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Auction design in strategic freight procurement

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Auction Design in Strategic Freight Procurement

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Purpose: *This article aims to derive options for auction design in strategic freight procurement from the related literature and synthesize them into a design framework.*

Methodology: *The proposed framework is based on a comprehensive literature review on auction design in strategic freight procurement. After conceptualizing the research topic and defining the scope of the review, a broad literature search was conducted. Inclusion and exclusion criteria were applied to select the literature. A coding scheme was used to extract the data.*

Findings: *The literature review reveals design features and associated design options for each feature. This paper additionally identifies shortcomings in the scientific literature for auction design in strategic freight procurement. Based on this, the further need for research is derived.*

Originality: *The literature to date has focused primarily on describing the auction process and solving the Winner Determination Problem as a subset of the auction process. In contrast, the specific auction design (e.g., bid types, lane design, number of auction rounds) is only considered in a fragmented way. The proposed framework fills this research gap by synthesizing design options from the freight procurement literature.*

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1 Introduction

In times of uncertain supply chains and rising costs of transportation services, effective and efficient transportation management is of great importance for shippers to be resilient and keep costs under control (Caplice, 2021).

Strategic Freight Procurement is a core Transportation Management (TM) activity for shippers to establish contractual relationships with carriers for the provision of transportation services (Brilka and Clausen, 2021). In order to establish contractual relationships, reverse auctions (also referred to as freight tender by some authors (Andersson and Norrman, 2002; Guo, et al., 2006; Lim, Xu and Wang, 2008; Wang and Wang, 2015) are utilized. In a reverse auction, the shipper receives bids from selected carriers for lanes that the shipper has bid out and determines the winning bids as the basis of long-term contracts between the shipper and the carriers. An essential function of the contracts is to govern the assignment of carriers to lanes and the prices for transportation services. (Caplice and Sheffi, 2003; Sheffi, 2004; Caplice, 2007; Seiler, 2012; Holcomb, Liao-Troth and Manrodt, 2014)

Despite the relevance of strategic freight auctions, its process design has only been considered in a fragmented way in previous research. A synthesis of the various design approaches has been lacking so far. This paper aims to close this gap. For this purpose, design options are extracted from the existing literature and synthesized into a design framework. In this way, a holistic design framework is created to support shippers in designing freight auctions. Additionally, the literature reviewed provides a comprehensive overview of the freight procurement knowledge base and can be used as a foundation for future explanation-oriented and design-oriented research.

The remainder is structured as follows. The review methodology is described in Chapter 2. In Chapter 3, the review results and the design framework are presented. Finally, in Chapter 4, the research findings are discussed, and further research opportunities are identified.

2 Methodology

This chapter provides an overview of the research methodology used. A systematic literature review was conducted to extract design options from existing literature. The literature review methodology is based on the guidelines for systematic literature reviews by Durach, Kembro and Wieland (2017).

The first step was to conceptualize the research subject and define the scope of the literature review. The next step was to establish inclusion and exclusion criteria for paper selection to ensure that only those that contribute to the design of the strategic freight auction process are selected. The criteria are listed in the following table.

Table 1: Inclusion and Exclusion Criteria

Criteria for inclusion or exclusion	Reasoning
Exclusion: Paper focus on short-term procurement via spot market	Short-term procurement via spot market is not strategic (Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015; Acocella, Caplice and Sheffi, 2020)
Inclusion: Paper focus on shippers and contribute to the design of freight auctions	The design of auctions is done by the shippers
Inclusion: Paper is written in English	English is the prevalent language in supply chain and logistics research (Pan, et al., 2019)
Inclusion: Paper only published in journals ranked in the top quartile in at least one category in the Scientific Journal Ranking 2021 of SCImago	The quality of the work is guaranteed by publication in a reputable journal.

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An exception to the journal ranking criteria is the monographic publication by Seiler (2012). The publication by Seiler (2012) was initially used to conceptualize the research subject, as it provides a comprehensive overview of TM, including a description of strategic freight procurement and its role in TM. Subsequently, the publication was included in the literature review despite the violation of the defined quality criterion in order not to ignore its contributions to auction design. However, this example illustrates that the quality criterion involves the risk that some high-quality publications were not included. The following shows the inclusion and exclusion criteria.

The Web of Science database was used for the literature search. The search was done using the keywords *freight procurement*, *freight auction*, and *freight tender* in all fields ((ALL=(*freight procurement*)) OR ALL=(*freight auction*) OR ALL=(*freight tender*)).

In the fourth step, the inclusion and exclusion criteria were used to remove irrelevant publications identified by the keyword search. An additional forward and backward search was performed using the same selection criteria for all remaining articles. The paper selection process is shown in Figure 1. The process was carried out jointly by the authors.

