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RESEARCH ARTICLE

Combinatorial-Based Auction for the Transportation Procurement: An Optimization-Oriented Review

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ABSTRACT This paper conducts a literature review on freight transport service procurements (FTSP) and explores the application of combinatorial auctions (CAs) mechanism and the mathematical modeling approach of the associated problems. It provides an overview of modeling the problems and their solution strategies. The results demonstrate that there has been limited scholarly attention to sustainable issues, risk mitigation and the stochastic nature of parameters. Finally, several promising future directions for FTSP research have been proposed, including FTSP for green orientation in the context of carbon reduction, shipper's reputation, carrier collaboration for bid generation, etc.

INDEX TERMS Literature review, combinatorial auction, FTSP problems, mathematical modeling, logistics and supply chain management.

I. INTRODUCTION

One of the most important aspects of logistics and supply chain management is transportation, which connects supply chain stakeholders to create a physical flow of materials. Transportation management is the backbone of the entire supply chain in logistics and is crucial since it represents almost one-third of the logistic costs (https://www.cogoport.com/blogs/transport-cost). Proper transportation management guarantees that the appropriate product is delivered to the right client at the right time. Transportation management also ensures that the overall characteristics of a product, such as size, shape, and condition, remain intact.

The digital transformation of management systems has changed the traditional transportation management and modern technology with the internet making operational actions happen more quickly [1], [2]. Also, technology enhances safety issues, for example, Advanced Driver Assistance Systems, as an integral component of intelligent transportation systems [3] that improves driving safety by assisting drivers in recognizing and addressing potential hazards in real-time. This reduction in accident risks saves lives and minimizes disruptions to the flow of goods and services, leading to more stable and reliable supply chains.

Although contemporary virtual reality reduces the need for physical activities such as choosing, ordering, and changing services by using online platforms, a firm cannot operate solely virtually to ensure its transportation needs of physical goods. Thus, logistics managers need to pay more attention to such a complex transportation management system characterized by its multitype mode, dependency of goods types and different sizes, geographical position of origins and destinations, specific time windows, etc.

Consequently, research on transportation management is even more important to help logistics managers to implement innovative technology and techniques. Researchers have been addressing a number of procurement methods [4], [5], [6], [7], [8] in digital progression [9] to reduce transportation costs while enhancing service quality. But the expansions of modern technologies and the new mode of transportation are posing critical challenges for FTSP [10].

Transportation service procurement is the primary strategic process of sourcing, negotiating, and contracting services to

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optimize cost, efficiency, and reliability in a supply chain. It encompasses the selection of transportation modes, carriers, and routes, as well as the management of tenders, contracts, and supplier relationships. This process plays a critical role in logistics management, enabling businesses to improve customer satisfaction, reduce lead times, and minimize transportation costs while adhering to regulations and sustainability goals. Whether in principle or practice, multiple procurement methods are available in today's freight transport markets. There is no unique answer for all FTSP challenges. Study [11] reported three primary mechanisms for transportation procurement: auction, negotiation, and catalog. They found that researchers have addressed the mechanisms of an auction at 81%, negotiation at 15%, and catalog at 2% in academia. But in practice, auction is being applied at 26%, negotiation at 71%, and catalog at 3% are used for transport procurement. Although the auction mechanism attracted the highest in academia, and the negotiation mechanism is highest in practice, the use of the auction mechanism for transportation procurement is gradually increasing in practice due to the advancement of smart technologies. In addition, an auction has become the mechanism for determining market-based pricing because bidders decide the price through competitive bidding. Potential purchasers want to know the maximum price to own goods or services and look for the best possible picks. From the shipper's perspective, processing contracts for an auction may increase the number of bidders and enhance the opportunity for competitive bidding and higher selling prices. The bundling concept of transportation services strengthens the effectiveness of the auction.

Thus, a system was needed for bundle buy and sold shipment transportation procurements to allow participants to declare prices for complete packages. As a result, CAs, where bids are placed on packages of discrete items, were created. Nowadays, CAs are more attractive than the individual-item auction mechanism in transportation procurement despite the complexities in modeling and optimizing being reported by various researchers [12], [13], [14], [15], [16], [17]. Thus, a comprehensive literature review of CA mechanisms in transportation procurement optimization is crucial to unearthing the current situation, trends, and future opportunities for FTSPs. This study addresses the following research questions by reviewing the existing literature on transportation service procurement mechanisms:

a. What are the main problems characterizing the FTSP under CA mechanisms and their modeling issues?
b. What are the major features that have been studied in the context of FTSP research under CA mechanisms?
c. What are the future opportunities for FTSP research?

A relevant literature review was carried out in [18] for the full truckload transportation service procurements. They discussed the bid generation problem (BGP), carrier assignment problem or winner determination problem (WDP), and collaboration problems in the context of demand patterns, price and non-price objectives, bid types as individual or combinatorial, and the category of papers as conceptual, mathematical, simulation, and case studies. The findings included simplistic demand patterns, a restricted focus on non-price variables, limited case studies, and little consideration of sustainability issues. Study [11] conducted another comprehensive literature review on FTSP, examining existing freight transportation organizations and procurement mechanisms. They discussed challenges and opportunities in omnichannel E-commerce and highlighted different procurement mechanisms, transportation modes, and sectors. The study also addressed the different classifications of auctions used in FTSP, terms of agreements, outcomes, and articles used to create their methodology.

On the other hand, the study [17] carried out a literature review to identify and explore the complicated issues surrounding the design of combinatorial auctions. They focused on four topics: the classifications and formulations of combinatorial auctions, combinatorial bid expressions, multi-round mechanism designs for determining allocations and prices when complete information about participants' preferences is unavailable, and the decision problems faced by participants in CAs. Then the study [19] reviewed the design of combinatorial auctions, emphasizing the conservation auctions. The key design aspects of combinatorial auctions include the challenge of selecting the winning offer, price structures, and the usage of iterative bidding formats that allow bidders to change their bids before a final decision is made. They investigated the CA in order to obtain a variety of agri-environmental services, such as native plant and other habitat conservation, wildlife protection, pollution offsets, and salinity management.

To the best of the authors' knowledge, a comprehensive review of recent literature that addresses the different issues related to modeling in FTSP problems under CA mechanism and their solution approaches is not available. Motivated by the importance of modeling in the FTSP research, this study investigated existing models for CA mechanisms. This work focusses on reviewing different FTSPs under CA model types, problems, and solution methods.

This paper is structured in the following manner. Section II presents the research methodology and data visualization. Section III describes the optimization problems in CA. Sections IV, V, and VI analyze the bid generation, winner determination, and shipper lane selection problems. Finally, the conclusions of this study with some promising research avenues for FTSP under CA have been drawn in Section VII.

II. REVIEW METHODOLOGY AND DATA VISUALIZATION

The issues of FTSP in a CA environment and their mathematical models are complex because of the intricacies of CA mechanisms. Therefore, the methodology of this literature review was configured by selecting databases, keywords, and exclusion and inclusion criteria, categorizing selected articles, analyzing different features of problems, and identifying future scope. Fig.1 depicts the overview of the methodology.

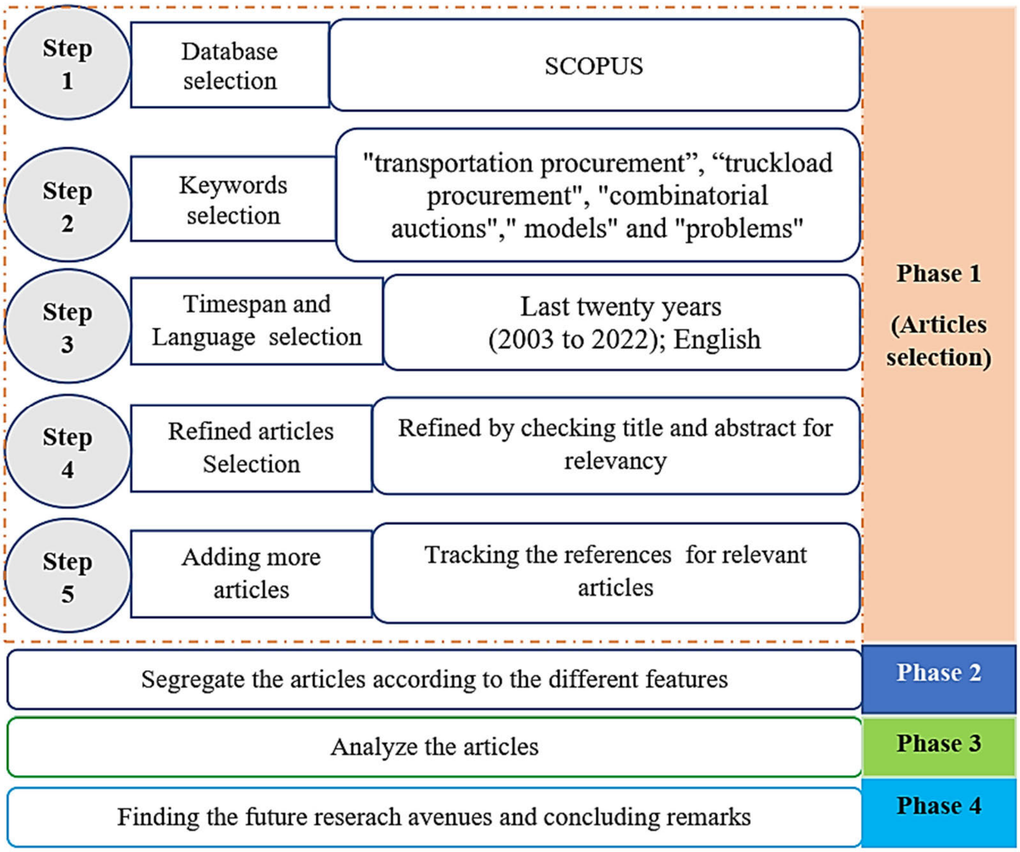

FIGURE 1. Review methodology.

In Fig. 1, Phase 1 shows the relevant article selection process for this study. A literature search using selected keywords (Step 2) and considering timespan and language (Step 3) produced 47 articles. Each article was then analyzed by reading the title and abstract (Step 4) to check the article's relevancy and to exclude irrelevant articles. This process reduced the set to 37 articles. Reference tracking of the 37 articles yielded 12 additional but relevant articles. These were added to produce a final set of 49 articles. Moreover, we carefully examined the relevant literature review articles in this field [11], [17], [18], [19], [70].

