Evaluating Synergy in Auctioned Customer Bundles for Transportation Carriers

Amina Antit
UR-OASIS, National Engineering School of Tunis, University of Tunis El-Manar, Tunis, Tunisia
amina.antit@gmail.com

Chefi Triki
Kent Business School University of Kent, Canterbury, United Kingdom
c.triki@kent.ac.uk

Safa Bhar Layeb
UR-OASIS, National Engineering School of Tunis, University of Tunis El-Manar, Tunis, Tunisia
safa.layeb@enit.utm.tn

Amel Jaoua
UR-OASIS, National Engineering School of Tunis, University of Tunis El-Manar, Tunis, Tunisia
amel.jaoua@enit.utm.tn

***Abstract*— In this study, we investigate the concept of calculating the bundle synergy factor for carriers participating in a customer auction via a coalition pool. We introduce a new mathematical model to evaluate the synergy of an auctioned bundle of customers, taking into consideration pre-existing customers and carrier's depot. The developed model is based on a function that takes into account the travel times and customer weights. To demonstrate the applicability of our approach, a proof-of-concept study is conducted on an illustrative example to analyze the key features of the proposed model.**

***Keywords*— Synergy, Transportation, Auctioned Customer.**

I. Introduction

Auctions serve as dynamic marketplaces where products or services frequently change hands through competitive bidding. There are two main types of auctions: traditional auctions, where items are typically bid for one by one, and combinatorial auctions, where bidders assemble sets of items and offer a single price for the entire lot. In the realm of combinatorial auctions, the competition operates on an "all-or-nothing" basis: the highest bidder claims the entire lot, or the items are divided among multiple bidders [1].

In the transportation sector, carriers engage in auctions to procure transportation services or facilitate the exchange of their loads or lanes. This paper focuses on carriers' participation in auctions through a coalition pool for the exchange of customer' contracts. These auctioned customers are of the shared type, as they accept outsourcing [2]. The carriers involved in this process provide delivery (distribution) services from a depot using Less-Than-Truckload trucks. The process involves two steps. In the first step, each carrier is required to push unprofitable customers to the coalition pool. In the second step, carriers undertake what is known as the "bid generation problem" to construct bundles of attractive customers. They then select the most appealing bundle to submit, along with their pricing. Interestingly, a carrier might submit a particular customer to the pool and later include them in one of their future bids. This happens because the customer becomes profitable only when combined with other customers offered in the pool by different carriers. Furthermore, a submitted bid might include a less attractive customer due to their high weight.

In fact, we assume that a customer with a significant weight may not be a favorable choice for other competing carriers due to their infrequently visited delivery location. Conversely, we assume a customer with a lower weight has the potential to form an attractive bid for competing carriers, thanks to their frequently visited delivery location.

Assessing the effectiveness of a bundle involves ensuring consistency among its constituent elements, a concept commonly referred to in the literature as "synergy"[3,4].

In this paper, each auctioned customer is characterized by a travel time separating them from the rest of the customers and depot, as well as a weight factor. Hence, the synergy value will play a key role in defining the quality of bundles of customer with respect to their proximity, all the while considering the importance of customers based on their respective weights. Given that each carrier departs from a depot and serves existing customers, and considering that customers already assigned to a pool are characterized by both weights and travel times, the paper aims to address the following question: How can the synergy value within a given bundle of customers be calculated?

The rest of the paper is organized as follows. Section II reports the literature review. Section III provides the synergy computation model. Section IV discusses an illustrative example, and section V draws conclusions and avenues for futures research.

II. Related Work

Recently, several research efforts have been dedicated to quantifying synergy of bundles within the context of combinatorial transportation auctions. Keskin et al. [3] developed three algorithms aimed at quantifying synergy as a critical measure for assessing the compatibility between the operator's existing network and contracts intended to be bundled. These algorithms incorporate contract deadlines for the booked contracts, factor in the revenues associated with the auctioned contracts, and consider the contract directions for both the booked and auctioned contracts. The study conducted by Hammami et al. [5] addresses the issue of combinatorial bid construction with stochastic prices. In calculating the synergy factor, the authors utilized the synergy formula initially developed by Triki et al. [6]. The later calculated bundle synergy as the average of all pairwise synergies between contracts within a bundle, as well as between booked contracts and those in the bundle. Different approaches were presented for estimating pairwise synergies: one based on the Euclidean distance between contracts, while the other quantified distance based on the number of hops.

