Enhancing the Carriers Synergy in the Full-Truck Transportation Industry

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Abstract

This paper deals with the maximization of the synergy within a carrier's transportation network. This key concept of synergy is particularly important when participating in combinatorial auctions for the procurement in full-truckload transportation service. Our ideas derive from the advances achieved in the field of graph theory and are based on the technique of minimizing the distance between the booked and auctioneed lanes. We develop two optimization formulations that mainly differ in the objective function and that have been described by using an illustrative example that has taken from the literature and suitably adapted for the purpose of our application.

Keywords
Synergy, transportation industry, integer formulations, auctions

1. Introduction

Transportation is one of the major activities in supply chain management. It represents also an important share of the cost of most of the products or services. Reducing transportation costs means not only optimizing the vehicle routes but also trying to avoid the useless empty movements needed for repositioning. According to Eurostat data 2012 almost 24% out of all the distance travelled for the freight transportation in Europe is performed by empty trucks. Moreover, the average load of the traveling trucks amounts to only 56% of their weight capacity (Palmer et al., 2012). This paper has the objective of trying to avoid such inefficiency by employing some the advanced techniques achieved in the field of graph theory. More specifically, this study represents an attempt to adapt the optimization models of Ishihara and Kobayashi proposed in the context routing with interference constraints (Ishihara & Kobayashi, 2015) to the field of full-truck transportation networks. The objective is to develop optimization formulations for the maximization of the synergy among the lanes to be served by a transportation company (or carrier). Such models may be considered as an extension of the recent work of Triki who proposes an optimization scheme for the synergy approximation in combinatorial auctions for the transportation procurement (Triki, 2016). In his paper, Triki has developed a mathematical approach based on the use of the minimax location approach typically employed for the facility planning. The resulting approach belongs, thus, to the approximation techniques since no exact models have been proposed for the synergy maximization. Besides the above mentioned work, we are aware of one other single paper that takes explicitly the synergy into account in order to define bidding strategies in combinatorial auctions. An et al. proposed, indeed in (An et al., 2005), a mathematical expression that incorporates the pairwise synergy between each pair of loads in order to estimate the value of the bundles. This paper represents an attempt to feel this gap by suggesting two integer formulations that allow the exact solution of the problem under exam.

We suppose here that the carrier has already a set of committed (or booked) lanes L_0 that the transportation company is obligated to serve on the bases of previous shipping contracts. On the basis of the underlying transportation network, the carrier has already defined a set of trucks paths that cover all the booked lanes. Consequently, we denote such k trucks paths as $(s_1, t_1), (s_2, t_2), \ldots, (s_k, t_k)$ where s_i and t_i represent the begin and end vertex of truck path i, respectively. Such paths $i=1, \ldots, k$ will inevitably include some empty movements that the trucks must cover in order to connect the booked lanes. Clearly these repositioning moves cause additional traveling costs to the carrier without generating any profit. Any opportunity of filling those gaps with new business will represent a great chance for the carrier to transfer those operational costs into useful profits.

Bearing this goal in mind, the carrier will participate in some combinatorial auction organized by shipping companies that use such trading tool in order to procure their transportation needs. We denote as L the set of auctioneed lanes among which the carrier can select those that fit better his network without any obligation to serve them. The main criteria of selection will be based on the concept of distance *dist(e, e')* between any pair of booked lane $e \in L_0$ and auctioneed lane $e' \in L$. The concept of synergy is inversely proportional to the distance measure, i.e. a small distance between lanes is a good indicator of their strong synergy. The idea is, thus, to select among the auctioneed lanes those that will cover one of the empty movements or other close ones that will, thus, force the corresponding truck to make one or more detours.

Given two points $u, v \in V$ in the graph, the distance *dist(u, v)* is simply the standard Euclidian distance between u and v whereas the distance between two lanes *dist(e, e')* can be defined through one of the following two definitions (Ishihara & Kobayashi, 2015):

Definition 1: consider *P(e)* and *P(e')* the two-dimentional planes defined by each of the two lanes. The distance between the two lanes will be given by the minimum distance between any two points of the two planes:

$$dist(e, e') = min_{u \in P(e), v \in P(e')} dist(u, v)$$

Definition 2: let *V(e)* and *V(e')* the set of vertices belonging to the lanes *e*, *e'*, respectively, then the distance is given by:

$$dist(e, e') = min_{u \in V(e), v \in V(e')} dist(u, v).$$

In order to illustrate the difference between the two definitions, consider the example depicted in Fig. 1. The application of the first definition will result in a value $D_1(e, e')$ but if we adopt the second one then the distance value will be $D_2(e, e')$. Clearly, the second definition of distance seems to be more suitable for the context of transportation networks.

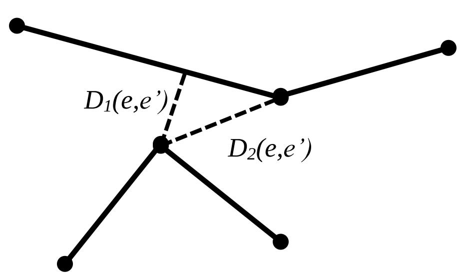

Figure 1. Definition of distance between two arcs

2. Optimization Models

The transportation network will be represented here by a directed graph $G = (V, E)$ and the decision variables will mainly consist on the flow i along the arc $e \in E$ in the path s_i–t_i.

