Cooperation among carriers in seaport containerized transportation: towards economic and environmental savings

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Abstract: This paper proposes a heuristic approach for planning cooperation among multiple carriers with the goal of eliminating empty truck trips while maximizing the cost saving resulting from their collaboration. The aim of this methodology is to improve collaborations among carriers serving a port area. The approach foresees three main phases: in the first step, the transportation demand is decomposed in two parts based on freight flows trade-off; in the second step, a linear optimization model, which takes compensation mechanisms among carriers into account, allows to combine trips belonging to different carriers two by two in order to decrease the number of empty movements. Finally, in the third step, a second optimization problem enables assigning trips of each carrier to trucks with the goal of minimizing the travel costs. The proposed heuristic approach has been evaluated using a data set taken from daily truck trips of the port of Genoa, Italy. The environmental implications of combining trips has also been analyzed.

1. INTRODUCTION

Today, the issue of negative externalities related to freight road transportation is of major concern. In this perspective, empty movements of trucks must be minimized. This can be done by properly planning and optimize trips belonging to the same carrier and, whenever this is not possible, trips related to different carriers. In other words, it becomes crucial to share partial demands from different carriers with the goal of bringing benefit both to each carrier involved and to the social community. In fact, the rationalization of road transportation has strong implications in terms of environment and social congestion.

Maximizing capacity utilization of trucks by eliminating empty truck trips was first studied for a single carrier which dates back to three decades ago (Gavish and Schweitzer [1974], Powell [1987], Imai et al. [2007], Coslovich et al. [2006], Chung et al. [2007], Jula et al. [2005], Ronen [1992], Zhang et al. [2010], Caballini et al. [2013]). The problem has been solved both for static and dynamic cases, considering different objective functions, such as minimizing the total cost of deadheading and total distribution costs. On the other hand, more recent studies are aimed at forming collaboration among two or more carriers in order to utilize their unused capacity. As previously said, this form of cooperation, if properly defined, in addition to positive environmental impacts, has economic advantages for the collaborating carriers. A proper form of collaboration ensures fair division of costs and savings and prevent each carrier to loose the customers related to the orders shared with other carriers. As a result, several smaller carriers linked together will also be able to compete with larger carrier companies. This latter issue is studied in detail in Yilmaz and Savasaneril [2012] specifically under uncertain conditions. Ergun et al.Ergun et al. [2007], studied how truckload shippers can collaborate to minimize asset repositioning, thereby reducing deadhead trips. They formulated the problem in terms of the lane covering problem, in which a set of constraint with minimum cost are found that cover a subset of arcs in a directed graph. In another study, Zener and Ergun developed cost-allocation schemes in similar shipper alliances (ÖZener and Ergun [2008]). In Krajewska et al. [2007] the distribution of both costs and savings arising from horizontal cooperation is studied using cooperative game theory. Caballini et al. Caballini et al. [2014] proposed a model for collaboration among multiple carriers with the objective of maximizing the cost saving of the system obtained from collaboration among carriers.

A high ratio of container transportation originates or ends at sea port areas. The trucks carrying the container to a destination from seaport has to return to the port to leave the container at the empty depot. Thus, these trips are two-way trips, one leg of which is usually performed empty. In this context, i.e. port to in-land container transportation, trip combination is specifically beneficial. This problem has been faced in this paper, which studies the effect of collaboration among multiple carriers serving the container demand arriving at/departing from a seaport, considering the requirements of such trips as well as the ports and inland destination time windows constraints. More specifically, the goal of the present work is to maximize balanced trips (which will be called ”re-used” trips in the paper) in order to gain economic and environmental advantages.

The paper is organized as follows. In Section 2 the problem under consideration is described, while in Section 3 the optimization scheme adopted for optimizing multiple carriers collaboration is presented, including the mathematical formulations. Section 4 provides some experimental results tested on a big real case study and shows the computational analysis carried out in order to test the efficiency of the proposed approach. In Section 5 the results emerging from an environmental analysis are described and, finally, the solution approach and some concluding remarks on the developed model are reported in Section 6.

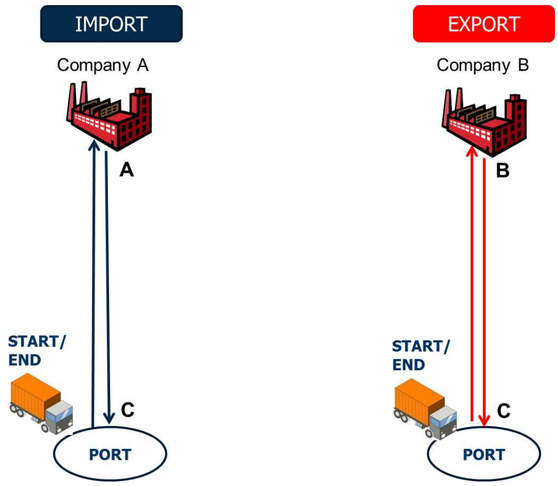

Fig. 1. Scheme of a typical sea-land ”round-trip” (import and export)