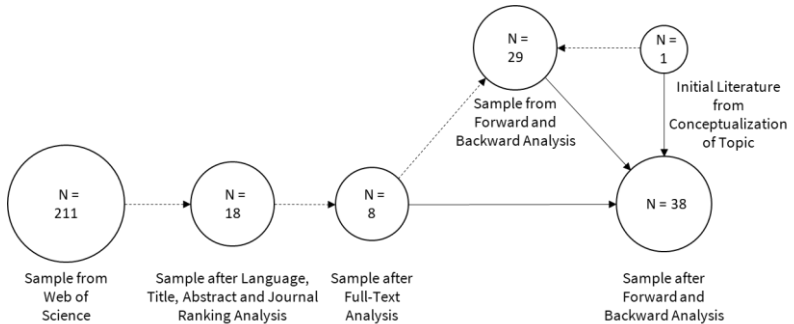


Figure 1: Paper Selection Process

In the next step, the selected literature was fully analyzed and integrated in terms of design options. A predefined coding scheme was used, to extract relevant data. The coding was done by two coders. Fields with discrepancies were resolved through a

repeated joint coding of the respective publications. Literature was coded by author, year of publication, title and design options. In order for all coders to have an equal understanding of what a design option is, it was defined as a possibility for action to influence the way the strategic auction process is carried out. After an initial review of the material, the coding category of design options was divided into pre-auction stage design options, auction stage design options, and post-auction stage design options, following Caplice (2007), who divides the strategic auction process into these three stages. Table 2 shows which design options were assigned to which stage based on Caplice's (2007) descriptions.

Table 2: Strategic Auction Process – Stages

Stages	Explanation
Pre- Auction Stage Design Options	Design options that influence the way the auction preparation is performed.
Auction Stage Design Options	Design options that influence the way the auction execution is performed starting from the communication of the bid information.
Post-Auction Stage Design Options	Design options that influence the way the bid analysis and carrier assignment is performed.

In addition, each coder iteratively generalized each text passage and representation in the material that contained a design option and iteratively subsumed it under an inductively formed design feature. Inconsistencies were resolved through repeated joint generalization and feature formation.

Once all the design options were identified and grouped under the design features, the auction design framework was developed. For the development of the framework, morphological boxes were used, which according to Zwicky (1967) can be used for solving design problems. According to the process division into three stages, a morphological box is created for each of the process stages. To create a morphological

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box, a matrix is created in which the design features are arranged in the left column and the individual expressions (design options) are entered in the respective rows of the features (Hettterscheid and Schlüter, 2019). According to Zwicky (1967), the design options assigned to a feature are mutually exclusive. However, this need not always be the case as Hettterscheid and Schlüter (2019) and Pousttchi, Schrödl and Turowski (2009) show. For the design of the morphological boxes in this paper, the second approach is followed, since some identified design options of a feature, as shown in the literature, do not necessarily have to exclude each other.

3 Review Results and Design Framework

Based on 38 selected peer-reviewed journal articles, 38 design features with a total of 220 design options, distributed over three auction stages, were identified and compiled into a design framework. The design framework is shown in Figure 2. The framework consists of three design packages corresponding to the three stages of an auction process: pre-auction stage design, auction stage design, and post-auction stage design. Each design package consists of several design features, each of which includes several design options and is arranged in a morphological box (Figures 3 to 7). For better clarity, the morphological box for pre-auction stage design has been divided into three sub-boxes (Figures 3 to 5). By combining at least one design option per feature of each morphological box, different design variants can be created for the auction process. In the following sections, the morphological boxes are illustrated, and the design options per feature of a box are presented according to the review results.

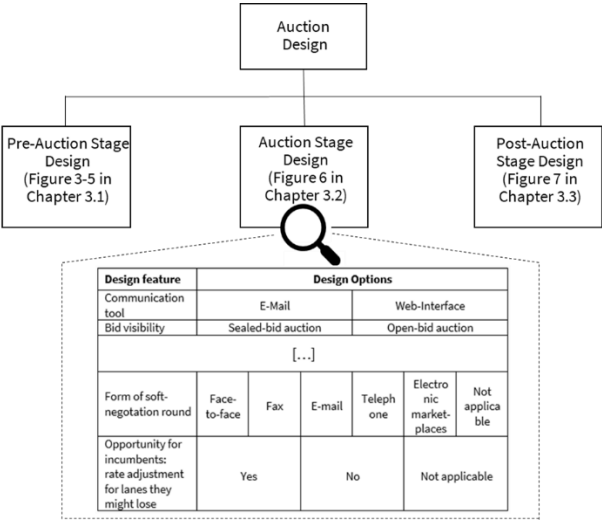


Figure 2: Auction Design Framework for Strategic Freight Procurement

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3.1 Pre-Auction Stage Design

In the pre-auction stage, the shipper determines how the network is presented to the carriers, which carriers are to be invited, what information the carriers must submit (Caplice, 2007), and what terms and conditions the carriers must satisfy (Basu, Bai and Palaniappan, 2015). Figures 3 to 5 show the design features and options in the context of these tasks.

Design feature	Design Options				
Classification of lanes	Point-to-point		Zone-to-zone	Zone-to-point	Point-to zone
Lane design approach	Threshold volume approach		Distance classes approach		Origin-destination pairs
Demand forecasting approach	Estimation based on historic demands		Stochastic determination from historical data		No demand planning
Distribution of forecasted demand	Based on day		Based on week		
	Based on month		Based on year		
Lanes auctioned off	Higher volume lanes			Lower volume lanes	
	With provision of a volume forecast		Without provision of a volume forecast		Without provision of a volume forecast
Agreement of back-up rates for lanes not auctioned off	Yes		No		Not applicable

Figure 3: Pre-Auction Stage Design – Part 1 of 3

The network of a shipper consists of a set of lanes. Lanes are unidirectional arcs between two nodes on which a specific transportation service is to be provided (Caplice and Sheffi, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019). According to Caplice (2007), nodes are either points or zones, and lanes can thus be classified as point-to-point, zone-to-zone, zone-to-point, or point-to-zone. Depending on the geographic specificity used, a point is a specific ship-to or ship-from-point, a city, or a postal code area. Anything larger than each is considered a zone (Ledyard, et al., 2002; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Yang and Huang, 2021).