When reviewing the relevant articles, attention was drawn to the types of problems addressed by the researchers. The issues discussed were primarily from the perspectives of the bidder/carrier (or auctioneer/shippers). The main issues from the carrier side were the BGP, also called the bid construction problem (BCP). On the other hand, shipper's main challenge was assigning appropriate carriers to shipment lanes leading to the carrier assignment, better known as the WDPs. Along with these two main, there is another important but less addressed problem which is the shipper lane selection problems (SLSPs) or shipper contract selection problems (SCSPs). These are pre-auction issues that deal with prescribing which lanes shippers' own fleets will serve and which ones will be handled by third-party logistics (3PLs) through CA.

When the nature of CAs was analyzed, two types were found: single-round (SR) (sealed bid or first-price, etc.) and multi-round (MR). The single-round auction is a typical procedure. All bidders must submit their bids by a specific date in this design. The auctioneer examines all the offers simultaneously and selects the group of bidders that maximizes the seller's profit. On the other hand, a multi-round auction allows for more sophisticated bidding by allowing post-round information to be strategically used (see[20]).

The environment of the FTSP process is identified as truckload (TL) and less than truckload (LTL). Different mathematical modeling techniques and solution methods appear. The nature of models can be deterministic or stochastic depending on known and unknown inputs.

Mathematical modeling problems are then characterized as linear programming (LP), mixed-integer linear programming (MILP), or non-linear programming (NLP) models. Studying models is necessary for describing objectives, making decisions, and optimizing resources. Modeling of the problems addressed the objective, either single or multiple. Considering the problem and modeling perspective, the main criteria for categorizing the literature in this study are presented in Fig. 2.

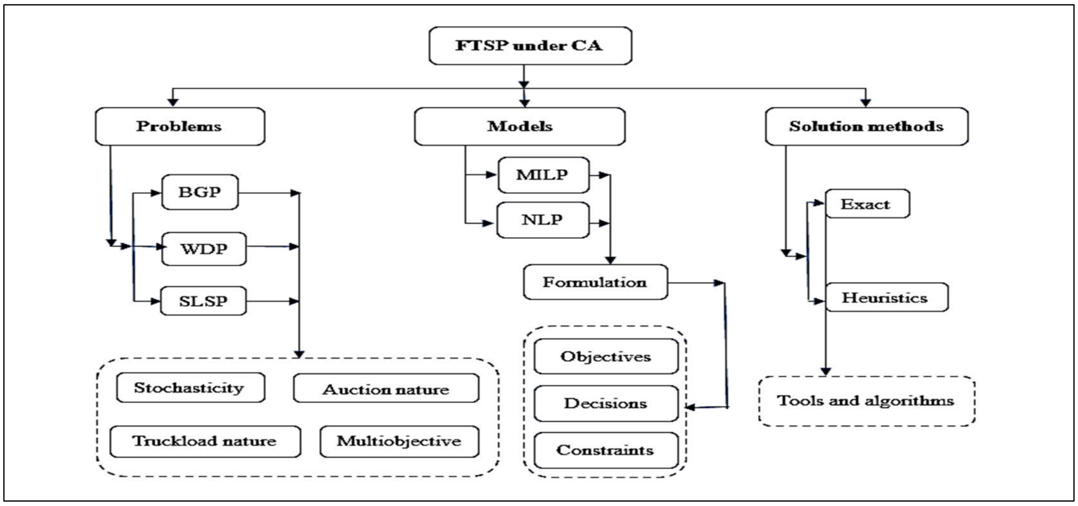

FIGURE 2. Model-oriented categorization.

Finally, the solutions of the different models were configured as an exact and heuristic method or metaheuristics method. An overall view of the categorization of the selected articles is described in Table 1.

Data related to publication year, source, keywords, and author's collaborations are presented in the sequel. Fig. 3 is a word cloud depicting the frequency that this study's chosen keywords appear in the references selected for this study. For example, "combinatorial auction," "transportation service procurement," "truckload procurement," "procurement," "winner determination," "bidding," "transportation," and "bid generation problem" are the keywords with the highest frequencies. Fig. 4 is for the historical direct citation network of the articles and shows that studies [21], [6], [22], [23] set a new trend in their own time. These articles will be discussed in the following sections.

Fig. 5, Fig. 6, Fig. 7, and Fig. 8 show the most relevant authors and sources, the distribution of articles over the years, and the top-cited articles since 2014. This data helps to identify which authors' works should get more attention, which sources are more relevant, and how much research has focused on this topic over the year.

FIGURE 3. Word cloud.

III. OPTIMIZATION PROBLEMS IN CAs

The literature on FTSPs under CAs mainly discusses problems dealing with bidders and auctioneers. The main problems this study identified are bid generation, winner determination, and the pre-auction issue of shipper lane selection. Bid generation is a crucial problem for bidders (carriers). To resolve this, carriers must propose feasible bids, including an appropriate combination of lanes to achieve optimal profit. At the same time, carriers must consider market competition and the optimum use of resources. Then BGP optimization aims to ensure efficient resource allocation, reduced costs, high-quality service, supply chain resilience, and environmental responsibility while adapting to changing market conditions.

Winner and lane selection issues arise from the shipper's side. Before processing any auction, the shipper must select the lanes to outsource carriers. The shipper's lane selection problem addresses this issue. After deciding which lanes to procure for the transportation service, the shipper will announce an auction with some rules, and bidders will bid for the lanes according to the bidding rules. The auction is then ready for its clearing process, which leads to a problem with the winner determination among the bidders. The WDP optimization goal is to select the most advantageous bid combinations submitted by multiple carriers, factoring in cost, service levels, and risk factors for an optimal mix of transportation services.

For example, consider a set of lanes $P = \{L1, L2, \ldots, Ln\}$ to be served for the shipper, and they will select lanes $Q = \{SL1, SL2, \ldots, SLm\}$, $Q \subseteq P$ for outsourcing due to the shortage of the own transport capacity. That leads to a SLSP. Once the lanes are ready for auction, the auctioneer calls for bidding. Now the bidders/carriers $\{C1, C2, \ldots, Ck\}$ must solve the BGP and generate the bundles of bids $B1 = \{c1b1, c1b2, \ldots\}, B2 = \{c2b1, c2b2, \ldots\}, \ldots\ldots, Bk = \{ckb1, ckb2, \ldots\}$ to submite to the auction. After submitting the bids, the auctioneer solves the WDP and clears

TABLE 1. Summary of the article features.

Article	Problem			Auction nature		Loading		Model Nature		Formulation technique		Objective		Solution	
	BGP	WDP	SLSP	SR	MR	TL	LTL	Determi-nistic	Stoch-astic.	IP/MIP	NLP	single	Mul-ti	Exact	Heuri-stic
Yang and Huang,2021		*		*		*		*		*	*	*		*	
Hammami et al,2021	*			*		*			*	*	*	*		*	*
Triki 2021		*		*		*		*		*		*		*	*
Triki et al.,2021a		*		*				*		*		*			*
Lyu et al,2022	*				*	*			*	*	*	*			
Yin et al.,2021		*		*		*			*		*	*			
Qian et al,2020,2021		*		*		*			*	*		*			
Triki et al,2020		*		*		*		*		*		*		*	*
Shao et al,2020		*		*			*	*		*		*			*
Mamaghani et al,2019	*			*		*		*		*		*			*
Hammami et al,2019	*			*		*		*		*		*			*
Remli et al,2019		*		*		*			*	*		*		*	
Yan et al,2018	*	*		*			*		*	*			*		*
Triki 2016	*			*		*		*				*			*
Amor et al,2016		*		*		*		*	*	*		*		*	
Zhang et al,2015		*		*		*			*	*		*			*
Wang and Wang, 2015	*				*	*		*					*		*
Basu et al,2015		*		*		*		*		*		*			*
Triki et al,2014	*			*		*			*		*	*			*
Zhang et al,2014		*		*		*			*	*		*			*
Xu and Huang,2014		*			*	*		*		*		*			*
Ignatius et al,2014		*		*				*		LP		*			*
Mehrizi and wang,2013		*			*	*		*		*		*		*	
Fhoula et al,2013		*		*		*			*			*		*	
Remli et al,2013		*		*		*			*	*		*			*
Mesa and Ukkusuri, 2013	*			*			*	*		LP		*		*	
Mesa and Ukkusuri, 2015	*					*			*	*		*			*
Rekik et al,2012		*		*		*		*		*		*		*	
Tian et al,2011		*		*		*		*		*		*			*
Buer et al,2011		*		*		*		*		*			*		*
Buer and Pankratz,2010a		*		*		*		*		*			*		*
Guastaroba et al,2010			*	*		*		*		*		*		*	
Buer and Pankratz, 2010b		*		*		*		*			*		*		*
Ma et al,2010		*		*		*			*	*		*			*
Chen et al,2009	*	*		*		*		*		*		*		*	
Chang 2009	*			*		*		*		*		*		*	*
Lee et al,2007	*				*	*		*			*	*			
Guo et al,2006		*		*		*		*		*			*		*
Wang and Xia,2005	*			*		*		*		*		*			*
Song & Regan et al,2005	*			*		*		*		*		*			*
Caplice & Sheffi et al,2003		*				*		*		*		*		*	
Song & Regan et al,2003	*			*		*		*		*			*		
Kwon, et al,2005;	*	*			*	*		*		*		*			
Lyu, et al,2020	*				*	*		*		*		*		*	
Othmane, et al,2014		*		*		*		*				*		*	
Othmane et al,2019	*			*		*		*		*		*			*
Triki et al.,2017,2021b			*	*		*		*		*		*			*

