Paper No. 03-4370

Framework for Study of Carrier Strategies in Auction-Based Transportation Marketplace

Miguel Andres Figliozzi, Hani S. Mahmassani, and Patrick Jaillet

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 and that are difficult to explore by using standard analytical or statistical tools. Some results and the overall simulation framework are also discussed.

It is well recognized that information and communication technologies (ICTs) are changing many aspects of the way in which 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 mostly been limited to generalities and speculation, with few attempts to provide formal models or numerical results.

The changes that ICTs could bring to companies' strategies and market structures have been examined from a broad perspective. As early as 1987, Malone et al. predicted that reducing coordination costs (while holding other factors constant) should increase the proportion of economic activity coordinated by the markets (*2*). 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 investigators suggest the opposite, namely, that the widespread availability of ICTs will reduce the number of suppliers and foster long-term cooperative partnerships (*3*). These two opposing views lead to the market model and to the emergence of hierarchies, respectively. 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 that can be used to sell and buy goods and services 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.

M. A. Figliozzi and H. S. Mahmassani, Department of Civil and Environmental Engineering, Martin Hall, University of Maryland, College Park, College Park, MD 20742. P. Jaillet, Department of Civil & Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139-4307.

DEFINITION OF AUCTION MARKETPLACES

Many Internet-based sites have emerged to serve the transportation industry, and they offer 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, mainly on the basis of price, yet that still satisfy customer level-of-service demands. The specific focus of the study is the reverse auction format, in which shippers post loads and carriers compete over them (bidding).

McAfee and McMillan 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 (*6*). 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 an uncertain or a nonstandard value.

Transportation auctions are a relatively recent phenomenon, characterized by rapid change and fast development. This type of market has not yet reached maturity, as indicated by the significant number of start-ups, mergers, consolidations, and liquidations that have taken 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 18, 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, and so forth. Even if auctions are not the most-used procurement tool for transportation services, they provide a useful and appropriate framework to

- Gain insight into the 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' levels of service, and
- Monitor system evolution and describe market conditions by using price and other performance parameters as system indicators.

However, as detailed below, transportation marketplaces possess certain characteristics that preclude the direct transferability of the conclusions and the 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 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, which are "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), which is 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 when products have no standard value (*8*), as opposed to situations in which a fixed price can be posted for the products. In the case of transportation services, the price can be reasonably bounded by (*a*) 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) and (*b*) what the carrier must pay for rerouting the vehicle, loading time, unloading time, and extra compensation for the driver (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, nonstorable commodities;
- The penalties or 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;
- Demand and supply are uncertain over time and space;
- Future fleet use levels are uncertain;
- The value of the traded item (shipment) may be strongly dependent on the acquisition of other items (e.g., nearby shipments); that is, there is a group effect;
- The value of a shipment is related to the current spatial and temporal deployments of the fleet; that is, there is a network effect; and
- There are strong substitution or 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 shippers and carriers 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 or 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 or her actions have a significant impact on his or her rival's payoffs and vice versa. Compared with 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 by using game theory. Game theoretical 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 the 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 bids strategically in an effort to exploit market power opportunities.

The repeated interaction among oligopolistic carriers allows the possibility to learn about strategies, the environment, and competitors. This realistic assumption implies that carriers can analyze the history of play with different degrees of sophistication and estimate the possible future consequences of current actions. Therefore, carriers and shippers must be modeled as entities or intelligent agents that determine their interactions 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 establish an expected connection to a relatively new branch of economics, agent-based computational economics (*14*), which studies the economics of self-organization and evolution on the basis of the following:

1. Heterogeneous agents interact among each other and with the environment on the basis of their behavior and experience.
2. Agents coevolve 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 coevolve.
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 agent-based computational economics 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 that will determine an individual player's optimal decision-making 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's 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-making framework for fleet operations.

Advances in ICTs have also affected the ways in which 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 are key inputs needed 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 the drive to the load at the time that it must be moved or serviced. Different approaches to solving the dynamic vehicle routing problem include stochastic programming (*17*, *18*), variations of the probabilistic traveling salesman problem (*19*), and heuristics for real-time applications (*20*).