Furthermore, Caplice (2007) outlines an approach to deciding which shipping locations to be treated as a point rather than combined into a zone. The approach can be referred to as “threshold volume approach” (Caplice, 2007). The approach proposes to use volume thresholds that must be reached as a point-to-point, zone-to-zone,

zone-to-point, or point-to-zone lane. The thresholds are defined in such a way that higher volumes travel on point-to-point, zone-to-point and point-to-point lanes, while low volumes travel on zone-to-zone lanes. The objective of the approach is to consider both effectiveness and coverage when establishing the representation of the network. On the one hand, most lanes should be sufficiently specific to allow the carrier to price them accurately; on the other hand, lanes should cover all regions where traffic could occur throughout a contract period. (Caplice, 2007)

A prerequisite for using the threshold volume approach is a forecast of the demand of each origin-destination flow for the transportation service to be procured through the auction process. Several methods for forecasting demand can be found in the literature. The demand can either be estimated based on historical demand data or calculated using stochastic methods (Moore, Warmke and Gorban, 1991; Basu, Subramanian and Cheikhrouhou, 2015; Qian, et al., 2020). In addition, the demand can be determined from future material flow data such as sales forecasts or production plans (Lim, Rodrigues and Xu, 2008; Seiler, 2012). Besides lane design, demand forecasts are also essential information for the price calculations of carriers (Caplice and Sheffi, 2003). Nevertheless shippers occasionally do not provide them at all (Caplice, 2007) or do not provide them in sufficient quality. On the one hand, quality problems arise from inaccurate forecasts (Basu, Subramanian and Cheikhrouhou, 2015) and, on the other hand, from the inaccurate provision of the distribution of expected demands. Caplice and Sheffi (2003) show how the provision of expected demands per year negatively affects shippers' bidding behavior. Alternative time units reported in the literature to indicate demand distributions are day, week, or month (Caplice, 2007; Rekik and Mellouli, 2012; Basu, Bai and Palaniappan, 2015).

An alternative approach for designing lanes is shown in the GVE (Güterfernverkehrsentgelte). The GVE is a collection of standard rates for long-haul transportation in Germany (Seiler, 2012). In a GVE rate structure presented by Seiler (2012), lanes are defined in distance bands of 100 km each to a point. It is thus a network representation based exclusively on the point to zone or zone to point scheme, where each zone corresponds to a distance class (e.g., until 100km, until 200km, etc.) from or to

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a point. A third method simply defines lanes as origin-destination pairs (Ledyard, et al., 2002; de Vries and Vohra, 2003; Basu, Bai and Palaniappan, 2015; Yang and Huang, 2021).

Another design feature of the network representation is to decide which lanes to bid out. Caplice (2007) points out that shippers typically auction off the higher volume lanes with a forecasted volume. The lower volume lanes, however, will not be explicitly auctioned. Instead, shippers typically request back-up rates from carriers for a collectively exhaustive and mutually exclusive set of zones without giving a volume forecast.

In order to determine which carriers to invite to an auction, the first step is to identify potential carriers. On the one hand, potential carriers are carriers that have been used in the past and, on the other hand, carriers that have not been used yet (Caplice and Sheffi, 2003; Caplice, 2007). To identify new carriers, various sources of information are available to shippers, such as carrier websites (Caplice and Sheffi, 2003), public exchanges (Caplice, 2007), trade media, word of mouth, or carrier promotion (Krapfel and Mentzer, 1982). The search for potential carriers can lead to a high number of hits. In addition, especially for potential carriers who are not incumbents, performance data is usually not or hardly available (Caplice and Sheffi, 2003). In order to reduce the number of carriers and thus the complexity as well as costs of the final selection and to ensure a certain level of quality of the carriers, the shipper can perform a pre-selection before inviting carriers to an auction (Coulter, et al., 1989; Moore, Warmke and Gorban, 1991; Ledyard, et al., 2002; Rekik and Mellouli, 2012; Basu, Subramanian and Cheikhrouhou, 2015; Wang and Wang, 2015). However, according to Sheffi (2004), a pre-selection of carriers has the disadvantage that carriers may be excluded prior to an auction based on their performance level, even though their price level would compensate for the deficiency.

Design feature	Design Options						
Carriers considered for an auction	Carriers used in the past			New carriers			
Sources of information used for the search of new carriers	Carrier websites	Public exchanges	Trade media	Word of mouth	Carrier promotion	Not applicable	
Carrier pre-selection	Includes incumbent carriers		Includes non-incumbent carriers		No pre-selection		
Evaluation method for pre-selecting non-incumbent carriers	MCDM method				Non-formalized method		Not applicable
	Weighted Sum Model	Analytic Hierarchy Process (AHP)	Other MCDM method				
Evaluation criteria for pre-selecting non-incumbent carriers	On-time performance	Cut-off times	Reliable pick-up service	Completeness of service offered	Break bulk usage	Direct service points	
	Hub locations	Full state coverage	EDI capability	Discount percentage	Barcode tracing	Satellite tracing and communications	
	FAK class rate	Quality/safety program	Carrier security	Claims ratio	Operating ratio	Claims payment	
	Safety ratings	Insurance coverage	Transtimes (Two-day service)	Service flexibility	Carrier reputation	Familiarity with shipper operations	
	Quality of carrier personnel	Billing service	Service frequency	Rate changes	Loss/damage history	Financial stability	
	Quality of customer service (e.g., ability to handle special needs and emergencies)		Pricing flexibility		Handling capabilities	Area coverage	
Numbers of persons and fuctions involved	One person from one business funtion		Multiple persons from one business function		Multiple persons from multiple business functions		