Assumption: *We suppose here that the carrier operates in a regional/local context and will also participate mainly in auctions covering his own area.*

The above assumption means that both the booked and auctioneed lanes are enough short that they can be considered to cover only one single arc. Accordingly, we do not need to distinguish in the sequel between the concepts of lane and arc of the network because they will coincide. In order to cover a more general situation, it will be necessary to introduce the arc-lane mapping in order to identify each arc to which lane it belongs. This can be easily done by introducing additional notation and new constraints with the obvious consequence of increasing the complexity of the mathematical models but without adding remarkable insights on their importance and applicability.

On the basis of the above assumption, our notation is summarized, thus, as follows:

- C_e: cost of traversing arc $e \in E$
- L: set of auctioned lanes
- L_0: set of booked lanes
- $R(L_0)$: Revenue deriving from serving the booked lanes
- $R(L)$: Revenue deriving from serving the auctioneed lanes
- $E\backslash\{L\ U\ L_0\}$: all the other arcs that can be traversed but do not need service
- *dist(e, e')*: distance between two arcs *e* and *e'* as defined above
- *D(e, e')*: a threshold distance specifying a given value of *dist(e, e')*
- $H_{e,v} \in \{—1, 0, 1\}$ $(e \in E, v \in V)$: $+1/—1$ if the head/tail of arc *e* is *v* and 0 otherwise

Moreover, our decision variables are denoted as:

(A1) $F_{i,e} \in \{-1, 0, 1\}$ $(i \in [k], e \in E)$: $+1/-1$ if the flow indexed by i goes through edge e in the forward/backward direction and 0 otherwise.

(A2) $\bar{F}_{i,e} \in \{0, 1\}$ $(i \in [k], e \in E)$: absolute value of $F_{i,e}$.

(A3) $B_{i,v} := \sum_{e \in E} F_{i,e} H_{e,v}$ $(i \in [k], v \in V)$.

In the sequel, two integer formulations will be proposed that mainly differ in their objective function. The first one will maximize the profits of the transportation company and the second will seek to minimize the lanes distances and, consequently, maximize the synergy in the carrier's network.

Model 1: Profits Maximization

Maximize $R(L_0) + R(L) - \sum_{i \in [k]} \{ \sum_{e \in E \backslash L} C_e \bar{F}_{i,e} + \sum_{e \in L} C_e/2\ \bar{F}_{i,e} \}$ (1)

Subject to:

$F_{i,e} \leq \bar{F}_{i,e}$ and $-F_{i,e} \leq \bar{F}_{i,e}$ $\quad \forall i \in [k], \forall e \in E$ (2)

$B_{i,v} = 0$ $\quad \forall i \in [k], \forall v \in V\{s_i, t_i\}$ (3)

$B_{s_i,i} = 1$ and $B_{i,t_i} = 1$ $\quad \forall i \in [k]$ (4)

$-1 \leq F_{i,e} + F_{i',e'} \leq 1$
and
$-1 \leq F_{i,e} - F_{i',e'} \leq 1$ $\quad \forall i, i' \in [k], i \neq i', \forall e \in L, e' \in L_0$, $dist(e, e') \leq D(e, e')$ (5)

$F_{i,e} = 1$ $\quad \forall e \in L_0$ (6)

(A1)—(A3) (7)

The objective function (1) consists in maximizing the carrier's profits defined as the difference between the revenue deriving from serving both the booked and auctioned lanes minus the total travelling cost along all the network. It is to be noted that the cost of traversing the auctioneed lanes L has been reduced (by half) in order to boost their selection in the trucks paths with respect to other arcs with equal or similar cost. Constraints (2) define the absolute value of $F_{i,e}$. Constraints (3) and (4) ensure the continuity of flow connecting the truck path s_i-t_i. Inequalities (5) are the synergy constraints to guarantee that any selected auctioneed lane *e'* included in one of the paths is located within a threshold distance *D(e, e')* with respect to a booked lane *e*. Constraints (6) will ensure that all booked lanes are included in one of the trucks paths and, finally, constraints (7) define the domain of the decision variables.

Model 2: Synergy Maximization

$$\textbf{Minimize} \quad \sum_{i\in[k]} \left\{ \sum_{e\in E\setminus L} \bar{F}_{i,e} + \sum_{e\in L_0} \sum_{\substack{e\in L \\ dist(e,e')\leq D(e,e')}} dist(e,e')\bar{F}_{i,e} \right\} \tag{8}$$