As described 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 fields mentioned above 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 must keep in mind the marginal cost and desired profit from a particular transaction. This is often difficult in real-time situations. Furthermore, this is increasingly difficult when optimal decision-making entails the solution of NP hard problems (problems in which the computational time required to reach an optimal solution grows exponentially as the 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 the 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 into the cost of serving future shipments;
3. Fleet management complexities (vehicle routing problems, with time windows, penalties, etc.); this is an NP hard kind of problem, and for real-world fleet sizes, these problems cannot be solved optimally;
4. The need for fast responses; information is received and updated in real time, and responses to requests and changes in initial conditions must be dealt with before the arrival of new requests or changes in the initial conditions take place;
5. Demand; spatial and temporal stochasticities preclude the use of naïve or unsophisticated bidding and fleet management techniques; and
6. Combinatorial bidding (bidding on bundles), which makes the problem even more complicated if it 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

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, for example, the number of carriers, arrival rates, and auction types, in a wide spectrum of scenarios allowed by the many potential market settings. Table 1 provides a categorized list of parameters that can be studied 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 noncooperative decision environment with various 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 for studying important questions and a test bed for defining and investigating bidding and operational strategies for fleet management.

MARKETPLACE AGENTS

The 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 the completion of transactions between carriers and shippers. Carriers are the sellers of transportation services. Carriers' behaviors are described 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 conditioned by the carrier's state, and carriers coadapt their behaviors as the marketplace evolves over time. The number of carriers is an important parameter. In an oligopolistic market (a market with relatively few carriers), a present carrier's action may influence competitors' future behaviors and significantly affect its own future profit. On the other hand, with a relatively large number of carriers, the actions of an individual carrier

TABLE 1 Market Settings and Dimensions

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

NOTE: TL = truckload; LTL = less than truckload.

would not significantly alter its future rewards by modifying other players' behaviors.

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, costs incurred when there is not enough stock or inventory to fulfill a request, time window, etc.). Furthermore, shippers maximize profits by setting the right reservation price, the highest price that a shipper is willing to pay a carrier for servicing a given shipment. The shipper achieves a profit (savings) when it pays less than the reservation price. A rational shipper rejects transportation services exceeding the reservation price (the shipper does not incur a loss). Table 2 summarizes the functions performed by each agent type in the 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 (a population much larger than the number of carriers) is considered, the individual effect of a shipper on the system's outcome is negligible. The reservation prices are derived mostly from individual shipper's characteristics rather than from strategic or learning considerations.

Figure 1 presents a schematic overview of how a transportation auction 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 updates of their own beliefs to take into account bidding outcomes and service costs.

TABLE 2 Overview of Agents' Functions

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

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. Samples of performance measures by agent type are provided below.

1. Marketplace level: total system welfare, number of inefficient outcomes (the 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), and lost welfare (lost wealth originated by inefficient outcomes);
2. Shipper: consumer surplus, service time, and percentage of served loads; and
3. Carrier: profit, fleet utilization, ratio of the loaded to the empty distance, empty distance, loaded distance, number of shipments in the carrier's system, and market share.

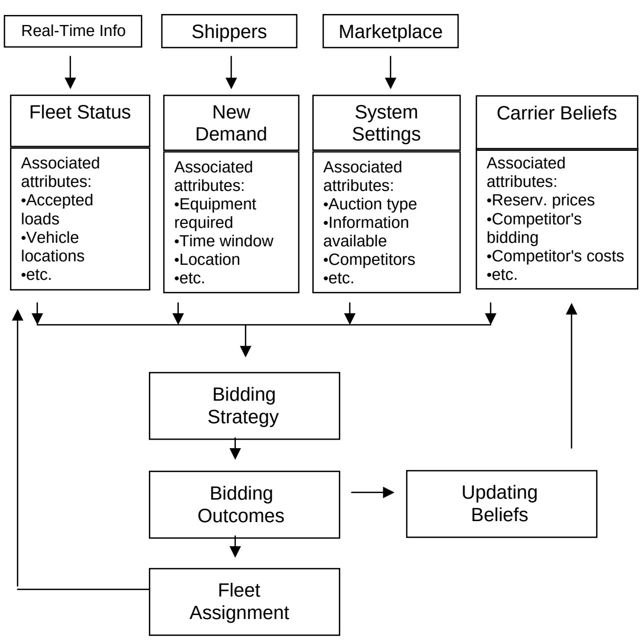

FIGURE 1 Overview of an auction marketplace (reserv. = reservation).