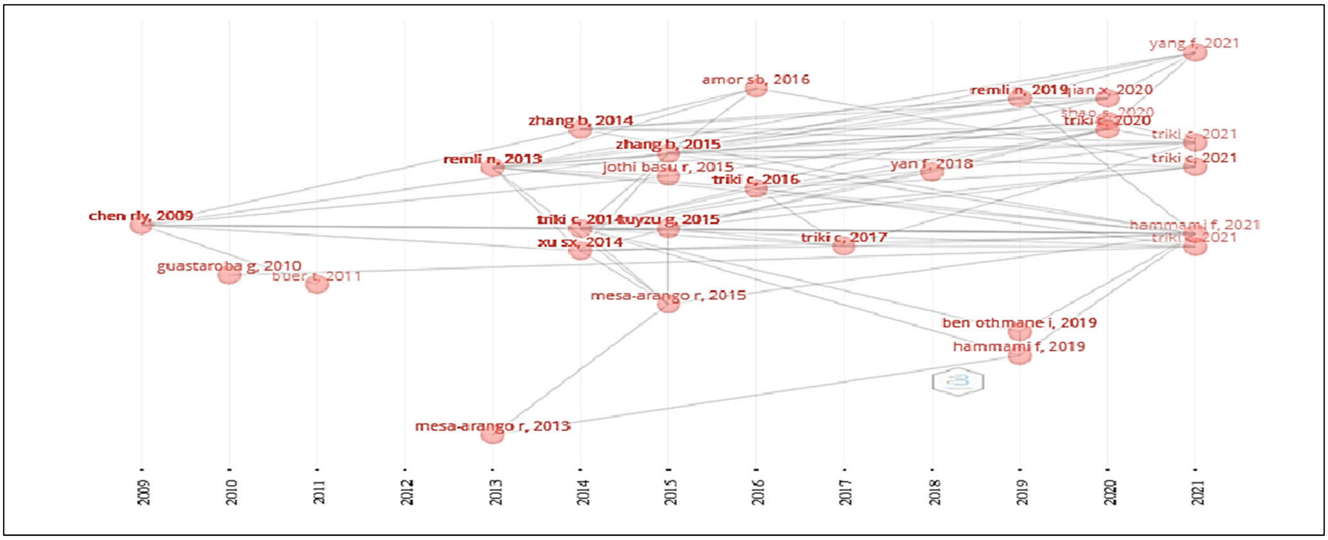

FIGURE 4. Historical direct citation network.

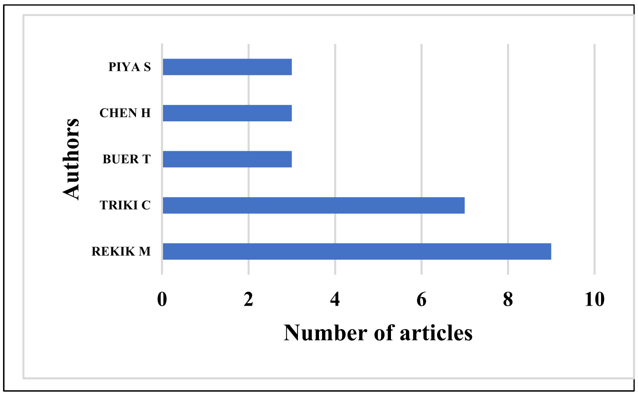

FIGURE 5. Top 5 relevant authors.

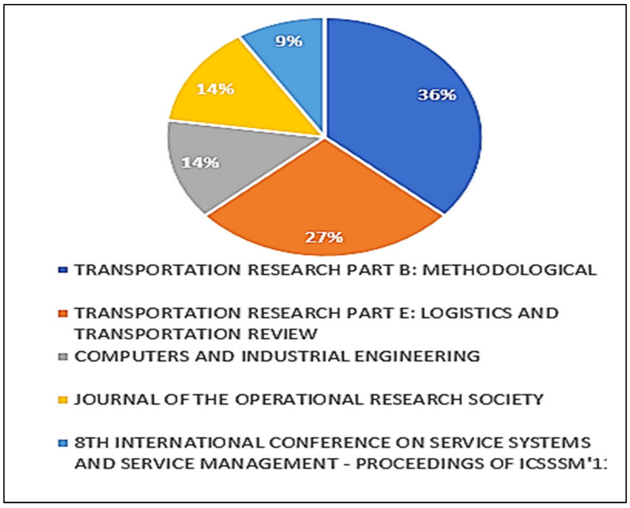

FIGURE 6. Top 5 relevant sources.

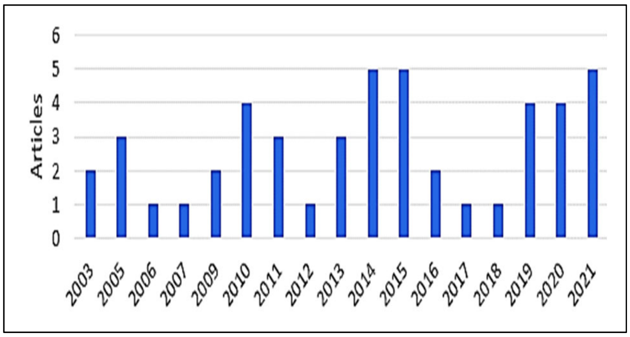

FIGURE 7. Distribution of articles per year.

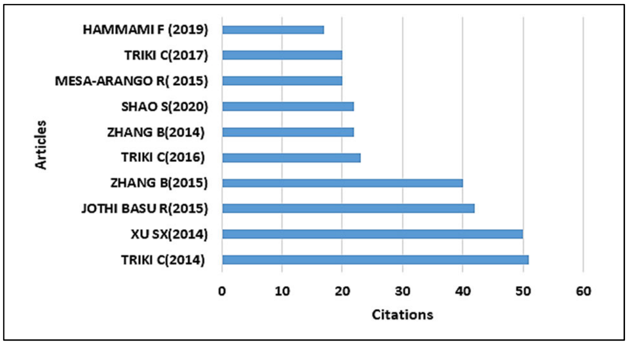

FIGURE 8. Top 10 cited articles (published in 2014 and onwards).

the auction with the decisions of selected carriers (winners) $SC = \{SC1, SC2, .., \}$ selected (winning) bids $SB = \{sb1, sb2, \ldots..\}$ with some fundamental auction rules; all auctioned lanes should be served i.e., $\{sb1 \cup sb2 \cup \ldots\} = Q$ and winning bids are disjoint i.e., $\{sb1 \cap sb2 \cap \ldots\} = \emptyset$. The three FTSP problems under CA are presented in Fig. 9.

The distribution of the included articles according to the problem types is depicted in Fig. 10.

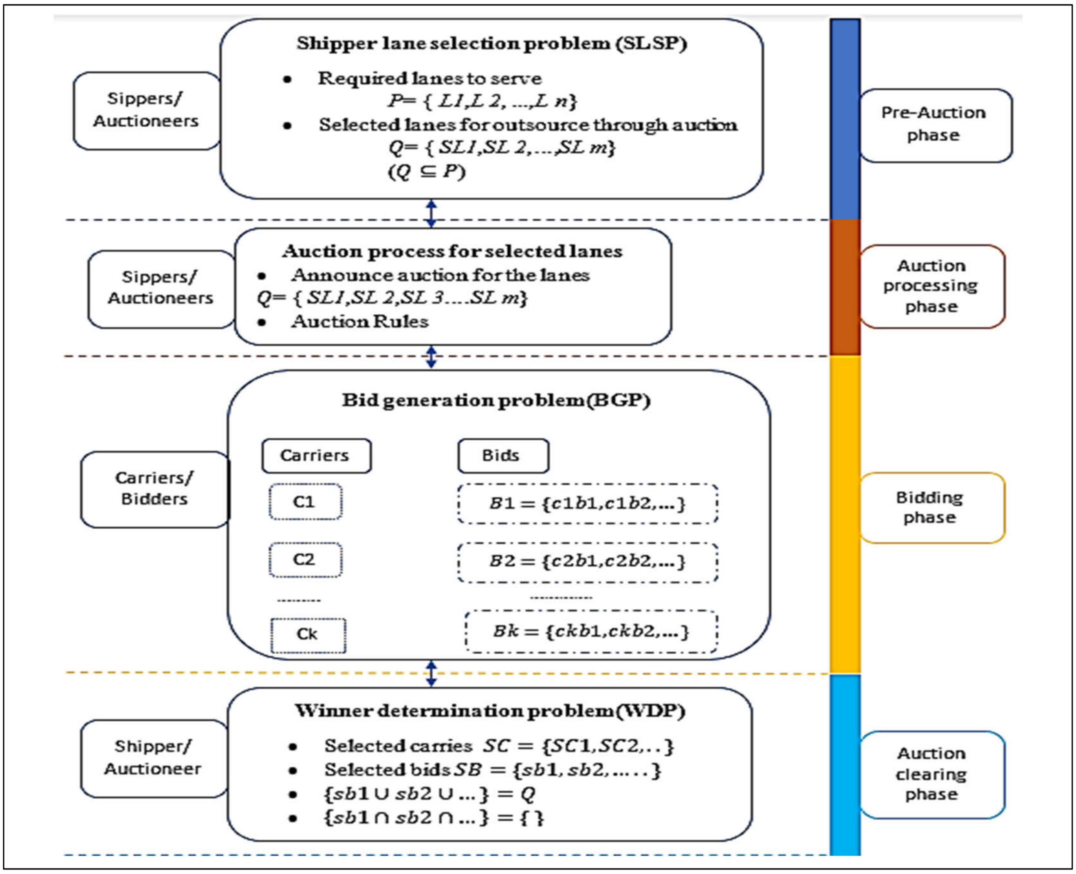

FIGURE 9. FTSP Problems under CAs.

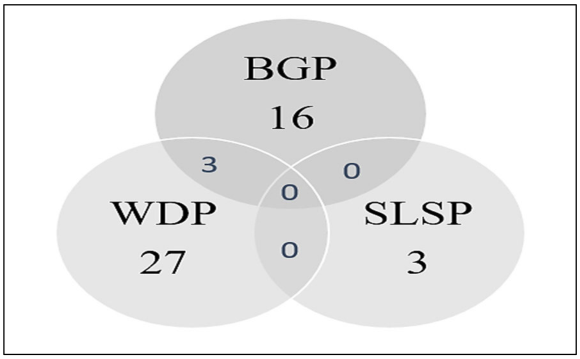

FIGURE 10. Article distribution according to the problems type.

IV. BID GENERATION PROBLEM

Inputs for auction mechanisms come from bidders (i.e., carriers). Bids cannot be arbitrarily chosen because the auction rules control them. The bid generation for individual lanes or services is quite simple but is complicated for packages or combinations of lanes or services [24]. In the case of CAs, bidders need to create a bundle of services with a single bid price. The discussion about BGPs in FTSPs under CAs will cover the development of the BGP and identify the truckload, auction, and stochastic nature and objective settings. Table 2 shows the clusters of the selected articles in BGP.

TABLE 2. Article distribution according to the primary features for BGP.