Figure 4: Pre-Auction Stage Design – Part 2 of 3

When a shipper pre-selects carriers, this may include non-incumbents as well as incumbents, although it is rare that incumbent carriers are not invited to an auction, according to Caplice (2007). The pre-selection of carriers is also known as Request for Information (RFI) (Andersson and Norrman, 2002).

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As Basu, Subramanian and Cheikhrouhou (2015) show, the decision to invite or not invite incumbents to an auction is made based on the output of the carrier performance review process. Since the process of the performance review is not the subject of this paper, evaluation criteria and methods relevant to the design of this process are not discussed in the following. For non-incumbents, in contrast, carrier evaluation is part of the screening process. How such screening activity can be conducted is demonstrated by the case study of MicroAge Computer Centers Inc. with 300 carriers described by Sheffi (2004). In 1994, the company pre-selected carriers for an auction using a weighted sum model that evaluated carriers based on their responses to 18 evaluation criteria. In addition to these 18 criteria, other criteria can be considered when selecting carriers, as the results of literature reviews on carrier attributes conducted by Meixell and Norbis (2008) and Coulter, et al. (1989) reveal. The individual evaluation criteria presented in both publications are summarized in the morphological box in Figure 4.

Meixell and Norbis (2008) also show that in addition to the Weighted Sum Model, the Analytic Hierarchy Process (AHP) is also used as a multi-criteria decision making (MCDM) method for carrier selection purposes. In addition, they point out that non-formalized methods are also used for carrier selection. Basu, et al. (2016) further show that in addition to the Weighted Sum Model and AHP, there are other MCDM methods such as Data Envelopment Analysis (DEA) or Grey relational analysis. However, their suitability is discussed only in the context of criteria weighting for a final carrier selection method in the post-auction stage.

Another design feature for carrier screening concerns the number of persons and business functions involved in the selection decision. According to Krapfel and Mentzer (1982), selection decisions can be made by one or more persons from one business function or multiple persons from multiple business functions (e.g., Purchasing and Logistics).

Determining what information the carrier must submit back includes the form of the price, service details, and the types of bid allowed (Caplice, 2007). According to Seiler (2012), the price for a lane includes a basic rate structure, optional discounts, and surcharges.

Design feature	Design Options															
Form of basic rate structure	Per move		Per distance unit		Per load size scale		Per move and per load size scale		Per load size unit / load size scale		Per weight / weight scale / product class					
					With dimensional conversion factor			Without dimensional conversion factor								
Surcharges and discounts	Index-based surcharges and discounts (e.g., diesel floater)		Additional driver surcharges		Surcharges for unplanned eventualities such as demurrage		Additional stop costs		Fees for customs clearance		Discounts on continuous moves		Discounts on the total transportation expenditure with a carrier			
Service components (S = specified by shipper; C = specified by carrier)	Transit days		Capacity availability				Equipment type				Maximum waiting time free of charge				Latest amendments or cancellations	
	S	C	S	C	S	C	S	C	S	C	S	C				
	Weekend Coverage		Brokerage rights				Safety factors				Performance factors					
	S	C	S	C	S	C	S	C	S	C						
Additional terms and conditions	IT capabilities	Minimum volume or spend guarantees	Payment terms		Penalty rules for service deficiencies		Required insurance coverage of the carrier		Contract period		Working instructions		Other (e.g., from ADSp)			
Types of bid allowed	Simple lane bid	Simple segment bid	Simple lane bid with volume constraints	Static package bids (And)		Static either/or package bids (XOR)		Flexible Package Bids		Simple reload bids	Tier Bids					
				Shipper created		Carrier created										
Limitation of the number of bids	Yes						No									
Back up carrier bids required	Yes						No									

Figure 5: Pre-Auction Stage Design – Part 3 of 3

Depending on the service, there are different ways to represent the basic rate structure, as publications addressing the rate structure of FTL services, LTL services, and parcel services reveal (Lapierre, Ruiz and Soriano, 2004; Caputo, Fratocchi and Pelagagge, 2006; Caplice, 2007; Seiler, 2012; Yang and Huang, 2021). Several options can be derived from these publications to represent the basic rate structure. The price is either given *i)* per move, *ii)* per distance unit, *iii)* per load size scale, *iv)* per move and per load size unit, *v)* per load size unit per load size scale, and *vi)* per weight unit per weight scale per product

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class. Load size scales and the load size units are commonly given in the dimensions of weight, cube space, or floor space (Seiler, 2012). However, to ensure that carriers are not solely dependent on one dimension when determining prices, a volume/weight ratio is often also specified as a conversion factor. This allows carriers to price a load either by weight or by volume, depending on which dimension utilizes a means of transportation more. (Lapierre, Ruiz and Soriano, 2004; Seiler, 2012) An alternative to using a dimensional conversion factor is followed in alternative vi) with pricing by product class. This option is typical for LTL services in North America. There, product classes are formed primarily by weight density in accordance with the National Motor Freight Traffic Association guidelines, which also allow carriers to take volume and weight into account when pricing a load. (Lapierre, Ruiz and Soriano, 2004)