In addition, Yan et al. [4] examined a bid generation problem within the context of combinatorial transportation auctions, specifically focusing on in-vehicle consolidations. They defined the concept of synergy within each bundle of contracts, considering elements such as bundle profit, service cost, and the total distance required to serve these contracts. They also introduced three distinct formulas to calculate the synergy between an auctioned bundle of contracts and the booked contracts, considering vehicle capacity. The synergy value was determined by combining these expressions in a convex manner. Olcaytu and Kuyzu [7] also addressed the concept of synergy in evaluating auctioned contracts, considering both the bundle's cost and the associated distance with each contract. Triki et al. [8] explored maximizing synergy in carrier transportation networks through combinatorial auctions while minimizing empty transport. They introduced two integer programming models with different objectives: one aimed at maximizing carrier profit, and the other aimed at minimizing lane distances to enhance synergy. Triki [1] presented an optimization approach based on location techniques for the synergy approximation in combinatorial transportation auction. This approach sought to maximize synergy within the sets of auctioned contracts and between these auctioned contracts and existing ones.

In this work, we are addressing the case of carriers collaborating through a coalition pool in order to exchange customers. Thus, each carrier will act by first pushing the set of customers that are unattractive and in a second step, each carrier will form through the available customers in the pool a bundle of interesting customers to submit hoping to win it. Previsely, our objective is to quantify the synergy of each bundle. It's worthy to note that (i) the bundle comprises a combination of customer contracts, (ii) the customers of a particular carrier are defined by both a weight and a travel time, and (iii) the assessment of a bundle takes into account the carrier's depot and the pre-existing customers.

III. Synergy computation

The considered problem can be defined using a fully connected directed graph, denoted as G=(V, A), where V represents the set of vertices encompassing all customers, including the depot, and A comprises the set of edges that model all potential routes between customers and the depot. To clarify, here are definitions of the key sets and parameters used in this context:

D is the set of depots. In this case, we assume that the number of depots is one.

N_e is the set of pre-existing customers.

N_p is the set customers existing in the pool.

N is the set of all vertices, where $N=N_e \cup N_p$

N_b is the set of customers bundle $b \subset N_p$

N_s is the set of pushed customers of a given carrier, where $N_s \subset N_p$

TT_{ij} is the travel time separated all vertices where $(i,j) \in A$

W_i is the weight of a given customers i , where $i \in N_s$. Note that customers other than N_s have a weight value of zero.

Subsequently, Expressions (1) and (2) respectively express the contribution in terms of synergy of each customer i belonging to bundle b and the synergy of a bundle b:

$$S_i = 1 - \frac{\sum_{j \in N_b \cup N_e \cup D} TT_{ij}}{max_{(i,j)\in A}\{TT_{ij}\} \times (|N_b| + |N_e|)} \times (1 - W_i) \text{ , } \forall i \in N_b \quad (1)$$

$$S_b = \frac{\sum_{i \in N_b} S_i}{|N_b|} \quad (2)$$

In Equation (1), the individual synergy S_i quantifies the contribution of a specific customer within a bundle N_b relative to other customers in the bundle, pre-existing customers, and the depot. This calculation is based on the total travel time, normalized by the maximum travel time value, and is further adjusted by the weight assigned to the customer, reflecting their significance.

Equation (2) calculates the bundle synergy S_b, representing the average of all synergies concerning each node of the bundle. A synergy value S_b closing 1 indicates that customers within bundle b exhibit a high degree of synergy conversely, as the value of S_b closes zero, it suggests a lower level of synergy within the bundle.

IV. Illustrative example

As proof-of concept of the proposed approach, we consider an illustrative example. Suppose carrier X has a depot D and a truck, and has four customers, N1, N2, N3, N4 to serve from the depot. The carrier participated in the auction by pushing the customers N2, N3 and N4 into the coalition pool. The coalition pool already includes customers N5, N6 belonging to other competitors. The carrier wants to calculates the synergy of different bundles. The weight value and the travel times separating the different nodes is indicated in the matrix below.

Table 1. Travel Times matrix (in hour) & assigned weights for each customer

	Travel Times							Weights
j \ i	D	N1	N2	N3	N4	N5	N6	
D	0	1	2,2	3	3	0,8	3,7	-
N1	1	0	1,5	3,2	3,3	0,3	3,3	-
N2	2,2	1,5	0	4,8	0,5	0,4	1	0.1
N3	3	3,2	4,8	0	3,5	3	2,5	0.85
N4	3	3,3	0,5	3,5	0	0,9	0,7	0.05
N5	0,8	0,3	0,4	3	0,9	0	2	-
N6	3,7	3,3	1	2,5	0,7	2	0	-

We propose to calculate the synergy of then randomly selected bundles in two scenarios: (S1) considering

customer weights and, (S2) where customer weights are not taken into account, meaning that a weight value of zero is assigned.
Here are the bundles: b1= {N2,N5,N6}, b2={N3,N5,N6}, b3={N4,N5,N6}, b4={N5,N6}, b5={N2,N5}, b6={N2,N3}, b7={N2,N4,N5,N6}, b8={N2,N3,N4,N5,N6},b9={N6}, b10={N2}.