Features	Articles
TL, SR Deterministic	Mamaghani et al. (2019), Hammami et al. (2019), Triki (2016) Chen et al. (2009), Chang (2009), Song and Regan (2005), Wang and Xia (2005), Song and Regan (2003), Othmane et al. (2019)
TL, MR, Deterministic	Wang and Wang, (2015), Lee et al. (2007), Kwon et al. (2005), Lyu et al. (2020)
LTL, SR, Deterministic	Mesa-Arango and Ukkusuri, (2013)
TL, SR, Stochastic	Hammami et al. (2021), Triki et al. (2014)
TL, MR, Stochastic	Lyu et al. (2022)
LTL, SR, Stochastic	Yan et al. (2018)
TL, Stochastic	Mesa-Arango and Ukkusuri (2015)

At first, study [25] proposed an initial BGP in the context of CAs for FTSPs by considering that bidders may have pre-existing commitments to other contracts, and bids may be placed for new lanes to enhance the possibility of empty movement reduction. They address the impact of CAs on carrier operations and profitability compared to the traditional request-for-quote-and-negotiation method, commonly used in the transportation industry. This problem was investigated by creating a procurement simulation system. The study also looked at how carriers should design bids in CA processes and found average carrier empty cost decreases from 2% to nearly 14% according to the number of new lanes available for bidding, the lowering of empty travel costs can be accomplished if additional lanes are offered for bidding. The same authors [24] expanded on their previous work by analyzing two scenarios: bidding carriers having no past obligations to other contracts and circumstances where prior commitments exist.

Research [26] clarified the optimal criterion to solve a BGP for a forward auction. They suggested that a single carrier should offer an auction for a set of movements or lanes, and multiple shippers should place a bid to buy the lanes. But reverse auctions are more common than forward auctions for FTSPs. Also, the study considers pickup time windows for the origin and destination lanes, whereas study [27] created a bidding advisor to assist carriers in identifying profitable contracts. The suggested method transforms the BCP into a synergetic flow issue with the lowest cost that considers the estimated average contract synergy without compromising the service level. Another study [21] proposed an implicit bidding strategy in which each carrier transmits the parameters of its bid-generating function (BGF) in place of providing an exponential number of bids. This function is determined by the network configuration of carriers, pre-existing contracts, and new contracts on which the carrier wants to submit bids.

Afterward, research [28] introduced a multi-objective BGP for price complementation and combination consistency criterion with optimal bundling. They presented a two-round bidding auction method as a novel auction mechanism. In the first round of bidding, bidders select lane combinations to prepare to bid. The auctioneer then divides objects into different bundles of lanes based on the first-round bidding results. In contrast, study [29] investigated a BCP variant in which a carrier incorporates profitable contracts into current routes to optimize its operations. They considered that route networks were already built for existing contracts. New contracts are either introduced to replace the old route's deadhead arcs or are served by a new truck not previously used for existing contracts. As a result, trucks' predefined itineraries for serving existing contracts remain unchanged.

Considering a heterogeneous fleet to solve a BCP in a TL settings makes the problem more complex. The study [30] addressed this issue for the first time. They suggested an arc-based solution to a symmetry-breaking constraint problem. Again, study [31] addressed a multi-period BGP for a carrier that considers transportation costs and order delivery lead times. In this BGP, the carrier is expected to have two requests: reserved and selective. All reserved requests must be met. In addition, a shipper or other carriers can make selective requests, which are put up for a bid in a CA.

While the problems discussed above are deterministic, most situations are stochastic in reality. Study [22] looked at a BGP for CAs with stochastic clearing prices by considering the challenge of synergy between loads. They offered a probabilistic model of bid construction with pricing problems. A chance constraint was established and linearized based on the probability distribution of contract clearing prices for each potential bundle of auctioned contracts.

Study [32] recommended a bundle synergy strategy based on dependent sampling and a sequence of network transformations based on past shipment pricing and volume demand data. They dealt with demand forecasting and price unpredictability, where the actual demand usually differs from the forecasted demand. In these scenarios, carriers suffer economic losses and may compensate by lowering service levels. That impacts the shipper's routine operations and supply chain.

Similarly, study [33] suggested a location-based model strategy to approximate pairwise synergies (see also [72]). A few studies included a factor expressing synergy in the BCP where the carrier calculated the pairwise synergy among the auctioned and pre-existing contracts without considering the values of potential competitors. The most recent proposal by study [15] was for a BCP with stochastic clearing pricing that considered the uncertainty of rival carriers' proposals. An innovative non-enumerative solution approach was employed to generate single and multiple bids based on auction rules and carrier preferences. They are the first to solve a stochastic pricing BCP using an exact approach.

The above research focused on the single-round auction process. In contrast, [34] looked at a BGP for a multi-round auction process. They integrated winner determination and bid optimization while utilizing individual lane prices computed from current allocations. They found that shippers and carriers could achieve improved allocations and identify valuable alternate lane combinations. Research [35]proposed a carrier optimization problem as a BGP that combines route generation and selection in a multiple-round auction setting. The multi-round CA format might be an iterative ascending format with package costs and even individual lane prices (consistent with package prices) after each round. This process enables the creation of new bids based on present allocations. The carrier optimization model aims to optimize utility, defined as revenue from servicing routes with fewer transportation expenses.

In addition, [36] proposed a two-stage multi-round CA approach. A combinatorial clock auction was held in the first stage, where the auctioneer raised the price of each lane if no carrier bid for it. The auctioneer presented some supplemental bundles of bids, and each carrier chose whether to bid on one or more in the second stage. Then a BGP formulation was provided, which each carrier had to solve to decide their bids and truck routes in a decentralized context. A multi-period strategy was also considered by [16]. They took into account uncertain requests that may appear in the future. They assumed that the lanes chosen for bidding would be won. The carrier was obligated to serve each probabilistic request if it occurred during the relevant period, however, the carrier could decide not to fill a probabilistic request if it did not fit well in its network.

The discussion in this section revolved around the TL scenario. However, the same problem (BGP) will be discussed in the LTL context in the sequel. Study [37] compared the advantages of the vehicle consolidation of bids in an LTL environment to the bids in a TL environment. They employed a uniform vehicle fleet and framed the challenge as a multi-commodity one-to-one pickup and delivery problem. Another study [38] presented bi-level programming, which unifies bid selection and winner determination in the LTL context while considering the parties' information uncertainty. The authors suggested that even if carriers select the most advantageous bids, they lose all profit if the shipper does not accept the offer. The costs of the lane sets were represented as Lukasiewicz and Ruspini fuzzy random variables. The decision-maker determined the left and right tolerance intervals, whereas the random fuzzy cost was normally distributed with parameters derived from historical data. Finally, we found that the review of BCP/BGP highlights that work on multi-round bids, and the stochastic nature of parameters characterizing the problem is rarely addressed.

Moreover, Fig. 11 presents the networks of co-occurrences of words in different conceptual clusters for the articles that examined BGP, showing the research landscape and identifying key topics, trends, and gaps.

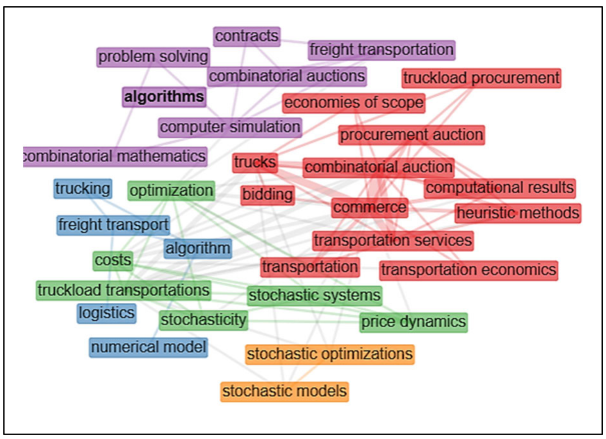

FIGURE 11. Co-occurrence network (BGP).

A. MODELING OF BGP

This subsection is dedicated to discussing BGP mathematical models and their formulation. Modeling is a crucial step in further analyzing any problem. Various types of mathematical programming have been used to present BGP. This study explores the modeling perspective of BGP for FTSP research over the years. The standard structure of BGP problem modeling is delineated in Fig. 12.

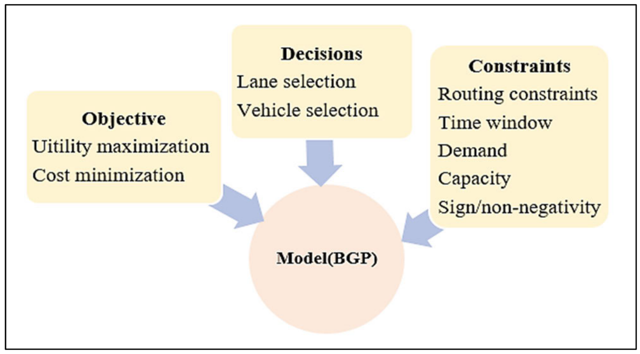

FIGURE 12. BGP modeling.

Initially, study [25] referred to a simple model for lane selection with pricing. They presented an integer programming (IP) model for a set partitioning problem to determine the bid price of new lanes. A slight extension of the same model was presented by the same authors in [24]. They considered the situation with and without pre-assigned lanes. Another extension of the model formulated as an NLP with a routing and time window phenomenon was presented by [26]. Research [37] developed a multi-commodity one-to-one traveling salesman problem as a MILP to select the lane with minimum cost. Concerns about vehicle routing for BGP have been addressed by [30], who presented a new variant of BGP formulated for the heterogeneous fleet. A similar model was also proposed by [36].

On the other hand, study [35] presented a new variant of the BGP model in which they captured three different lane flow volumes for an existing business, a new business, and empty. They identified the revenue from the bidding using a combined model for the carrier's optimal BGP, which included more details about the multi-dimensional characterization of the routing phenomenon. A similar model was discussed by [34]. Then, researchers [21] introduced a BGF for pricing bundle bids where the direct movement price was known, but the repositioning movement price needed to be determined. Whereas study [27] presented a minimum cost flow formulation.

Contrasting the deterministic model, study [22] introduced the stochastic modeling of BGP by considering the auction clearing price as a random variable. Later, [16] proposed another model containing probabilistic loads. The objective function was to minimize the projected total cost of the loads, with no consideration of serving times at nodes, journey times between nodes, or time window limits. Research [32] proposed a scenario-based LP model to formulate a problem with uncertain lane volume and price. Afterward, the study [15] presented two-stage modeling. The first stage was deterministic, similar to the one used by [30], and the second stage was probabilistic for clearing prices. They used the change constraint model to capture the stochasticity of the clearing price.