In addition to the multiple ways to determine the basic rate structure, the literature also provides several options regarding surcharges and discounts. Surcharges and discounts that have been identified in the literature are index-based surcharges or discounts (e.g., diesel price floater), additional driver surcharges, surcharges for unplanned eventualities such as demurrage, additional stop costs, fees for customs clearance, discounts on continuous moves and discounts on the total transportation expenditure with a carrier. (Caputo, Fracocchi and Pelagagge, 2006; Caplice, 2007; Seiler, 2012; Turner, et al., 2012; Scott, 2015; Yang and Huang, 2021)

The service details are either provided by the carrier based on requested service information (Caplice, 2007) or provided by the shipper as terms and conditions that the carrier must satisfy (Andersson and Norrman, 2002; Basu, Bai and Palaniappan, 2015). However, service components specified in an auction process have only been considered marginally in the literature. Although some service components are mentioned sporadically (Andersson and Norrman, 2002; Caplice, 2007; Seiler, 2012; Zhang, et al., 2018), a systematic exploration of different possibilities is missing so far. Service components identified in the different publications include the following: transit days, capacity availability, and equipment type, a maximum waiting time free of charge, the latest possible time until which a load tender can still be amended or canceled, weekend coverage, brokerage share, safety factors, performance indicators such as a tender acceptance ratio, service quality.

Besides the service components, the literature mentions additional terms and conditions that the shipper can formulate as the basis of the business relationship with the carrier. These are (Andersson and Norrman, 2002; Caplice and Sheffi, 2003; Lim, Rodrigues and Xu, 2008; Lim, Xu and Wang, 2008; Meixell and Norbis, 2008; Lim, Qin and Xu, 2012; Seiler, 2012; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015; Zhang, et al., 2018): required IT capabilities (e.g., electronic data interchange), minimum volume or spend guarantees, payment terms, working instructions, penalty rules for service deficiencies, required insurance coverage of the carrier, and the contract period, which is usually one to three years (Ledyard, et al., 2002; Caplice and Sheffi, 2003; Caplice, 2007; van Duin, Tavasszy and Taniguchi, 2007; Lim, Qin and Xu, 2012; Seiler, 2012; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015). Furthermore, there are standardized terms and conditions, such as the ADSp in Germany (Allgemeine Deutsche Spediteurbedingungen), which contain additional terms and conditions for defining the business relationship (Seiler, 2012).

Another design feature of the pre-auction phase is the definition of the types of bids allowed (Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). Basu, Subramanian and Cheikhrouhou (2015) distinguish two bid types, single bids and combinatorial bids, between which a shipper can choose. Single bids, also referred to as simple bids, are the traditional practice in transportation in which carriers bid for individual lanes or segments of the network, regardless of the volume of business they might win (Caplice and Sheffi, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). The advantage of single bids is that finding the lowest cost carrier can be done by simply sorting the lowest rates on a lane-by-lane (segment-by-segment) basis using a database application or spreadsheet (Caplice and Sheffi, 2003). However, a disadvantage of this type is that carriers are incentivized to hedge their bid prices against the possibility that they will not be awarded any supporting business (Caplice, 2007). Another disadvantage of the simple bid type is that system constraints, such as ensuring that a carrier wins at least a certain level of business or needing a minimum number of carriers serving a location, cannot be considered (Caplice and Sheffi, 2003). Combinatorial bids, in contrast, can consider system constraints. In addition, the uncertainty regarding the amount of business to be won can be reduced (Caplice and

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Sheffi, 2003; Lafkihi, Pan and Ballot, 2019). However, to find the lowest cost carrier when using combinatorial bids, it is necessary to apply a formal optimization method instead of a simple sorting method (Caplice and Sheffi, 2003). According to Basu, Subramanian and Cheikhrouhou (2015), combinatorial bids are bids where carriers can submit bids on combinations of lanes. A different understanding of combinatorial bids is expressed by Caplice (2007). The author equates combinatorial bids with conditional bids and understands them as the submitting of bids that are conditional on a pre-defined set of actions also taking place. Several forms of conditional bids are presented in the literature (Ledyard, et al., 2002; de Vries and Vohra, 2003; Abrache, et al., 2004; Guo, et al., 2006; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Chen, et al., 2009; Ma, Kwon and Lee, 2010; Ignatius, et al., 2011; Lim, Qin and Xu, 2012; Rekik and Mellouli, 2012; Remli and Rekik, 2013; Zhang, et al., 2014; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015; Wang and Wang, 2015; Basu, et al., 2016; Zhang, et al., 2018; Remli, et al., 2019; Qian, et al., 2020; Yang and Huang, 2021). Caplice (2007) describes six types of bids currently used in transportation practice. These are 1) Simple Lane Bid with Volume Constraints; 2) Static Package Bids (AND); 3) Static Either/Or Package Bids (XOR); 4) Flexible Package Bids; 5) Simple Reload Bids; and 6) Tier Bids. When using package bids, the shipper must additionally decide whether the shipper or the carriers should create the lane packages. While in most auctions, packages are created by the seller (e.g., art, antique, and other “collection-like” auctions), Caplice and Sheffi (2003) have found that in transportation, packages specified by shippers are less successful because carriers are better at identifying valid lane combinations based on their individual networks and perspectives.