2. PROBLEM DESCRIPTION

Road transportation keeps representing the most used transportation mode to cover short distances. However, the structural lack of planning and optimization of transport demand and trucks capacity lead to economic and social negative impacts, both for companies and for the community. In the perspective of facing such an issue, this paper tries to optimize the whole demand of multiple carriers by combining trips belonging to different carriers with the goal of minimizing empty trips. However, due to competitiveness issues, collaboration among carriers needs some compensation mechanisms in order to encourage them to share some of their trips with the other carriers.

Specifically referring to international transport, a trip can be related to the import or export cycle, depending on the fact that the goods arrives from from sea to land (i.e. it is imported) or from land to sea (i.e. it is exported). In fact, in this research we takes into account only trips that originate or end up in the port node; however, in land-land transportation the approach is similar.

As far as regards the import cycle, the following operations must be performed by the carrier (Fig. 1, left side):

(1) the truck picks up a full container in the port;
(2) the truck travels with the full container to the importer company or to a consolidation centre /warehouse where it will wait the container be unstaffed (link C-A);
(3) the truck brings the empty container to the depot of empty containers pointed out by the shipping company, which is usually located inside or near the port (link A-C).

On the contrary, when taking into account the export process, the operation to be executed by the haulier are the following ones (Fig. 1, right side):

(1) the truck picks up an empty container in the depot of empty containers indicated by the shipping company, located inside or near the port;
(2) the truck travels to the exporter company or to a consolidation centre where the container will be staffed (link C-B);
(3) the truck travels back to the port with the full container, where it will be released and continue its trip by ship (link B-C).

The performing of this two kinds of trip autonomously, called ”round-trips” (RT), leads to a lack of efficiency because it implies empty movements of trucks on the network; in fact one of the two trips does not generate added value because the truck travels empty (without a cargo payload) or with an empty container. The adoption of this kind of inefficient trips, which unluckily are very common, is due to technical and commercial reasons, which may bring back to the following ones:

- lack of planning tools or skills by road carriers (or freight forwarders in case they own the trip);
- unwillingness of giving trips to other carriers for the fear of loosing the final customer;
- imposition, by shipping companies, to leave empty containers in empty depots located near to the origin of the trip (which is represented by the port for what concerns the import cycle and by an area near the company for what regards the export one).

So, starting from the consideration that the more balanced the transport is, the best is both from the economic and environment standpoint, the goal of the present study is to maximize the number of the so-called ”re-used” (RU) - i.e. balanced- trips by sharing portions of carriers demands, so minimizing the travel distance covered by trucks on the network.

An import-export ”re-used” trip foresees the following steps (Fig. 2):

(1) the truck picks up the full container in the port (import cycle);
(2) the truck travels with the full container to the importer company -or in a consolidation centre - and wait for the container to be stripped (link C-A);
(3) the truck travels with the empty container to the exporter company -or in a consolidation centre - where the container will be staffed for the export cycle (link A-B);

(4) the truck travels with the full container to the port for delivering it. The container will continue its journey by ship (link B-C).

An export-import re-used trip is analogous to the export-import one; in both cases, the truck travels full on the main two links (C-A and B-C in Fig. 2) and it covers a lower total travel distance in respect to the round-trip case, especially when the two companies are quite close to each other. More specifically, for the convenience of the re-used case, the distance resulting by the sum of the links C-A, A-B and B-C should be lower then the sum of links C-A, A-C, C-B and B-C.

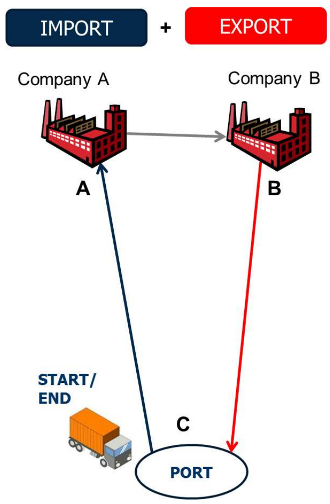

Fig. 2. Scheme of a typical sea-land "Re-Used" Trip

So, in this paper, effective collaboration among carriers is pursued. Each carrier has a certain amount of orders (pickup and delivery of containers) to be fulfilled; it is characterized by specific management costs and it owns a certain number of trucks having different time availabilities and costs.

The basic idea of collaboration among carriers lies on the fact that, in order to maximize re-used trips, each carrier may take care of orders belonging to other carriers or, vice versa, may leave some of its trips to other hauliers. However, carriers may not be willing to give some of their trips to other players due to the fear of loosing customers in a competitive market: this issue is considered in the paper by introducing a compensation mechanism, as it will be better explained and detailed in the next Section.