In addition, study [38] provided a bi-level program, where the upper level was for BGP. The authors suggested a global model for addressing the mutual dependency of shipper and carrier objectives. Study [31] introduced a multi-period BGP model. The MILP model considered all routing aspects. Their study differed because they considered a penalty cost for breaching the agreement lead time.

B. SOLUTION APPROACHES FOR BGP

This section identifies the techniques and methods to determine the problem's solution. The basic components of a BGP quantitative solution approach are depicted in Fig. 13.

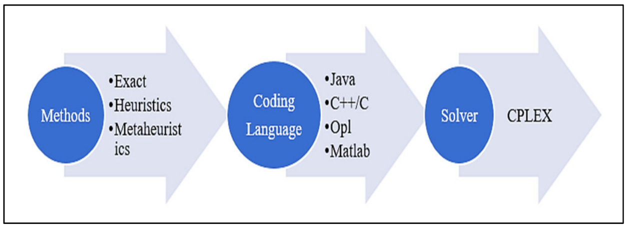

FIGURE 13. **Components of the solutions (BGP).**

The study [25] created a simulation of the transportation contract procurement process. Then, [24] introduced a modified branch-and-bound (B&B) approach that forced the solver to identify all optimal model results. The program was written in C++ and incorporated a CPLEX optimization component. Whereas [26] suggested the nearest insertion method for BGP if implementing the optimal fleet assignment algorithm implies high cost or technical difficulty.

The research study [34] presented a deconstruction of the carrier's bid-generating model to develop it into a master and sub-problem algorithmically. Regarding utility, the master problem (MP) delivered the best solution or bidding package(s). The sub-problem generated feasible tours based on the MP's dual information that can provide the most potential utility enhancement. The program was written in C and solved by CPLEX. Research [35] used a similar solution approach, where an approximate solution to the original carrier formulation was obtained using a column generation-like technique. Afterward, [27]employed an effective solution process of column generation to tackle the problem. Instead of explicitly enumerating all possible paths, the column generation approach generated columns (paths) only when needed, resulting in only a small proportion of all feasible paths. The solution algorithm was written in Java and connected to the CPLEX solver of linear programming.

Study [37] applied a branch-and-price (B&P) solution algorithm to handle a mixed integer programming (MIP) problem. Incorporating Dantzig-Wolfe decomposition and column generation into a B&B algorithm is known as B&P. This methodology reduced processing time and ran large instances of the problem compared to commercial solvers. The B&P algorithm was written in Java, and ILOG CPLEX was used to solve the problem. Then, [22] derived the exact solution of the BGP model for moderately-sized instances (i.e., until the set of auctioned loads reaches a specific cardinality). Then, heuristic algorithms that allowed for a sequential solution of the BGP were developed for greater dimensions. The model was implemented and compiled using Microsoft Visual C++ combined with IBM ILOG CPLEX.

On the other hand, a study [28] created an encoding strategy for the optimal bundling model, which is based on the nonzero members of the complementary cost matrix. A quantum evolutionary algorithm (QEA) and a genetic algorithm were designed as alternatives for the optimization problem. QEA achieves superior computational performances for small and medium-sized issues than a genetic algorithm, but the genetic algorithm performs better for large problems. Fortran Power Station encoded the QEA algorithm for bundling optimization. At the same time, researchers [32] introduced a novel algorithmic approach to demand clustering based on dependent sampling over historical data and a series of network changes. The Latin hypercube technique was used to collect price and volume samples. MATLAB was used to code and run the algorithm suite.

A three-stage heuristic was proposed by [29]. The first step was discovering new contracts that may be incorporated into the carrier's routes for existing contracts to generate more revenue. In the second stage, the new contracts not added in the first step were evaluated, and new routes for the unused vehicles were established to encompass all or a subset of the remaining new contracts. The third stage determined the price interval that the carrier should seek for each generated bid. All the algorithms were written in C++ and ran on a simulator, processing results on an IBM server. Study [30] suggested an adaptive large neighborhood search (ALNS) heuristic that uses BCP peculiarities to define insertion and removal operators. Then, the ALNS was merged with a local search method. Finally, a second heuristic form was created by combining the ALNS with a set packing problem (SPP) that mixed a subset of ALNS answers. The suggested hybrid ALNS heuristic was written in Java, and the Optimization Programming Language (OPL) and CPLEX were used to solve the models. In 2021, [15] suggested a two-stage solution approach that could function as an exact or heuristic method depending on whether the contract selection problem (CSP) phase was executed. The proposed solution strategy yielded results in exact for contract selection and pricing problem (CSPP) and hybrid heuristic for CSP + CSPP versions. The mathematical models were solved using CPLEX branch-and-cut, and the solution algorithms were created in Java and OPL.

Study [31] introduced an improved tabu search (TS) approach that kept numerous solutions in memory during the search and used a mutation operator to find a better solution in less time. While ITS can determine feasible solutions for large-sized instances, CPLEX is unable to obtain a suitable solution for large-sized examples within the compute time provided. Whereas, [36] solved the models, which were coded in C++ language for randomly generated data, using CPLEX. In 2021, [16] developed a Benders decomposition strategy to solve a model with Pareto optimal cuts to speed up the solution process. Numerical experiments on randomly produced cases assessed the approach's performance. The computational findings showed that the Bender decomposition strategy solves large instances of the problem substantially more efficiently than the CPLEX solution.

The solution approaches have an impact on the quality of the result, and the summary of some significant results is demonstrated in Table 3.

TABLE 3. Summary of the results for BGP.

Articles	Results
Hammami et al. (2021)	Results show the proposed exact non-enumerative method successfully obtains optimal solutions on instances with up to 50 contracts.
Mamaghani et al. (2019)	The performance of the recommended improved tabu search method significantly outperforms CPLEX in cases involving 20 to 100 contracts.
Hammami et al. (2019)	The results demonstrate that combining the large neighborhood search with the Set Packing Problem layer achieves the best trade-off between solution quality and computing time.
Othmane et al. (2019)	The suggested heuristic can solve a BCP with 300 new contracts and 300 existing contracts in less than 149 seconds.
Triki (2016)	The result verified that the location-based synergy approximation technique successfully generated the bids like a traditional BGP.
Wang and Wang (2015)	For small and medium-sized problems, the proposed Quantum Evolutionary Algorithm has been found to outperform the Contrast Genetic Algorithm.
Triki et al. (2014)	Compared to the exact solution, the proposed heuristics reduce execution times by more than 80% for heuristic I and around 90% for heuristic II. Furthermore, heuristic II consistently matches the precise solver's solution quality across all test scenarios.
Mesa-Arango, et al. (2013)	According to the results, serving a bundle via in-vehicle aggregation regularly costs the same as or less than direct shipment.

V. WINNER DETERMINATION PROBLEM

Determining winners is a core part of any auction. Once the bid submission phase is over, the auctioneer will clear the auction by solving the WDP in such a way that they minimize shipment procurement costs while showing no disrespect to the feasibility of each carrier's bids. This indicates that every successful bundle should be accepted whole (i.e., the all-or-nothing rule), and no shipments should be routed to more than one carrier in a CA. The complexities of winner determination in a CA led to various research studies of FTSP. Table 4 shows the clusters of the selected articles.

TABLE 4. Article's distribution according to the primary features for WDP.

Features	Articles
TL, SR, Deterministic	Yang and Huang (2021),Triki (2021), Triki et al. (2021), Triki et al. (2020), Amor et al. (2016), Basu et al. (2015a), Ignatius et al. (2014), Rekik et al. (2012), Tian et al. (2011), Buer et al. (2011), Buer et al. (2010a), Buer et al. (2010b), Chen et al. (2009), Guo et al. (2006), Caplice and Sheffi (2003), Tian et al. (2011), Othmane et al. (2014)
TL, MR, Deterministic	Xu et al. (2014), Mehrizi and Wang (2013), Kwon et al. (2005)
LTL, SR, Deterministic	Shao et al. (2020)
TL, SR, Stochastic	Qian et al. (2020,2021), Yin et al. (2021), Remli et al. (2019), Zhang et al. (2015), Zhang et al. (2014), Fhoula et al. (2013), Remli et al. (2013), Ma et al. (2010)
LTL, SR, Stochastic	Yan et al. (2018)

Study [39] looked at mathematical models for assigning lanes to specified carriers (winner determination) with or without combinatorial bids and considered how they might be extended to include business-side constraints. Instead of the usual WDP, [21]proposed an implicit WDP (I-WDP). Constructing bid values in real-world truckload procurement auctions with thousands of lanes for the whole exponential set of bundles is impractical. Even if carriers could generate and submit bids for all bundles, it is not easy to solve for the auctioneer using a typical WDP. The authors demonstrate that these obstacles can be solved by employing an implicit bidding strategy that embeds a carrier's BGF into the WDP. In a WDP, [40] characterized practical FTSP situations as constraints.

Research [7] discussed a WDP involving carriers' reputations for on-time delivery, canceled shipments, and damage to commodities. Also, [41]proposed a reputation-based WDP that considers the carriers' and bidders' global, local, and historical importance. A well-known carrier assignment problem (also called a WDP) regarding the implications of a CA on FTSP sustainability was examined by [42]. Then, [43] incorporated a WDP within a production scheduling framework, and [14] pioneered the integration of a crowd shipping mechanism with a WDP to build a case study for hiring occasional drivers in the freight transportation industry. Later, [44] proposed CAs with vehicle routing to solve the ridesharing problem and designated a vehicle routing problem (VRP)-WDP optimization framework for the first time.

A transportation services problem in the commercial garbage collection sector was identified by [45]. Unlike most one-sided auctions that address shipper-centric structures, the commercial garbage collection business follows a carrier-centric pattern. Hence the proposed mechanism was geared toward resolving the WDP from the carrier's perspective. Furthermore, discount-based procurement in transport services is a widespread strategy that influences service provider selection. Study [46] investigated shipping distance-based and volume-based discounts in FTSP and the effect of these discounts on WDP performance under the CA mechanism.