Additionally, regardless of allowing a form of simple or conditional bidding, the shipper must decide whether to set an upper bound on the number of lanes or packages that can be bid on or not (de Vries and Vohra, 2003; Wang and Wang, 2015). Furthermore, shippers must decide whether to require carriers to bid only to serve lanes as primary carriers or serve lanes as alternate or back-up carriers (Caplice and Sheffi, 2003).

3.2 Auction Stage Design

In the auction stage, the shipper communicates the bid information to the carriers, and the carriers submit their bid rates (Caplice and Sheffi, 2003; Caplice, 2007; Seiler, 2012; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015). The design features and options of the auction stage are shown in Figure 6.

Communication tools are used to transmit the bid information to carriers and receive their bids. Nowadays, shippers usually use either e-mail or some sort of web interface (Caplice, 2007; Wang and Wang, 2015).

Concerning the design feature of bid visibility, the literature distinguishes between sealed-bid auctions (no real-time visibility of the rates submitted by competitors) and open-bid auctions, also referred to public-bid auctions (real-time visibility of the rates submitted by competitors) (Ledyard, et al., 2002; Caplice and Sheffi, 2003; Lafkihi, Pan and Ballot, 2019). With open-bid auctions, the initial prices paid can often be significantly reduced due to the transparency of competition created. Disadvantages, however, are that conditional bidding is not possible, that performance factors are ignored, and that a “damaging price war between carriers” is promoted, which can lead to a large portion of the network having to be re-sourced later. In addition, the acceptance of open-bid auctions is low among some carriers, increasing the risk that some carriers refuse to participate in an auction. (Caplice and Sheffi, 2003)

In terms of the number of rounds, a distinction is made between single and multiple auction rounds (Ledyard, et al., 2002; Caplice and Sheffi, 2003; de Vries and Vohra, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019). Single round auctions can reduce the probability of a “damaging price war between carriers”, incentivizing carriers to give accurate prices “without playing games” and causing less effort than multiple rounds. Multiple rounds, in contrast, provide carriers with the opportunity to adjust their bidding strategies and allow the shipper to exert more pressure on the carriers to lower their bids (Caplice and Sheffi, 2003; Rekik and Mellouli, 2012; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019). Lafkihi, Pan and Ballot (2019) refer to such auctions, where the bidder adjusts their starting bid downwards in the auction as a descending auction.

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Design feature	Design Options					
Communication tool	E-Mail			Web-Interface		
Bid visibility	Sealed-bid auction			Open-bid auction		
Number of rounds	Single round		Multiple rounds			
Exclusion of carriers between rounds	Not applicable		Yes		No	
Price information for the carriers between rounds	Not applicable		Provision of the current winning bid on each lane between rounds	Provision of a complete distribution of the bids on each lane between rounds	Provision of a partial distribution of the bids on each lane between rounds	
Change of bid type between rounds	Not applicable		Yes		No	
Withdrawal rule	Withdrawal of bids is allowed			Withdrawal of bids is prohibited		
Stopping rule	After a specified time has elapsed		Standing bid is not outbid within a specified time	After the acquisition cost to a previous round did not decline by a specified percentage + a final round	After a defined number of rounds	
Final soft-negotiation round	Yes			No		
Form of soft-negotiation round	Face-to-face	Fax	E-mail	Telephone	Electronic market-places	Not applicable
Opportunity for incumbents: rate adjustment for lanes they might lose	Yes		No		Not applicable	

Figure 6: Auction Stage Design

Options for shippers to influence the bidding of carriers in the next round include deciding how to handle non-winning bids and what information to provide to shippers for the next round (Caplice and Sheffi, 2003). To deal with non-winning bids, Basu, Subramanian and Cheikhrouhou (2015) and Wang and Wang (2015) present the option to call each bidder for the next round. The literature does not address the alternative option of carriers being excluded from the bidding process for certain lanes or packages based on one or more criteria.

Information provided to shippers for the next round is not much represented in the literature. Regarding the information provided to carriers for the next round, Wang and

Wang (2015) and Ledyard, et al. (2002) state that reference prices should be shared with carriers to enhance competition. However, the construction or content of reference prices is not defined. According to Caplice and Sheffi (2003), shippers have the options of, among other things, presenting carriers with a complete or partial distribution of the bids on each lane or providing carriers with information on the current winning bid on each lane

Furthermore, Wang and Wang (2015) show that shippers can change the bid type between rounds under certain circumstances and accordingly provide the relevant information to carriers before the next round. In the use case presented by the authors, the carriers are to submit self-created package bids in the first round. Based on the bids, the shipper then creates overlap-free packages covering all lanes, on which the carriers have to bid in the next round. The goal of the approach is to leverage the advantages of carrier-created packages without taking the risk of not finding a solution in carrier assignment that covers all auctioned lanes without overlaps.