In Table 2, the synergy calculation results for each bundle, as well as the synergy relative to each element within each bundle, are computed for both scenarios.

TABLE2. COMPUTATION RESULTS

b(i)	Sce-na-rios	N2	N3	N4	N5	N6	Sb
b1	(S1)	0,7609	-	-	0,8177	0,4792	0,6859
	(S2)	0,7344	-	-	0,8177	0,4792	0,6771
b2	(S1)	-	0,9086	-	0,6823	0,4010	0,6639
	(S2)	-	0,3906	-	0,6823	0,4010	0,4913
b3	(S1)	-	-	0,6091	0,7917	0,4948	0,6318
	(S2)	-	-	0,5885	0,7917	0,4948	0.6250
b4	(S1)	-	-	-	0,7847	0,3750	0,5798
	(S2)	-	-	-	0,7847	0,3750	0,5798
b5	(S1)	0,7438	-	-	0,8958	-	0,8198
	(S2)	0,7153	-	-	0,8958	-	0,8055
b6	(S1)	0,4688	0,8854	-	-	-	0,6770
	(S2)	0,4097	0,2361	-	-	-	0,3229
b7	(S1)	0,7900	-	0,6873	0,8167	0,5542	0,7120
	(S2)	0,7667	-	0,6500	0,8167	0,5542	0,6968
b8	(S1)	0,6750	0,8958	0,6075	0,7431	0,5417	0,6926
	(S2)	0,6389	0,3056	0,5868	0,7431	0,5417	0,5632
b9	(S1)	-	-	-	-	0,2708	0,2708
	(S2)	-	-	-	-	0,2708	0,2708
b10	(S1)	0,6531	-	-	-	-	0,6531
	(S2)	0,6145	-	-	-	-	0,6146

When examining Table 2, several observations could be derived:

When comparing the synergy results for all bundles between the two scenarios, there is a notable increase in synergy values when transitioning from Scenario (S2) to Scenario (S1). However, this increase is not observed for bundles b4 and b9. The synergy values for b4 and b9 remain unchanged in both scenarios because these bundles do not include any customers (N2, N3, N4) with non-zero weights.

Specific customers, such as N2 and N3, tend to have higher individual synergy contributions when included in bundles, particularly in Scenario 1. For example, in bundle b2, the individual contribution of N3 is 0.9086 in Scenario 1 compared to 0.3906 in Scenario 2, showing a significant drop when weights are ignored

The relationship between the size of a bundle and its synergy value is not straightforward. For example, bundle b5, which includes only two customers, has a higher synergy value than bundle b8, which includes five customers. Similarly, bundle b10, which includes a single customer, has a higher synergy value than bundle b3, which includes three customers. These cases indicate that the inclusion of more customers does not always lead to higher synergy values.

The synergy value inversely correlates with travel time. For instance, in bundle b5, customer N5 achieves the highest individual synergy value due to a short travel time of 0.3 hours separating it from customer N1. Conversely, customer N3 in bundle b6 has the lowest synergy value, primarily because of a long travel time of 4.8 hours separating it from customer N2.

The synergy value of a bundle composed of a single customer, such as b9 and b10, is different from zero. This value is equal to the individual synergy value of that customer, reflecting the interaction of the bundle's element with the pre-existing depot

Evidently, this is an illustrative example used for the purpose of verifying and validating our model. It represents an initial preliminary study that will be followed by a more comprehensive numerical investigation on benchmark instances in future work.

V. CONCLUSIONS

This study introduces a mathematical model for quantifying the synergy factor of bundles of auctioned customers. This approach is particularly relevant for carriers participating in auctions to exchange customers through a coalition pool. The framework incorporates two main parameters: customer weights and travel times, providing a comprehensive approach to assess the compatibility and potential for synergistic benefits within customer bundles. The illustrative example demonstrates the practical application of this approach, showing that considering both customer weights and travel times significantly influences synergy calculations. This approach enables carriers to make more informed decisions when forming bundles for auctions, ultimately leading to improved collaboration and efficiency in the transportation industry. Extensive computational study will be conducted to validate these findings.

As a next step, it would be valuable to explore the integration of economic parameters, including customer costs and profits, for assessing the synergy of a bundle of auctioned customers. Additionally, developing additional methodologies, such as mathematical modeling and heuristics, could lead to the creation of more advanced tools for quantifying and optimizing the synergy of a bundle of auctioned customers.

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