Most of the research regarding FTSPs uses the deterministic approach to examine WDPs under CAs for all parameters related to the problem. Although it is less realistic because significant components, such as demand, capacity, scheduling, and quantities, are frequently not constant. The uncertainty or stochasticity of WDP under CAs has been reported lately in the literature, which is still growing. Study [47] first attempted to WDP model using a stochastic programming winner determination technique to deal with shipping volume uncertainty in CAs, and [6] examined the same problem using a different method. They proposed a two-stage robust formulation rather than a stochastic programming one. The major distinction between stochastic programming and robust optimization approaches is how uncertainty is described. Unlike stochastic programming, there is no probability law for the uncertain parameters in robust optimization, and discrete scenarios describe the uncertainty.

The research has most frequently addressed the uncertainty of shipment volume to propose the stochastic WDP. For example, Study [48] suggested a sampling-based two-stage stochastic programming approach to solve a WDP under shipment volume uncertainty. In their following work, [23] proposed a new tractable two-stage resilient optimization (RO) technique to solve a WDP for TL service procurement in the context of uncertainty in shipment volume. Meanwhile, the study [49] addressed a WDP with the uncertainty of shipper demand, carrier capacity, and carrier lead time. At the same time, study [50] tackled a novel WDP with uncertain parameters such as carrier capacity.

The goal of shippers is winner determination through the CA conflicts with carriers' goal in bid placement because both counterparts try to optimize their cost in a single process. To investigate a WDP in such a situation,[38] addressed the bi-level connection between carriers and shippers and information sharing uncertainty. Study [51] proposed a two-stage stochastic winner determination model built using a hybrid mitigation method that incorporates fortification, reservation, and outside option strategies to deal with disturbances. Then, [52]extended [51] by incorporating a quantity discount. Again, in 2021, [53] further developed the research by linking a sustainability and responsiveness score with the mitigation plan in a WDP.

All the above works have characterized the problem using single objectives. But multi-objective is very common in practice. Generally, cost minimization, customer satisfaction, or related service level issues are frequently considered simultaneously. The research journey of multi-objective WDPs under CAs for FTSPs was initiated by [54]. They addressed procurement cost minimization while also improving the level of service provided in the execution of transportation contracts. Consequently, [55] extended the bi-objective winner determination research by formulating a well-known set covering problem (SC). Finally, the importance of multi-objective WDPs for transportation procurements under CAs was discussed by[56], who proposed three factors in deciding the winning criteria: cost, marketplace fairness, and marketplace confidence.

Research has been divided into two distinct streams in examining WDPs for single-round and multi-round auction processes. However, all previously discussed studies have specifically addressed the situation within a single-round bid auction process. The analysis of multi-round auctions in FTSPs to characterize WDPs is rarely reported in the literature. Study [34] introduced a multi-round CA concept in which the winner determination was combined with bidder optimization via individual lane pricing determined from a current round allocation. Reference [57] proposed a descending multi-round approach for allocating lane packages to agents. Agents first calculated and submitted their recommended packages based on their pricing structures to the auctioneer. The auctioneer then solved a WDP to provide agents with a provisional allocation of lanes to reduce payments. Afterward, [5] suggested a primal-dual Vickrey (PDV) auction with the following steps: (i) choose high initial prices, (ii) try to discover an allocation that fulfills each carrier's supply at current prices, and (iii) if no such allocation exists, change prices, and repeat. As a result, the auction model is a multi-round declining auction. Thus, the WDP was assessed in a PDV auction environment.

Regarding load, most FTSP research considers TL situations. In this review, we found only the works of [45] and [38] addressing the LTL situation and discussing a WDP under a CA. Even fewer works have addressed the shipper's reputation, simultaneous goals as an objective, uncertainties, and sustainable issues. A word co-occurrence network in Fig. 14 for the articles that address WDPs examines links between keywords in the literature to better understand the knowledge components and structure of a scientific and technical subject with different conceptual clusters.

A. MODELING OF WDP

Modeling is one of the core components of FTSP research. This subsection discusses the modeling techniques used to formulate WDPs under CAs. The standard form of WDP modeling according to the objective, decision variables, and constraints is identified in Fig. 15.

Study [39] introduced a general carrier assignment problem called a WDP and formulated it as the simplest MILP. The only decision variable was selecting the appropriate carrier for the lanes under the condition of cost minimization,

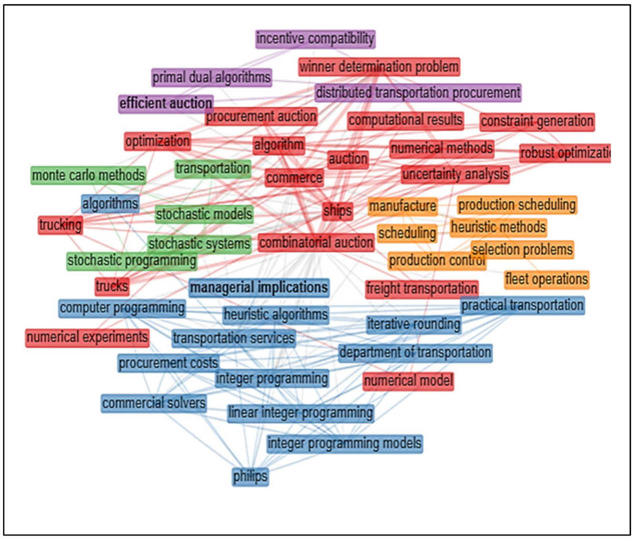

FIGURE 14. **Co-occurrence network (WDP).**

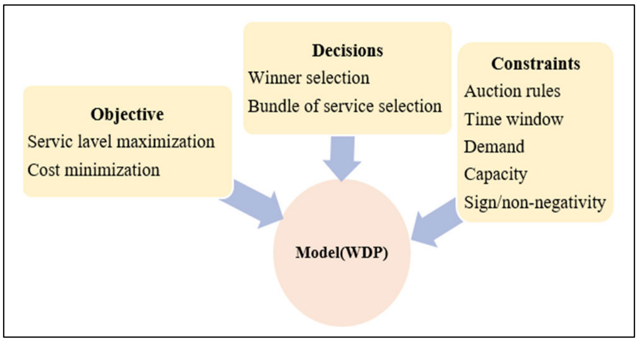

FIGURE 15. **WDP modeling.**

where every lane should be served precisely once. A very similar model to that of [39] was reported by [34]. The only constraint they modified was that each lane be visited at least once. In the study of [42], the basic WDP model was extended by integrating practical factors. For example, demand in each lane was assessed, and the lane distance for the round trip was provided. They only modified the objective by minimizing the total amount spent servicing all the lanes' demands during the contract period. The costs were calculated per distance traveled in a bundle.

Research [58] extended the previous model by adding constraints assignable to a carrier's minimum and maximum number of lanes. However, they also proposed another model with non-price business considerations, such as excluding or penalizing carriers at transit points while considering carrier performance indicators such as service level by applying fines and transit point charges. Study [21] proposed two different WDP models: the traditional WDP (T-WDP) and the I-WDP. The T-WDP formulation is a modified version of the model in [39], where they added a capacity/volume constraint to the lane.

In the research of [47], a stochastic winner determination model was introduced and formulated as a two-stage MILP with first-stage decisions and recourse decisions in the second stage. They incorporated the important side business of shippers and carriers, such as constraints for deciding the number of winning carriers in the final allocation between a stated minimum and a maximum number of carriers. These restrictions guarantee that some carriers get the minimum and maximum total override amounts and limit particular carriers' abilities to win at ports. In addition, the auctioneer may include other commercial concerns, such as incumbent favoritism, and performance indicators, such as on-time percentages, claims performance, refusal rates, and Electronic Data Interchanges. Afterward, [6] proposed a two-stage robust formulation of a WDP similar to that discussed by [47]. They modified some restrictions to deal with a wide range of situations. Study [48] presented another two stages of the stochastic MILP formulation of a WDP with uncertain shipment volume.

Later, study [23] presented a revised bidding structure based on [47] to better characterize the implications of shipping volume uncertainty on a WDP solution. A shortage in carriers' required volume was permitted, but a fine was implemented. Furthermore, the approach allowed different carriers to compete for the same lane, giving the shipper more flexibility in selecting the winners and proposing a two-stage model formulation for robust winner determination. Study [50] formulated a robust WDP using the same technique as [6]. They examined it in two contexts: a context where only the demand on shipment volume was uncertain and a context where both the shipment volume and carrier's capacity were uncertain. For the first time, [49] simultaneously integrated uncertainties for shipper demand levels, carrier capacities, and carrier service times. They presented a two-stage stochastic MILP model based on scenarios. In addition, [51] introduced a WDP by considering the mitigation strategy of accidental disruption for the first time and presented a stochastic MILP formulation with two stages. Furthermore, mixed-integer nonlinear programming for the stochastic formulation of a WDP with a mitigation strategy and quantity discount schemes was developed by [52].

Study [54] presented a bi-objective WDP model that generalizes the SC problem, termed 2WDP-SC. The procurement cost minimization (first objective) and service level maximization (second objective) were considered simultaneously. The same model was examined by [55] Another study [40] proposed a WDP demand/load allocation model for a cargo transportation system for bidders and carriers. They considered a constraint to their model that multiple bidders could serve any lane's demand, which differs from the above-discussed models. Study [7] incorporated carrier reputations into a basic WDP model [34] and introduced a hidden cost in the objective function. Author [41] formulated the same model as [7] for a centralized market and modified the objective function.

The research [57] introduced a simplified version of a WDP model for the multi-round auction mechanism and formulated it as an integer programming (IP). Study [43] integrated a production scheduling phenomenon with a WDP for transportation procurements and developed a MILP model. Furthermore, [14] introduced a crowd shipping phenomenon of transportation with a CA paradigm and proposed a combined optimization MILP model of vehicle routing for delivering goods using its fleet and winner determination of an occasional driver for auction clearing. In addition, [44]formulated a MILP to select ridesharing drivers for inbound and outbound requests while maximizing profit. Recently, [46] presented a new variant of a WDP with an NLP formulation considering shipment distance and a volume base discount from the carriers to attract the shipper.

B. SOLUTION APPROACHES OF WDP

After proposing a model of a problem, it is necessary to examine possible outcomes. This examination process relies upon solution techniques and tools. Different solution techniques have been proposed in the literature, such as exact and heuristic. This section investigates WDP solution approaches as depicted in Fig. 16.

