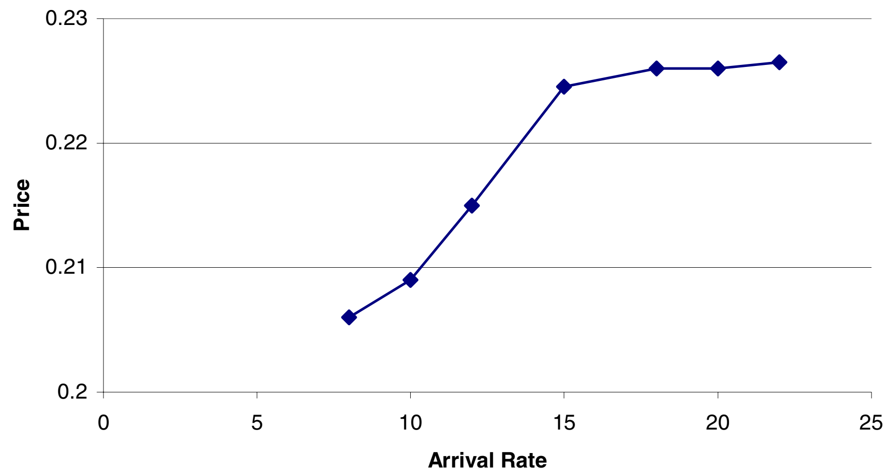

Figure 9 Average Price Bids Won vs. Arrival Rate