Two other design features for the design of the auction stage are the withdrawal rule and stopping. The withdrawal rule is an additional design feature for the design of multi-round auctions. The stopping rule applies to the design of both single and multiple round auctions. Based on Ledyard, et al. (2002), the shipper's decision whether to allow or prohibit the withdrawal of a provisional winning bid is defined as the withdrawal rule. Ledyard, et al. (2002) argue in their paper that shippers should not be allowed to withdraw provisional winning bids as this creates bad incentives and prolongs the auction. The stopping rule is also addressed by Ledyard, et al. (2002). According to the author, the stopping rule specifies when an auction ends. Three stopping rules are presented by the authors: 1) the auction ends after a specified time has elapsed; 2) the auction ends if no one outbids the current standing bid within a specified time; 3) the auction ends after a final round, which is declared if the acquisition cost did not decline by a specified percentage compared from the previous round. Another stopping rule for multi-round auctions is shown by Wang and Wang (2015). The auction presented by the authors ends after a defined number of rounds. In addition, several authors mention stopping rules but do not specify them. (Abrache, et al., 2004; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019).

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Another design feature for both single and multi-round auctions is the decision whether there should be a final soft-negotiation round (Andersson and Norrman, 2002; Caplice, 2007). If a final soft-negotiation round is to be conducted, there are two further design decisions that apply. The shippers must decide whether incumbent carriers are offered the opportunity to adjust their submitted rates on lanes they stand to lose (Caplice, 2007), and what the form of negotiation will be. The traditional form of negotiation is face-to-face. Other forms include using fax, e-mail, telephone, or electronic marketplaces. (Lafkihi, Pan and Ballot, 2019)

3.3 Post-Auction Stage Design

The post-auction stage includes the analysis of the bids submitted per round, the assignment of the business to specific carriers, and the assembling of the routing guide (Caplice and Sheffi, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). Figure 7 shows the identified design features and options in this stage.

Caplice and Sheffi (2003) distinguish three types of methods used in practice for bid analysis and carrier assignment. These are simple sorting of lowest rates, MCDM, and optimization-based analysis. Simple sorting of the lowest rates is a standard method by shippers running bids in-house. An advantage of the method is that it can be performed with little effort if the network complexity is low. However, the disadvantage of the method is that neither performance and sustainability factors nor conditional bids and business constraints can be considered. Whereas with an MCDM method, it is possible to consider performance factors. (Caplice and Sheffi, 2003)

Design feature	Design Options					
Bid analysis and carrier assignment method	Simple sorting of lowest rates	MCDM method			Non-formalized method	Optimization-based analysis
		Weighted Sum Model	Analytic Hierarchy Process (AHP)	Other MCDM method		
Performance factors considered in carrier assignment	On-time performance	Reliable pickup service	Billing service	Claims performance	Refusal rate	
	Transit time	Response time	EDI capability	Surge capacity	Loss/Damage history	
	Area coverage	Insurance coverage	Financial stability of carrier	Route optimization of carrier	Energy efficiency of carrier	
	Carbon foot print of carrier	Electronic documentation	Carrier security	Satellite tracing and communications	Quality of carrier personnel	
	Carrier reputation	Familiarity with shipper's operation	Completeness of service offered	Pricing flexibility	Loading and unloading facilities	
	Handling capabilities	Service frequency	Rate changes	Willingness to focus on continuous improvement	Willingness to meet cost goals	
	Quality of customer service (e.g., ability to handle special needs and emergencies)		Established safety programs		Not applicable	
What-if scenarios with different business considerations	Yes			No		
Business considerations in carrier assignment (to choose for each scenario)	Carrier base size restrictions	Back up carrier bids	Minimum/Maximum Coverage	Threshold volumes	Service requirement for alternates	Restricting carriers
	Core carrier guarantees	Favoring of incumbents	Penalizing the nomination of additional carriers	Carriers' disruption risk	Shortages in carriers' required shipment volumes	Valuing performance
Numbers of persons and fuctions involved	One person from one business funtion		Multiple persons from one business function		Multiple persons from multiple business functions	
Allocation mechanism	First-price auction			Second-price auction		
Documentation of auction rates and assignment	In paper-based system			In electronic catalog		
				With integration into an execution software system		Without integration into an execution software system
Documentation of non-winning rates to be used as backup rates	Yes			No		

Figure 7: Post-Auction Stage Design

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Yet, only a few studies have addressed the use of MCDM for bid analysis and carrier assignment. Basu, et al. (2016) contrast a weighted sum model with optimization-based analysis. In addition, they show that MCDM methods, such as AHP, Data Envelopment Analysis (DEA), or Grey relational analysis can be used to determine the weights of performance factors in a weighted sum model or an optimization-based analysis. However, the extent to which these MCDM methods are suitable as sole methods for carrier selection is not discussed. Meixell and Norbis (2008) give some examples from literature where carrier selection was made using AHP. Furthermore, Meixell and Norbis (2008) show that carrier selection is also performed by some shippers using non-formalized methods.

When using an MCDM method, a key design feature, in addition to deciding on a specific method, is the selection of performance factors to be evaluated. In the literature review, we found various performance factors that can be considered (Coulter, et al., 1989; Caplice and Sheffi, 2003; Sheffi, 2004; Guo, et al., 2006; Meixell and Norbis, 2008; Rekik and Mellouli, 2012; Basu, Subramanian and Cheikhrouhou, 2015; Basu, et al., 2016; Zhang, et al., 2018). The individual performance factors are shown in the morphological box in Figure 7.