EXPERIMENTAL DESIGN AND RESULTS

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

A Vickrey or second-price auction is used. This is a one-shot (or one-period) auction in which 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 that rational carriers that are profit maximizers bid in each instance, with no look ahead; i.e., the future is ignored), 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 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 a Vickrey auction is used, it is possible to concentrate on the effect that the arrival rate and the 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 the 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 the carriers' fleet assignment strategies are 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;

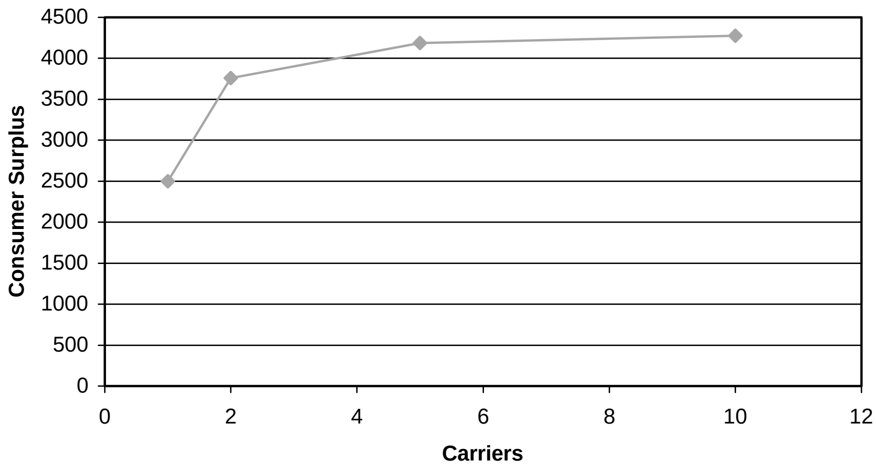

FIGURE 2 Consumer surplus versus number of carriers.

- Shipment type: truckload movements only;
- Shipments reservation price: ≈uniformly distributed (0.5, 1.0);
- Shipment time window length: four 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); and
- Fleet size: 10 vehicles (constant) serving the market.

As stated earlier, these are simple and stylized market settings, yet they provide the necessary features that capture the most important stochastic elements of the problem: the stochasticities of reservation prices, origins and destinations, time windows, and competitors' bids and costs.

The parameters to be varied include (*a*) the number of carriers (1, 2, 5, or 10 with fleet sizes of 10, 5, 2, and 1, respectively) and (*b*) the Poisson arrival rate [from 8 to 20 shipments per unit of time (very uncongested to extremely congested conditions)].

RESULTS AND INSIGHTS

Although 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. When the total fleet size is kept constant at 10 vehicles, the consumer surplus (calculated as the accumulated reservation price minus the price paid to the winning carrier) begins to taper off at between two and four carriers. Carrier profit decreases as the number of carriers increases, and similar to consumer surplus, it also tapers off. Consumer surplus and carrier profit even out at about the same point (two to four carriers), because with a Vickrey auction, carrier profits and consumer surplus are complementary; in other words, by 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 in which shippers can set a ceiling to the amount to be paid to the carrier. There is obviously 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, on average for the second-lowest-cost carrier, it is more costly to pick up an additional shipment, since the fleets are smaller and hence the price is 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 carriers 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 general welfare also taper as the system approaches capacity. The slight increase in general 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 nonexistent. 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, respectively). However, the average loaded distance decreases

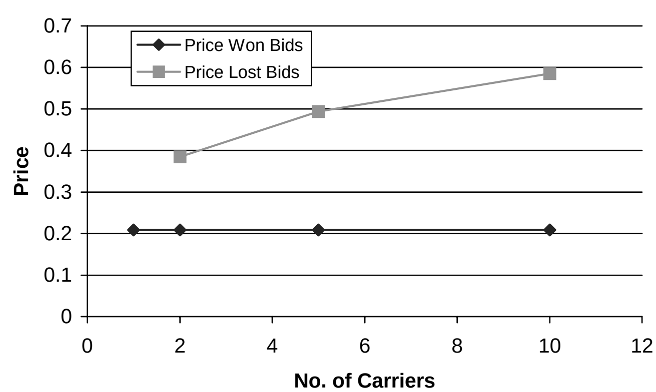

FIGURE 3 Average prices of bids (per carrier) versus number of carriers.