In the proposed work, some assumptions have been made. Firstly, it is supposed that the number of trucks of each carrier is adequate for meeting its demand; this is a quite realistic assumption, since the number of trucks usually does not represent a strong constraint for a truck company which, if needed, can rent them or outsource the work. Then, it is assumed that only one container per time is transported; this is again realistic in the current context especially for what concerns full containers, due to constraints at the point of staffing and stripping of containers (in fact, not all the companies are equipped with handling means in order to load/unload containers to/from trucks) and to container weights.

Finally, it is assumed that trucks leave start their travel at the origin of the trip, so that the distances to be covered from their depot to the trip origin is neglected (this is also a realistic assumption).

In order to properly formalize the problem, let us consider a generic network, which is modelled as a graph $\mathcal{G} = (\mathcal{V}, \mathcal{A})$, being $\mathcal{V}$ the set of nodes and $\mathcal{A}$ the set of links. Nodes represent the points of pick up and delivery of containers - i.e. the companies and the port - while links represent portions of the road network that connect these points (which are assumed to be the shortest paths). The considered transportation demand is defined in terms of containers to be transported. When decomposing the overall network of trips $\mathcal{N}$ (with card($\mathcal{N}$) $= N$) as described above, two further sets of trips are identified, namely $\mathcal{N}^R$, which is the set of trips related to the round-trips networks and $\mathcal{N}^U$, gathering trips belonging to the re-used trip networks. Note that $\mathcal{N}^R$ and $\mathcal{N}^U$ are given by the sum of the re-used and round-trip network of each carrier ($\mathcal{N}_r^U$ and $\mathcal{N}_r^R$), respectively.

3. OPTIMIZATION SCHEME

The designed heuristic solves the problem of combining the trips of multiple carriers in three phases:

(1) *a pre-processing phase*, in which the demand network of each carrier is divided in two parts: the Re-Used Trips network (RU), which comprises the balanced trips that can be performed by each carrier singularly, and the Round-Trip network (RT) that is not balanced and is shared with the other carriers.
(2) *a first optimization phase* (*step 1*), in which trips belonging to the RT networks are tried to be matched two by two with the goal of maximizing the cost saving earned by combining them. The assignment is based on the basis of the costs sustained by each carrier but it also taken into account the disadvantage of the carrier that "loses" its order.
(3) *a second optimization phase* (*step 2*) in which trucks are assigned to trips (trips belonging to the re-used network plus the ones combined and the remaining trips which have not been combined) so as to minimize total costs related to trucks and drivers.

Fig. 3 provides the optimization scheme above proposed.

In the following, each phase of the proposed framework will be explained in detail.

3.1 Phase 1: Pre-processing step

In the pre-processing phase, the original demand network of each carrier is split into two parts: a RU network, which refers to balanced trips that can be performed autonomously by the carrier, and a RT network, in which half of each trip is performed empty so not fully exploiting the truck capacity.

So, the main goal of this work is to try to combine, two by two, the trips belonging to all the RT networks of the carriers with the goal of getting more balanced freight flows and minimizing empty trips. The splitting process is made as follows: for each pair of origin and destination node, the demand that is shared equally on both the two

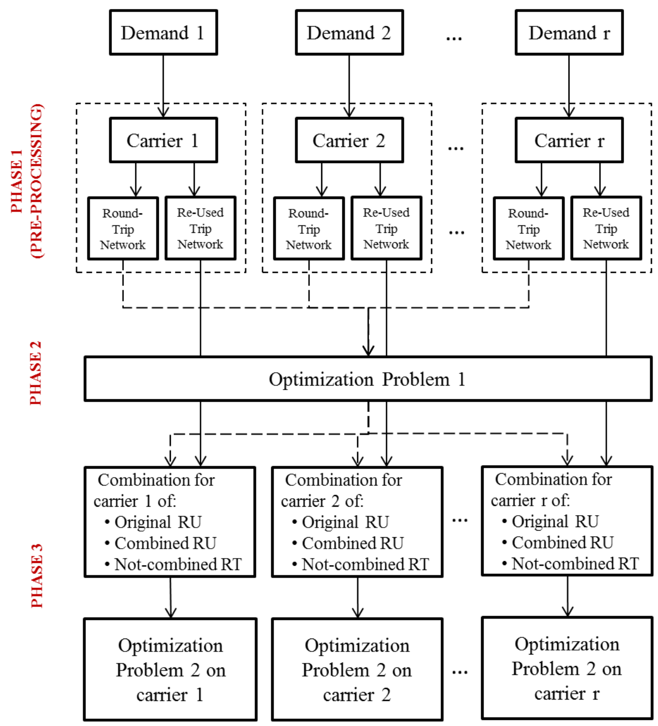

Fig. 3. The optimization scheme proposed.

opposite links connecting the two nodes will belong to the RU network, while the demand that do not have a counterpart on the opposite direction will be part of the RT network and so it will be shared with the other carriers.