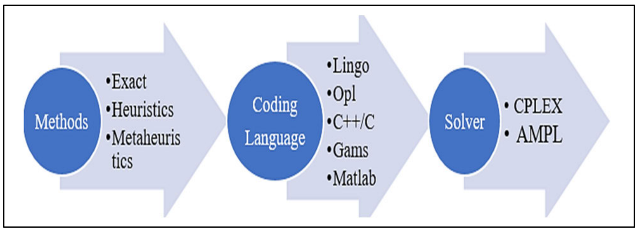

FIGURE 16. Components of the solutions (WDP).

Study [58] discussed B&B and the heuristics of computational experiments. At first, the authors used the B&B method for a small-size test example to obtain the optimal solution and then compared the solution with the solution obtained by the proposed heuristics. Next, the best solutions for larger-sized instances obtained by different heuristics were compared. The B&B method and three heuristics, namely genetic algorithm (GA) [59], tabu search [60], and hybrid GA+TS, were coded by C++. The required time varied according to the size of the problems for B&B, and GA took more time than the other two heuristics. The method of B&B takes more time for larger-size instances because the method depends on input sizes, but the time heuristics take is more likely independent of input size. The GA method did not perform well compared to its results in smaller test instances. As the sample size grew, the gap in relative performance between GA and GA+TS rose from about 4% to 43%. Furthermore, GA requires 8–10 times more time than GA+TS.

Study [21] developed an implicit bidding strategy to solve the WDP problem, considering bundles' exhaustive sets. This method directly handled the two primary CA issues: bidding on an increasingly large collection of bundles and solving the related exponentially large WDP. C++ and ILOG Concert Technology were used to code the models and algorithms, and ILOG CPLEX was used to solve them.

Study [47] examined the value of the stochastic solution (see [61]) by setting the input dimension as follows: (number of lanes for sale in an auction) – (number of bidders) – (number of scenarios) – (number of packages submitted by each bidder) – (upper limit on the number of lanes in any package for a bidder). They showed that AMPL and CPLEX determine an optimal solution with up to 600 lanes and 50 bidders in a reasonable time. The value of the stochastic solution for each instance was the difference in percent between the objective values of the deterministic WDP and stochastic WDP, which is in the range of 7.15% to 0.40% with a size between 60-30-3-10-20 and 600-50-3-10-30.

Study [54] proposed two techniques to solve the model. First, an exact bi-objective B&B algorithm was presented using the epsilon constraint technique. Next, problem-specific evolutionary operators were added to the well-known multi-objective evolutionary algorithm to solve the bi-objective WDP. Eight variations of this genetic algorithm were created by mixing these operators in different ways. As a result, the exact B&B technique was inadequate for large-scale transportation procurement auctions. The multi-objective genetic algorithm (MOGA) version's relative performance was evaluated for the large examples. They indicated a high correlation between MOGA performance and initial population quality. A population initialized using more complicated heuristics will not compensate for solution quality losses. Finally, the best genetic algorithm was compared to the precise algorithm for the tiny examples. In these cases, the genetic algorithm produced solutions close to the Pareto solution set.

The research [55] presented a Pareto-based Greedy Randomized Adaptive Search Procedure (GRASP) with a post-optimization technique that blends truncated path relinking and accurate B&B. Various GRASP versions were built by combining three distinct bundle bid rating operators and two reduction operators for path relinking. The performance of these versions was assessed using seven small and 30 large instances presented by [54]. The two best GRASP variations were determined through a series of preliminary tests. According to the hypervolume indication, the first variant performed better, whereas the second variant outperformed the epsilon indicator. The GRASP results were compared to known optimal solutions using tiny cases and to the outcomes of an evolutionary algorithm employing small and large cases. The evolutionary algorithm routinely outperformed both GRASP variations. When cost and quality were considered, the GRASP technique significantly enhanced the performance of transportation procurement auctions regarding management. Another metaheuristic solution algorithm, the Hybrid Pareto Neighborhood Search (HPNS), utilized on the same problem, was introduced by [62]. The HPNS combines GRASP and large neighborhood search principles with an exact B&B procedure. The HPNS was able to find 14 new best values from a total of 30 benchmark examples in the literature. The HPNS's median hypervolume is the third highest of all techniques.

Study [40] proposed an iterative heuristic algorithm, identified the basic assumptions of bid generations for reverse CAs, and solved the linear relaxation program using CPLEX Version 11.1. They generated ten data sets to examine the model and observed that the CPLEX gave better results within a shorter time for small instances (e.g., up to two lanes, five carriers, and only ten bids) than the heuristic. But for larger sizes, like 50 lanes, six carriers/bidders, and 45747 bids, the heuristic performed very well within 3.1 seconds, while the CPLEX could not produce a feasible solution.

A reputation-based WDP was solved by [7] using the B&B algorithm in CPLEX and C++ code. They analyzed performance by testing for various sizes of inputs. They observed that the proposed method had adequate speed (maximum ten minutes) and could be implemented for up to 60 contracts/lanes, 180 bids, and 36 bidders/carriers. Study [41] solved the standard WDP (without reputation) and the decentralized reputation based WDP for four shippers, 14 contracts, and four carriers. They also solved the WDP for the three weighting methods (global importance, local importance, and historical importance) using a centralized reputation based WDP. They showed that four shippers could save 9.37% on their costs by working together.

Study [6] proposed a constraint generation algorithm [63] to solve a robust WDP using CPLEX. They examined the computational performance for up to 600 contracts, 120 carriers, and 1200 combinatorial bids. They showed that their algorithm was comparatively better than that [47]. Then [50] also used the same algorithm to solve a WDP with stochastic demand and capacity.

Research [48] proposed a Monte Carlo Approximation (MCA) algorithm and modified the instance presented by [47] by solving it using a nominal approach and an MCA. They also proposed a solution algorithm to compare the nominal approach with an MCA and found that the MCA gave an excellent solution for most cases. They coded the problem in GAMS and MATLAB, also known as GAMS from MATLAB, and used the CPLEX 12.4 MIP solver. Study [23] used the same tools to solve a robust WDP using the constraint generation (CG) and solving reformulation (SR) methods. They mentioned that the SR method is more efficient than CG. When a robust solution and deterministic solution for a WDP were compared, it was discovered that the robust WDP outperforms the deterministic WDP regarding numerical tractability, especially when the issue scale is large.

Researchers [42] formulated a heuristic algorithm and tested the problem with the heuristic and complete enumeration methods. They observed that their heuristic reduces significant time while only minorly compromising the result. Another study [43] solved a MILP using the exact method for limited-sized instances and proposed memetic algorithms (MAs) ([64], [65]) and a two-phase iterative heuristic algorithm to avoid the difficulties of solving large-sized instances. They coded both the model and heuristics algorithms in MATLAB. Various comparisons between exact and heuristics and between heuristics were made. It was reported that the MA algorithm performs better in solving large-sized instances.

Study [38] proposed a discrete particle swarm optimization (PSO) solution algorithm. A numerical simulation was utilized to create a model and algorithm analysis. The algorithm comparison demonstrated that while a GA can identify a few more Pareto solutions than a PSO, it takes longer, and the solutions are of worse quality. Whereas [51] created a scenario-based approximation methodology to solve a two-stage stochastic mixed-integer winner determination model (TSMWD). First, the scenario reduction technique was used to develop sample situations so that the enormous number of complete scenarios could be significantly reduced. The CPLEX solver then quickly solved the deterministic TSMWD using typical cases. The generated approximation solution can be seen as an upper bound of the TSMWD. The problem-based and dual decomposition Lagrangian relaxation methods were then used to produce two lower bounds. Finally, the upper and lower bounds gap was determined to assess the approximation solution's quality. Study [52] implemented the same solution approach to solve a stochastic winner determination model with quantity discounts and disruption risks.

Research [14] proposed two heuristics to solve the VRP with Occasional Drivers and Combinatorial Auction problem. The heuristics were decomposition-based and cost comparison-based heuristics. The author solved the model using the LINGO optimization package and conducted a case study. Proposed approaches gave better solutions than the human-operated one, notably, the decomposition-based heuristic determined a company cost savings of 30.23%. Another study [44] proposed a CA Ridesharing Solution Framework (CA-RS) with a new hybrid heuristic method that uses metaheuristic algorithms to handle large-scale problems. A CA-RS offers various new components, including an original solution format that allows routing and auction functionalities to be embedded in the same solution representation. This framework used metaheuristic methods to enhance a collection of previously developed solutions and obtained data that revealed no significant difference between the above mentioned metaheuristics. CPLEX solver was used to solve all exact cases, and then they were coded in the GAMS software package. The heuristic algorithms were written and executed in MATLAB. Whereas, [46] proposed a model formulation using superior encoding constraints to solve a MILP, prevent unbalanced B&B trees, and eliminate big-M constraints to reduce solution time. The suggested technique conducted numerical trials using real-world-sized truckload service procurement issues and confirmed a dramatic reduction in computational time when addressing large-size WDPs.

Solution methodologies derive research outcomes, where most studies enhanced computational efficiency for the examined WDP using individual proposed approaches.

In addition, a summary of significant findings is presented in Table 5.

TABLE 5. Summary of the results for WDP.

Articles	Results
Triki (2021)	A case study revealed that implementing CA in the occasional driver-based transport industry saves around 30% of costs.
Qian et al. (2021)	Results showed fourth party logistics must give priority to sustainability and responsiveness. Neglecting these qualities might result in higher prices and lower service levels.
Remli et al. (2019)	The proposed constraint-generation algorithm effectively solves small to medium instances of WDP under volume and capacity uncertainty with saving costs.
Zhang et al. (2015)	The proposed two-stage robust strategy can handle correlated lane demand. The numerical findings demonstrate its efficacy and value.
Basu et al. (2015)	Use of a flexible system of combinatorial bidding instead of the traditional technique of individual lane bidding with dedicated trucks for each shipper, carbon emissions can be decreased by up to 66%.
Zhang et al. (2014)	When solving WDP with uncertain shipment volume, Monte Carlo Approximation performs much better than the benchmark if the distribution of uncertainty is asymmetric or more variable.
Xu and Huang (2014)	The one-sided Vickrey-Clarke-Groves auction that is being suggested reduces the overall cost of transportation (i.e., allocative efficiency) and encourages carriers to make truthful bids (i.e., incentive compatibility).
Mehrizi and Wang (2013)	The experimental results show that the suggested model's procurement costs nearly match the centralized framework's optimal costs.