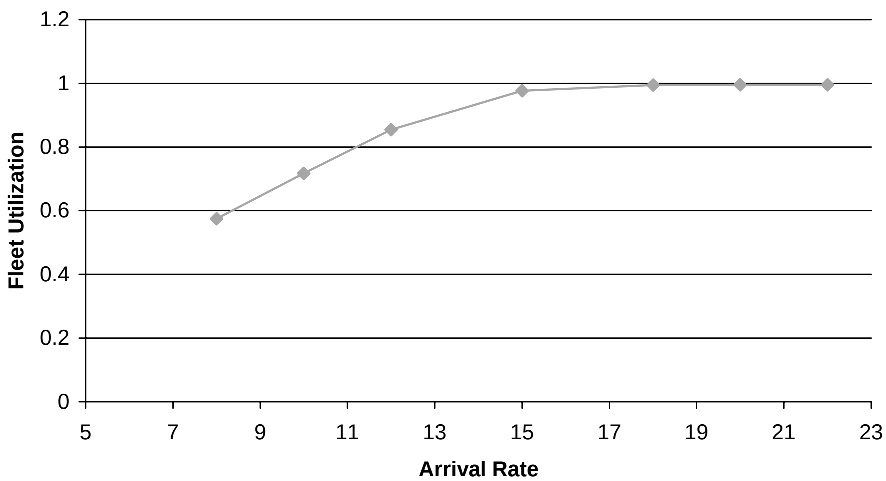

FIGURE 4 Average fleet utilization versus arrival rate.

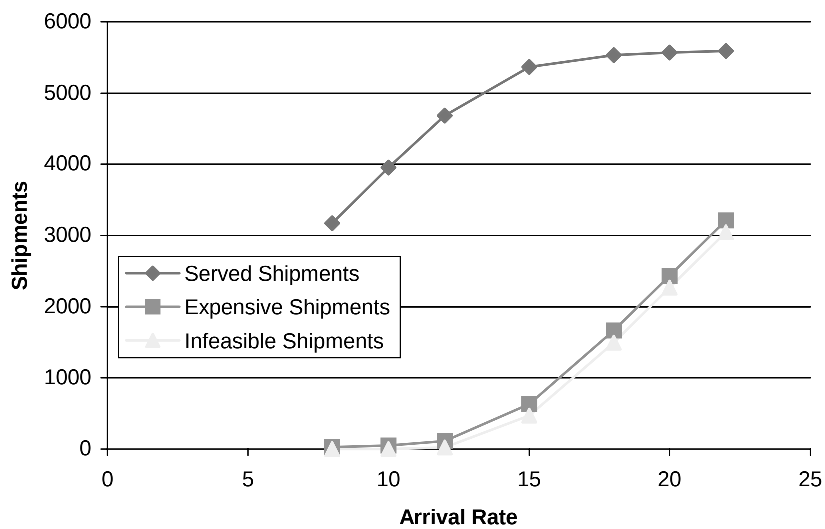

FIGURE 5 Shipments served versus arrival rate.

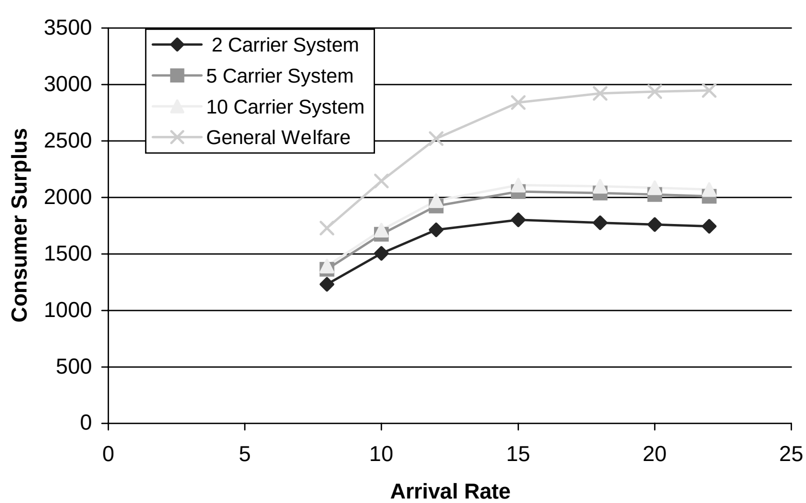

FIGURE 6 Consumer surplus and general welfare versus arrival rate.

