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The stochastic bid generation problem in combinatorial transportation auctions

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ABSTRACT

In this paper, we deal with the generation of bundles of loads to be submitted by carriers participating in combinatorial auctions in the context of long-haul full truckload transportation services. We develop a probabilistic optimization model that integrates the bid generation and pricing problems together with the routing of the carrier's fleet. We propose two heuristic procedures that enable us to solve models with up to 400 auctioned loads.

1. Introduction

In a combinatorial auction (CA), the shipper (auctioneer) wants to procure long-haul full-truck transportation services in order to move a set of loads from their pickup to their delivery locations. Interested carriers have to submit bids to the auction on the transportation loads that they want to serve, not individually like in traditional auctions, but grouped into packages or bundles of loads.

CAs have been applied successfully in different application contexts. A non-exhaustive list of companies using CAs to procure transportation services includes Sears Logistics Services, The Home Depot, Walmart Stores, Compaq Computer Co., Staples Inc., The Limited Inc., Limited Logistics Services, Kmart Corporation, and Ford Motor Company (Caplice & Sheffi, 2006; Elmaghraby & Keskinocak, 2003; Guastaroba, Mansini, & Speranza, 2009; Ma, 2008; Remli & Rekik, 2012; Sheffi, 2004; Ueasangkomsate & Lohatepanont, 2012).

Operations Research plays an important role in this context. Each carrier faces the *Bid Generation Problem (BGP)* in order to construct the bundles of loads to be submitted in the auction as bids. From the other side each auctioneer has to define the set of loads to be auctioned by solving the *Shipper Lane Selection Problem (SLSP)* and also has to solve the *Winner Determination Problem (WDP)* in order to allocate the loads to the winning carriers.

The BGP is a complex challenge that bidders, traditionally, avoid to face by submitting only singleton load bids or by adopting simple strategies based on bidding on high value packages, on combining attractive loads with less desirable loads in order to beat the competitors, or on putting together loads that increase its market share in a given area.

The complexity of the BGP derives from the necessity of evaluating an exponential number of potential bundles representing all the possible subsets that can be made out by the auctioned loads. It has been highlighted, indeed, in Park and Rothkopf (2005), Parkes (2000) that the BGP is a NP-complete decisional problem. Another complicating aspect of the BGP consists in the necessity of taking into account the existent *synergies* between the loads. This is particularly important for the bidders when the items are characterized by complementarity, i.e., when the sum of the values of items taken singularly is smaller than the value of the bundle aggregating them (think, for example, about a pair of shoes that is worth more than the sum of the values of any unpaired shoe). This aspect of synergy plays a key role in the context of full-truckload (TL) long-haul transportation and such importance will be reflected in this contribution while developing our BGP model. Yet, relatively few contributions have targeted this important issue.

The present paper aims to address this challenging problem and has the goal of defining, designing, implementing and assessing innovative mathematical models and solution methods for the

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BGP in combinatorial auctions for the TL transportation procurement.

We consider here a single-round, one-sided, sealed-bid, first-price combinatorial auction in a transportation spot-market (Abrache, Crainic, Gendreau, & Rekik, 2007) and we develop an *advisor* that may assist carriers in their bidding decisions taking into account the dynamic planning of the transportation operations. Specifically, we try here to remedy the lack of available literature of integrated mathematical models that determine not only the most profitable bundle of loads to be submitted to the auction and its corresponding price, but also the resultant routing of the carrier's fleet in order to serve both the submitted bundle (a set of auctioned loads) and the pre-existent carrier's transportation commitments (called also booked loads in the sequel) in a stochastic settings. We propose, thus, a probabilistic mixed integer optimization model having the following innovative features:

- the consideration of the bundle price as a decision variable instead of computing it by using simplified formulas (as in Rodrigo (2007), Song & Regan (2004, 2005)) or considering it a parameter equal to the sum of the ask prices of the bundle's loads (as in Chang (2009), Lee, Kwon, & Ma (2007));
- the assessment of the stochastic nature of the problem by representing the auction clearing prices as random variables. Only Ergun, Kuyzu, and Savelsbergh (2007) dealt with this important aspect but for the simplified case of several single independent auctions running simultaneously instead of the CA considered in our model. Moreover, we model such clearing prices as normal random variables instead of the uniform ones as considered in Ergun et al. (2007);
- the inclusion into the model of a set of probabilistic constraints (chance constraints), which look up at guiding the selection of the bundle with the highest winning chance, i.e., the bundle whose price is guaranteed to be less than the corresponding clearing price by a certain probability threshold;
- the inclusion of the dynamic aspect of the routing problem by considering the space–time extended network for modeling the BGP (as only Chang (2009) did before);
- the determination of the routing of the trucks over the whole temporal horizon by solving a fleet management problem (and not a vehicle routing problem as proposed in Lee et al. (2007) for the static variant of the BGP);
- the enclosure of the time windows related to the pickup/delivery of every auctioned and booked load;
- the study of novel techniques for computing the synergies between the auctioned and booked loads and also within the bundle's loads.