Unlike simple sorting of lowest rates and MCDM methods, the use of optimization-based analysis has been the subject of numerous publications (Ledyard, et al., 2002; de Vries and Vohra, 2003; Abrache, et al., 2004; Guo, et al., 2006; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Chen, et al., 2009; Ma, Kwon and Lee, 2010; Ignatius, et al., 2011; Lim, Qin and Xu, 2012; Rekik and Mellouli, 2012; Remli and Rekik, 2013; Zhang, et al., 2014; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015; Wang and Wang, 2015; Zhang, et al., 2015; Basu, et al., 2016; Zhang, et al., 2018; Remli, et al., 2019; Qian, et al., 2020; Yang and Huang, 2021). The Optimization-based analysis involves optimization-based approaches for solving the Carrier Assignment Problem (CAP) (Caplice and Sheffi, 2003), also called the Winner Determination Problem (WDP) (Caplice 2007). The CAP is about finding a carrier-lane assignment based on the auction bids that minimizes the shipper's total cost while ensuring that each lane is served and its required capacity is available (Basu, Subramanian and Cheikhrouhou, 2015).

The advantage of optimization-based approaches is the ability to analyze conditional bids and incorporate various business considerations, including performance factors, into the carrier assignment decision (Caplice and Sheffi, 2003). Some shippers even run multiple what-if scenarios with different business considerations to maximize the fit of carriers to their business needs (Caplice and Sheffi, 2003). Several business considerations can be found in carrier assignment models. The following business considerations can be found in carrier assignment models (Caplice and Sheffi, 2003; de Vries and Vohra, 2003; Guo, et al., 2006; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Chen, et al., 2009; Ma, Kwon and Lee, 2010; Lim, Qin and Xu, 2012; Rekik and Mellouli, 2012; Zhang, et al., 2014; Basu, et al., 2016; Zhang, et al., 2018; Qian, et al., 2020):

- Carrier base size restrictions at the system, region, facility, or lane level
- Preventing carriers from being assigned as a primary carrier and alternate or back-up carrier on a lane (back-up carrier bids)
- Ensuring that the amount of traffic assigned to a carrier, or set of carriers across the system, within a region, at the facility level, or on a lane is within a certain bound (Minimum/Maximum Coverage)
- Ensuring that if a carrier is awarded any business on a lane, from or to a facility, or system-wide, it has to be of a certain minimum threshold amount (Threshold volumes)
- Limiting the number of carriers within the system by requiring that all carriers operate as both primary and alternate carriers over different segments of the system (Service requirement for alternates)
- Restricting carriers (e.g., non-incumbents) from serving certain portions of the system
- Guaranteeing that a group of core carriers wins a target level of traffic across the system (Core carrier guarantees)
- Favoring incumbents by penalizing bids of non-incumbents or discounting bids of incumbents
- Penalizing the nomination of additional carriers by imposing a cost on each carrier used
- Valuing performance by allocating penalties or rewards to the bids based on measured performance
- Integrating costs of mitigation strategies to deal with carriers' disruption risk

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- Integrating penalty costs for demand uncertainty-related shortages in carriers' required shipment volumes

When valuing performance in a carrier assignment model, the shipper can choose from various performance factors, as shown in Figure 7.

Following Krapfel and Mentzer (1982), for the design feature of the number of persons and business functions involved in the assignment decision, just as in the case of carrier screening described above, a distinction can be made between 1) one person from one business function, 2) multiple persons from one business function, 3) multiple persons from multiple business functions.

With regard to the allocation mechanism, the shipper can choose between first-price auctions and second-price auctions. In first-price auctions, the carrier with the lowest bid wins the auction at the bid price submitted. In second-price auctions, the carrier with the lowest bid wins the auction at the price of the second-lowest bid. Compared to first-price auctions, second-price auctions are rare in transportation literature, although they have proven to be a truthful allocation mechanism. (Lafkihi, Pan and Ballot, 2019)

The assembly of the routing guide is the final step of the post-auction stage from a process perspective (Caplice, 2007). A routing guide is a paper-based system or an electronic catalog in which rates, assignments, and sometimes non-winning rates as back-up rates, are documented (Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). According to Caplice (2007), most shippers today use as a routing guide an electronic relational database that interfaces with an execution software system used to manage the day-to-day transportation operations (e.g., Transportation Management System). Basu, Subramanian and Cheikhrouhou (2015) also indicate that an electronic catalog is either integrated into the execution software system or not.

4 Discussion and Future Research Opportunities

The basis of this paper is that the design of the auction process for strategic freight procurement has so far been treated in research in a fragmentary way. Therefore, a holistic design framework that supports shippers in auction design has been lacking so far. In order to close this gap, first a systematic literature review was conducted to identify the various design fragments. In total, 38 peer-reviewed journal articles from 1982 to 2021 were systematically selected and analyzed. The literature review resulted in 38 design features with a total of 220 design options distributed across a total of three auction stages. Based on this, a design framework was developed which, for each of these stages, presents design features and design options in a structured and clear manner in matrices based on morphological boxes by Zwicky (1967). By combining at least one design option per feature of each morphological box, various of design alternatives can be generated for the auction process. However, the mere combination can also generate a variety of unsuitable or infeasible combinations. This represents a limitation of the design framework that can be addressed in future research by finding feasible and proven combinations. Another limitation of the design framework that should be addressed in future research is the evaluation of practicality and completeness. As the results of the literature review show, there are few or only a few comprehensive contributions to some design features, which creates the risk that not all potential options have been considered in the framework. The risk is further increased because most publications focus on road freight, and there in particular on FTL services.

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