VI. SHIPPER LANE SELECTION PROBLEM

Aside from the two major transportation problems (BGP and WDP), researchers have debated another key issue known as the SLSP or SCSP. Typically, the first thing a shipper will do is serve the required lanes with their fleet. However, making all the shipments with their fleet is often inconvenient due to various issues like capacity. Sometimes there is a chance to get a carrier with a lower possible cost for the same lanes through an auction procedure. As a result, the shipper must identify the lanes that will be auctioned to procure transportation.

Study [66] proposed an SLSP for transportation procurement for the first time. The authors examined the performance of two optimization models with a single period horizon on Solomon's limited-size problems [67]. Later, authors [4] explored the Periodic SLSP as a new type of SLSP that aims to save the shipper money on transportation costs over a more extended period. The shipper must determine the set of lanes that will serve by their fleet, considering the lanes' periodicity before finding the best routes. Study [68] integrated the production schedule phenomenon with SLSP and presented an integrated lane selection and production scheduling problem. They also developed an auction paradigm in which occasional drivers compete for shipments through bidding. The auction paradigm entailed determining which deliveries would be auctioned and which would be served by corporate vehicles. In contrast, a study [15] used a contract selection problem to identify profitable contracts from the carrier's perspective, which differs from an SLSP or SCSP. The subsets of these selected contracts are the combinatorial bids of the BGP. Thus, this CSP is a pre-staged BGP problem from the carriers.

A. MODELING OF SLSP

The initial mathematical IP formulation of an SLSP was proposed by [66] for a truckload case. Three selection variables were identified: which lanes should be served by the shipper's fleet, which lanes were for the auction, and whether an auction would be arranged. They proposed an alternative formulation that used the Capacitated Arc Routing Problem [69] for an SLSP. Authors [4] presented a new variant of an SLSP with an additional set of variables to select the ideal periodicity combination for each lane to enhance the amount of consolidation in their routes. They studied the related periodicity phenomenon in modeling. Study [68] formulated an integrated SLSP considering the production scheduling issues as a MILP. The decision variables measured the delivery tardiness of an order, order completion time, the production schedule of orders, the delivery schedule according to vehicle and order, the order to be selected for occasional drivers, and whether an auction was to be arranged. Whereas authors [15] introduced an NLP formulation for a CSP from the carrier's perspective to decide which contracts or lanes should be auctioned, which vehicles will serve which auctioned contracts, and the order of visiting the nodes.

B. SOLUTION APPROACHES OF SLSP

The first model [66] was solved by using CPLEX for Solomon's instances and showed another alternative model performs better for larger-sized instances. Afterward, authors [4] offered three heuristics based on the ideas of Minimum Daily Lanes Clustering, Synergy Clustering, and Random Clustering. These heuristics addressed the problem's complexity by first dissecting it in a clustering phase and creating groups of lanes to be served across each planning horizon. The clusters were then solved using the One Day Multi-Point Simulated Annealing method to solve the

SLSP. Finally, an improvement approach was implemented to improve the solution's a posteriori quality. MATLAB was used to code and run the heuristic strategies and the exact approach. Study [68] used a GA to solve an SLSP and evaluated performance parameters for the modified Solomon's instances. They also compared solution algorithms and found that the GA performed better. The coding and execution of the algorithms were done using MATLAB.

The solution methods produce the results as the study [66] introduced models SLSP1 and SLSP2. The outcomes showed that when the average number of lanes per node is 14 or more, SLSP2 consistently surpasses SLSP1 in terms of computational speed. However, SLSP1 performs best when fewer requests (i.e., seven lanes available) and the best solution auctions off some lanes. According to a later study [4], the proposed heuristic methods could produce acceptable results with insignificant cost differences and much less processing time than the exact method. Heuristics based on the Decomposition approach and Genetic Algorithm successfully solved large-scale problems in a different study [68].

VII. CONCLUSION AND FUTURE RESEARCH AVENUES

This literature review identifies the development of significant problems in FTSPs under CAs over the years. Research on challenges addressing problem environments, modeling issues, and solutions have been summarized. The quantitative analysis indicates the most relevant authors, sources, and articles for researchers and practitioners. This work identified the challenges and will propose future research opportunities for related professionals according to current world issues.

Researchers widely practiced the transportation procurement problems under CAs from the shipper's perspective. Determining winners while minimizing transportation costs is the main issue that leads to the well-known WDP, which is not simply related to the costs. It also considers the bidders' and carriers' service levels, reputations, and risk mitigation performances. These considerations make the WDP more complex. Besides this, truckload nature, stochasticity, and auction nature are issues that are tightly integrated with transportation problems. Another crucial point is to generate feasible and profitable bids from the carrier's side during the CA process by analyzing the BGP. Lastly, the pre-auction issue of identifying profitable contracts and lanes to construct a combination of contracts and lanes for the bidding process is addressed by the SLSP. This concept has not been widely studied in the literature to date. Thus, integrating state-of-the-art issues like sustainability and mitigations with an SLSP can direct new variants of this problem in the future.

However, the current literature survey shows that the researchers pay less attention to the non-price objectives like carbon emissions and risk mitigations. Besides this, integrating different transportation moods simultaneously, shippers' reputations and carriers' collaborations to generate profitable bids for FTSPs have never been studied. These practical issues can flourish as future research avenues in FTSP, and the possible directions can be as follows.

A. CARBON EMISSIONS

This is one of the main reasons for environmental disasters, and the transportation sector is one of the major sources of carbon emission. Thus, carbon emission issues, such as those mentioned below, must be included in FTSP's different research developments.

- CA mechanisms can integrate carbon regulations for bidders and auctioneers to minimize emissions throughout the transport procurement.
- Different reputations of carriers have addressed the WDP problem according to the service level, but reputations according to green investments to reduce carbon emissions have never been addressed. Thus, integrating a green reputation within a WDP in the sense of carbon reduction could be a promising future research direction.
- Priority or penalty management in WDPs according to different performances, especially carbon emission reduction or production, can lead to another futuristic research direction.

B. RISK MITIGATIONS

In practice, uncertainties and disruptions are common in the FTSP environment. The mitigation of risks created by the uncertainties and disruptions should be addressed in the following ways:

- Insuring the FTSP contract process between auctioneers and bidders using a third party can ensure minimum loss due to various disruptions.
- Sharing the loss between the parties in case of

disruption can be another mitigation strategy.

C. MULTIMODAL TRANSPORTATION MODES

Transportation modes can vary according to the nature of routes and goods. Combining various transportation modes to create a single complete shipment cycle frequently occurs. Possible new environments are stated below:

- Integrating road transport (truck) with sea or river transport (ships) and air transport (aircraft) or combining any of these transportation modes into a single contract between shippers and carriers is a future research direction.
- Hybridizing public transportation by integrating shipment service for goods, especially for small-sized goods, could be an attractive new research direction.

D. SHIPPERS' REPUTATIONS

Reputations of carriers have been studied in the FTSP literature. But shippers' reputations have never been addressed according to their commitment to the auction rules when they are auctioneers and to shipping items according to size, quantity, quality, and payment loyalty. Considering shippers' reputations from various FTSP process perspectives will lead to important future research.

E. CARRIERS' COLLABORATIONS

Collaboration among the parties is common in transportation research [71]. Carriers can collaborate to construct a feasible bid for their profit maximization. They then share the profit according to their participation in a single bid during a CA process which can add value for the auctioneer and the bidder. Sometimes a single combinatorial bid from a single bidder can be more costly than a bid proposed by collaborative partners (carriers). The following example explains this issue.

Let $S = \{s_1, s_2, s_3, s_4\}$ be a set of four auctioned shipments and $K = \{k_1, k_2, k_3, k_4\}$ a set of carriers or bidders. The carriers are willing to participate in the CA to gain some of shipments/contracts S, and they need to propose various combinations of contracts as combinatorial bids. The bids from the carriers are defined as follows:

$b_1 = \{(s_1, \bar{s_2}, s_3), p_1\}$, bid of carrier k_1 where p_1 is the price and $\bar{s_2}$ will be served during repositioning movements of the carrier.

$b_2 = \{(\bar{s_1}, s_3), p_2\}$, bid of carrier k_2 where p_2 is the price and $\bar{s_1}$ will be served during repositioning movements of the carrier.

$b_3 = \{(\bar{s_1}, s_3, \bar{s_4}), p_3\}$, bid of carrier k_3 where p_4 is the price and $\bar{s_1}$ and $\bar{s_4}$ will be served during repositioning movements of the carrier.

$b_4 = \{(s_2, \bar{s_3}), p_4\}$, bid of carrier k_4 where p_4 is the price and $\bar{s_3}$ will be served during repositioning movements of the carrier.

Anyone can notice that all the shipments during the repositioning trip are distributed in different bids. It is not realistic to make a bid where all the shipments will happen as a repositioning trip for a single carrier though the repositioning trips are available for all the shipments. But it is possible if the carrier makes collaborative bids, such as $B^1_{1,3,4} = \{\left(\bar{s}^3_1, \bar{s}^1_2, \bar{s}^4_3\right), \bar{p_1}\}$; Collaborative bid among the carriers $k_1, k_3, k_4 \in K$ with price $\bar{p_1}$ and $\bar{s_1}, \bar{s_2}$, and $\bar{s_3}$ will be served by carriers k_3, k_1, and k_4, respectively. While bid b_1 and $B^1_{1,3,4}$ contain the same shipments, it is possible to set the relation between prices as $\bar{p_1} < p_1$ because the collaborative bid includes all (or more than one) the shipments during repositioning trips of several carriers with low costs.

Similarly, carriers can generate additional collaborative bids containing more repositioning shipments which will reduce empty/repositioning trips and minimize the costs. On the other hand, auctioneers/shippers will get the opportunity to receive lower-cost shipments than usual process. Thus, this current proposal of collaborative bid construction can introduce a new variant of BGP that can be called collaborative BGP (C-BGP) as a possible future research avenue.

In summary, future research directions concentrate on tackling challenges in transportation procurement by integrating state-of-the-art issues with innovative solutions. Emphasis must be placed on integrating environmental sustainability and social responsibility in decision-making processes, since the transportation sector significantly impacts the ecological footprint and social well-being. This necessitates devising more efficient algorithms to solve large-scale combinatorial auction models, enabling better resource allocation and cost management. Combining cutting-edge computational methods with sustainable practices is crucial as the transportation industry is being transformed into a more environmentally conscious and socially responsible sector.

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