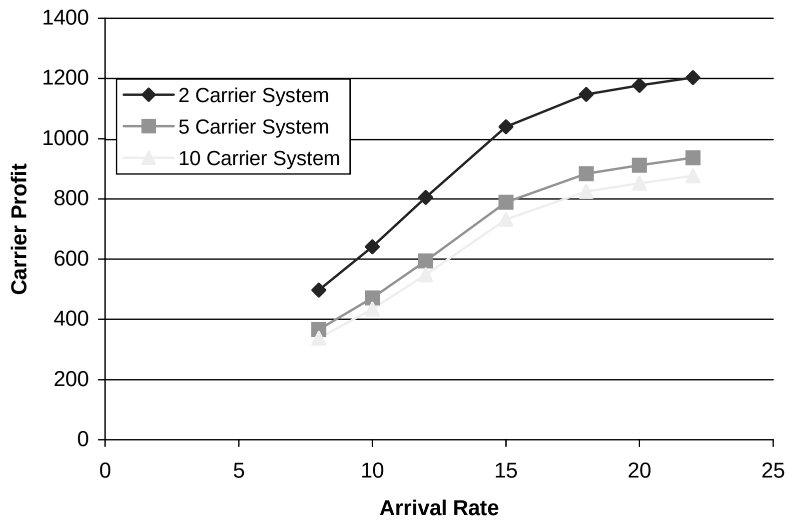

FIGURE 7 Carrier profit versus arrival rate.

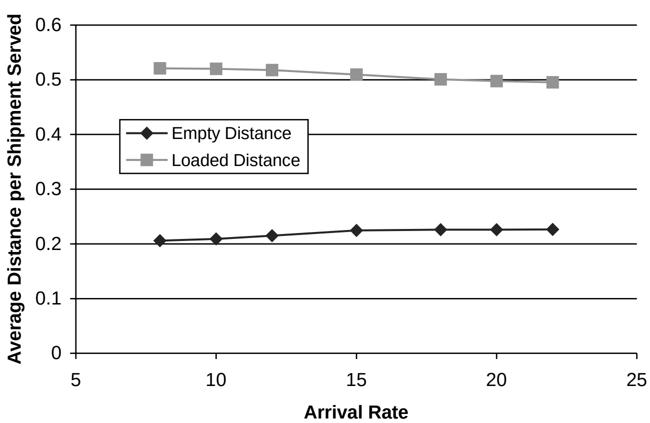

FIGURE 8 Empty and loaded distances versus arrival rate.

because there is a higher probability that shipments covering shorter distances will be appended 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 ways in which 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 by 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

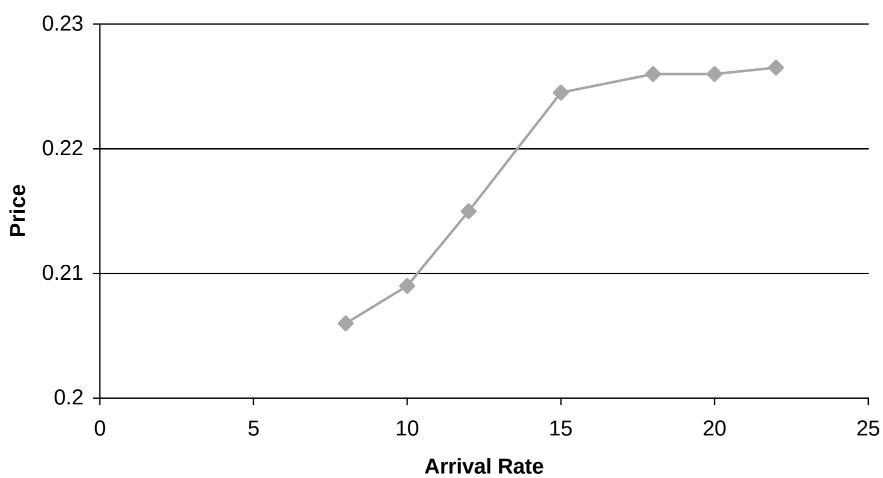

FIGURE 9 Average price of bids won versus arrival rate.

tools from fleet management, evolutionary economics, game theory, and learning and cognitive sciences in a manner that enables

1. Development of a test bed for the testing, refinement, and extension of dynamic pricing, bidding, and fleet assignment strategies;
2. Study of the performance and evolution of different market settings; and
3. Understanding of the connections relating structure, behavior, and welfare outcomes in markets that comprise boundedly rational agents who learn imperfectly from the past.

ACKNOWLEDGMENTS

This study was supported by a grant from the National Science Foundation. The authors acknowledge the contribution of Jessica Wang in conducting the simulations and preparing the graphical output.