The proposed model results to be, thus, more complete and more complex with respect to the already existing models for the BGP in combinatorial TL transportation auctions (Oprea, 2012).

The combinatorial nature of the problem has limited the exact solution of our model only to instances of moderate size, i.e., up to a certain cardinality of the set of auctioned loads. For higher dimensions, heuristic procedures that permit a sequential solution of the BGP have been constructed. The behavior of the proposed solution approaches has been evaluated on a wide range of test problems randomly generated to represent realistic contexts.

The paper is organized in six sections. In Section 2 we review the main scientific literature. In Sections 3 and 4 we introduce our mathematical model and we present our solution approaches, respectively. In Section 5 we report our experimental experience and discuss the numerical results. Finally, we draw in Section 6 some concluding remarks.

2. Literature review

The CAs have been proposed for the first time in 1982 by Rassenti, Smith, and Bulfin (1982) for the solution of an airport time slot allocation problem. They are multi-item auctions in which the bidders can define their own combinations of items (called packages or bundles) instead of bidding on single items or predefined bundles. These are flexible but more complex trading techniques with respect to the simultaneous auctions (Ergun et al., 2007) or the sequential auctions considered by (see for example Figliozzi (2004) and Figliozzi, Mahmassani, & Jaillet (2006)). Several excellent surveys have been published on how to design and run generic CAs (Abrache et al., 2007; Cramton, Shoham, & Steinberg, 2006; De Vries & Vohra, 2003; Gavish, 2003; Kalagnanam & Parkes, 2003).

In the TL transportation context, CAs offer significant advantages for both auctioneers and bidders. Auctioneers, indeed, can achieve more economic efficiency and transportation cost savings of up to 15 percent while maintaining or increasing their service levels (Sheffi, 2004). Bidders can take into account their economies of scope while expressing their preferences on the packages to be served.

Despite these benefits, CAs involve many inherently difficult problems to be faced not only by the bidders but also by the auctioneers who must face the solution of both the SLSP (Guastaroba et al., 2009) and the WDP (Remli & Rekik, 2012). While these last problems have been widely studied in the literature, there are only few studies that focused on the bid generation and evaluation problems. This scarcity of bibliographic contributions may be attributed to the objective difficulty of solving the BGP rather than its minor importance from the practical standpoint.

Crainic and Gendreau (2002) claim that carriers should analyze complex information available in the market and combine it with the management of their own fleet and personnel in order to determine their profitable bid strategies. The authors also point out that particular groups of loads may present a special interest for a given carrier due to the combinatorial nature of the carrier operations. Therefore, it is necessary to develop optimization-based decision support tools, the so-called "*advisors*", to help carriers making their decisions by combining efficiently the market information, the planning and the operation procedures in order to evaluate the select loads (see also Chang, Crainic, & Gendreau, 2002; Crainic & Gendreau, 2003).

Caplice and Sheffi (2003) argue that it is better to allow carriers to identify packages based on their own individual perspectives and networks since shipper specified packages result to be less successful for transportation. Caplice (1996) addresses several heuristic algorithms to help carriers generating open loop tours, closed loop tours, inbound/outbound reload packages, and short haul packages by using expected savings based on historical load volumes.

An, Elmaghraby, and Keskinocak (2005) propose a model to assess the bundle values given the pairwise synergies for single-round, first price, sealed-bid forward combinatorial auctions. They also developed bundle construction algorithms for selecting profitable bundles. Their algorithms add as many profitable items as possible to a bundle given that the value of a bundle increases, on average, linearly with the bundle size. The synergy model proposed in An et al. (2005) has as input the item values and pairwise synergy values and as output the bundle values for any combination. They also propose three bundling strategies focusing only on generating bundles (and not on pricing them) since they assume a fixed profit margin for their bids. However, since real data from