Subject to:

$$F_{i,e} \leq \bar{F}_{i,e} \quad \text{and} \quad -F_{i,e} \leq \bar{F}_{i,e} \qquad \forall i \in [k], \forall e \in E \tag{9}$$

$$B_{i,v} = 0 \qquad \forall i \in [k], \forall v \in V\{s_i, t_i\} \tag{10}$$

$$B_{s_i,i} = 1 \quad \text{and} \quad B_{i,t_i} = 1 \qquad \forall i \in [k] \tag{11}$$

$$F_{i,e} = 1 \qquad \forall e \in L_0 \tag{12}$$

$$\text{(A1)—(A3)} \tag{13}$$

This model is similar to the previous one. The two models share most of the constraints and differ mainly in the definition of the objective function. In this model (8) attempts to minimize the flow along all the arcs of the network. However, the interference between any auctioneed lane *e'* and booked lane *e* is weighted by the distance factor in order to involve as much as possible of the auctioneed lanes having a distance value $dist(e, e') \leq D(e, e')$. This will maximize the overall synergy within the carrier's transportation network. As a consequence, the constraints related to the distance restrictions (5) introduced in the model (1)—(7) are not needed anymore here and have been, thus, omitted.

It is worth noting that both the models can have as output the same auctioneed lane to be selected by two or more different truck paths because of its strong synergy with different booked arcs. In this case, it is necessary that the carrier makes a posteriori decision on which path fits better the selected lane. Moreover, he should also take into account the new clusters of (booked and auctioned) lanes in order to define the new trucks routes.

3. Illustrative Example

The network shown in Figure 2 is an example that has been adapted from Ishihara and Kobayashi (2015) for the purpose of our application. More specifically, the black paths represent the 8 pre-defined trucks routes with their corresponding origin and destination each. Some of the involved arcs in the paths belong to L_0 and the others are empty movements for repositioning. It is to be noted that the original example does not specify any direction for the paths but that have been introduced here in order to adapt the network to suit our application. Moreover, the blue short arcs represent the set *L* of auctioneed lanes. The output of the IP formulations and the corresponding post-processing procedure will result in a new set of trucks paths that include, possibly, all the auctioneed lanes that have strong synergy with the booked lanes. The oval red forms show some examples of booked and auctioneed lanes that are close enough to form a cluster with strong synergy. The models will suggest a new truck route that integrates them either on the basis of the revenue or the synergy maximization. However, it is the responsibility of the carrier to check a posteriori if the proposed detour is acceptable or should be modified.

4. Conclusions

This paper has dealt with the problem of maximizing the synergy within the transportation network of carrier that would like to minimize its empty movement through participating in combinatorial auctions. Two integer programming models have been proposed having two different objective functions. The first one maximizes the profits of the transportation company defined as the revenue minus the traveling costs. The second attempts to maximize the synergy within the carrier's network minimizes by minimizing the lanes distances. The paper has shown the scope of the models through an illustrative example but did not include rigorous experimental results that are left for future investigation. Moreover, it would be interesting to integrate such models within a bid generation optimization approach in order to discover how the synergy maximization will affect the procedure of defining the carrier's bids while participating in a combinatorial auction.

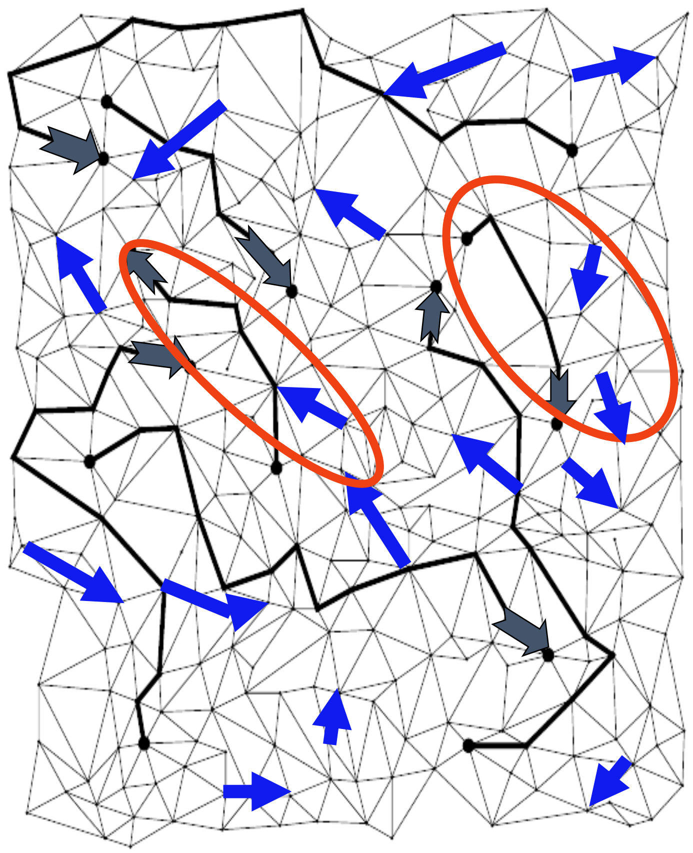

Figure 2. Example of synergy in a random network

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Biography

Chefi Triki is an Associate Professor of Operations Research and Logistics Systems. His major research interests lie in the field of stochastic programming with application to logistics and transportation. He has published and served as a reviewer in a variety of international scientific journals. His teaching activities consists in a wide range of undergraduate and graduate courses on logistics, simulation, informatics and optimization for the engineering, mathematics, computer science and management science students.