REFERENCES

1. Regan, A. C., H. S. Mahmassani, and P. Jaillet. Improving Efficiency of Commercial Vehicle Operations Using Real-Time Information: Potential Uses and Assignment Strategies. In *Transportation Research Record 1493,* TRB, National Research Council, Washington, D.C., 1995, pp. 188–198.
2. Malone, T., J. Yates, and R. Benjamin. Electronic Markets and Electronic Hierarchies: Effects of Information Technology on Market Structure and Corporate Strategies. *Communications of the Association for Computing Machinery,* Vol. 30, No. 6, 1987, pp. 484–497.
3. Clemmons, E. K., and S. P. Reddi. Some Propositions Regarding the Role of Information Technology in the Organization of Economic Activity. *Proc., 26th HICSS,* Vol. IV. *Collaboration Technology and Organizational Systems and Technology.* IEEE Computer Society Press, Los Alamitos, Calif., 1993, pp. 809–818.
4. Holland, C. P., and G. Lockett. Strategic Choice and Interorganizational Information Systems. *Proc., 27th HICSS,* Vol. IV. *Collaboration Technology and Organizational Systems and Technology.* IEEE Computer Society Press, Los Alamitos, Calif., 1994, pp. 405–415.
5. Wolfe, E. M., T. R. Wadewitz, and C. G. Combe. e-Gistics: How e-Commerce and the Supply Chain Click, June 2000. http://wpinter2.bearstearns.com/egistics/. Accessed Oct. 10, 2000.
6. McAfee, R. P., and J. McMillan. Auctions and Biddings. *Journal of Economic Literature,* Vol. 25, June 1987, pp. 699–738.
7. Krishna, V. *Auction Theory.* Academic Press, 2002.
8. Cassady, R. *Auctions and Auctioneering.* University of California Press, Berkeley, 1967.
9. Sashi, C. M., and B. O'Leary. The Role of Internet Auctions in the Expansion of B2B Markets. *Industrial Marketing Management,* Vol. 31, 2002, pp. 103–110.
10. Lucking-Reiley, D., and D. Spulber. Business-to-Business Electronic Commerce. *Journal of Economic Perspectives,* Vol. 15, No. 1, 2001, pp. 55–68.
11. Tirole, J. *The Theory of Industrial Organization.* MIT Press, Cambridge, Mass., 1988.
12. Martin, S. *Advanced Industrial Economics.* Blackwell Publishers, Cambridge, Mass., 1993.
13. Fudenberg, D., and D. Levine. *The Theory of Learning in Games.* MIT Press, Cambridge, Mass., 1998.
14. Tesfatsion, L. Agent-Based Modeling of Evolutionary Economic Systems. *IEEE Transactions on Evolutionary Computation,* Vol. 5, No. 5, 2001, pp. 437–441.
15. Bower, J., and D. Bunn. Experimental Analysis of the Efficiency of Uniform-Price Versus Discriminatory Auctions in the England and Wales Electricity Market. *Journal of Economic Dynamics and Control,* Vol. 25, 2001, pp. 561–592.
16. Regan, A. C., H. S. Mahmassani, and P. Jaillet. Dynamic Decision Making for Commercial Fleet Operations Using Real-Time Information. In *Transportation Research Record 1537,* TRB, National Research Council, Washington, D.C., 1996, pp. 91–97.
17. Powell, W. B. A Stochastic Formulation of the Dynamic Vehicle Allocation Problem. *Transportation Science,* Vol. 20, 1986, pp. 117–129.
18. Bertsimas, D. J., P. Jaillet, and A. R. Odoni. A Priori Optimization. *Operations Research,* Vol. 36, No. 6, 1990, pp. 1019–1033.
19. Jaillet, P. A Priori Solution of a Traveling Salesman Problem in Which a Random Subset of the Customers Are Visited. *Operations Research,* Vol. 36, No. 6, 1988, pp. 929–936.
20. Mahmassani, H. S., Y. Kim, and P. Jaillet. Local Optimization Approaches to Solve Dynamic Commercial Fleet Management Problems. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1733,* TRB, National Research Council, Washington, D.C., 2000, pp. 71–79.
21. Vickrey, W. Counterspeculation, Auctions and Competitive Sealed Tenders. *Journal of Finance,* Vol. 16, 1961, pp. 8–37.
22. Varian, H. Economic Mechanism Design for Computerized Agents. *Proc., Usenix Workshop on Electronic Commerce,* New York, 1995.

The contents of the paper remain solely the responsibility of the authors.