For better clarification, let us take into account the simple network provided in Fig.4-left side, composed of 4 nodes, 10 links and 25 trips to be performed. The demand is expressed in number of containers and is shown on each arc.

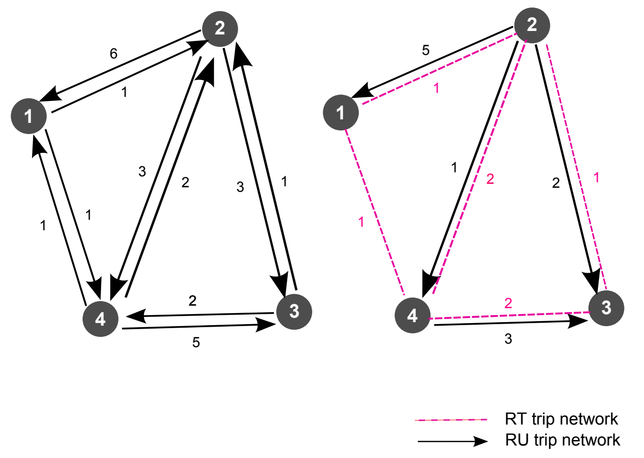

Fig. 4. Example of a generic demand network (left side) and its decomposition (right side).

Fig.4-right side provides an example of decomposition of the simple demand network shown in Fig.4-left side. As it can be noticed, 2 balanced trips on the same link go to constitute the "re-used trip" network (pink dotted lines) and are represented by not oriented arcs, while not balanced trips go to compose the "round-trip" network and are represented by oriented arcs.

3.2 Phase 2: first optimization problem

The objective of the first optimization phase is to maximize the cost saving by coupling, two by two, all the trips of the RT networks (consisting of the trips belonging to $\mathcal{N}^R$). In other words, the goal of this stage is to minimize empty trips and the outcome is a modified network, in which the combined trips increase trucks utilization by minimizing empty trips and the distance to be covered.

For modeling purposes, let us apply the following notation:

- $r = 1, \ldots, R$, is the number of carriers;
- $n = 1, \ldots, \mathcal{N}^R$ is the number of trips;
- t_n is the travel time for serving trip n (expressed in minutes), which depends on the distance to be covered and on the average speed v of the truck ($t_n = \frac{d_n}{v}$);
- d_n is the distance to be covered for serving trip n;
- c_r is the kilometer unit cost of carrier r which differs in relation to its variable and fixed costs;
- C_n^r is the cost for serving trip n by carrier r autonomously, and it is function of the distance to be covered and of the management cost typical of each single carrier: $C_n^r = 2d_n c^r \quad \forall n \in \mathcal{N}^R, \forall r$.

With reference to a pair of combined trips (n, k), $n, k \in \mathcal{N}^R$, $n \neq k$, the following notation must be introduced:

- t_{nk} is the time for serving the pair of trips (n,k);
- d_{nk} is the distance to be covered for serving the pair of trips (n,k) and is calculated as $d_n + d_k$;
- C_{nk}^r is the cost of combining trip n and k, sustained by carrier r;
- S_{nk}^r is the cost saving by coupling trip n and trip k if they are executed by carrier r;
- C_{nk}^d is the cost of delay for performing the combination of trips (n,k);
- c_d is the unit cost of delay;
- $z_n^r \in (0,1)$, $n \in \mathcal{N}^R$, are quantities, known in advance, which assume value equal to 1 if trip n is performed by carrier r and 0 otherwise;
- δ_n^r is a parameter representing the "value" of a single order/trip that is related to a specific carrier. It may take into account the importance of the related customer in terms of value or priority;
- ϵ is the distance needed for repositioning the empty container from a company to another one in case of re-used trips. In reality, it is rare that a company can grant both an import and an export trip in the same day, so we assumed that once performed a trip, the truck must travel for a short distance in order to reach another company. It is worth noting that, in case of two different containers are used, the repositioning cost refers to the distance to be covered by the truck from one node to the other one.

Moreover, time constraints are here considered in two forms:

- deadline of trips;
- opening and closing times of terminals and companies.

So, let us introduce the following additional notation:

- f_n is the finishing time of trip n;

- q_n is the starting time of trip n, which is defined as: $q_n = f_n - t_n$;
- h_n is the deadline of trip n, which coincides with its finishing time f_n (in fact, if the trip is performed autonomously, it is reasonable that it is performed so to respect its deadline);
- f_k is the finishing time of trip k, if not combined;
- $\tilde{f}_k$ is the new finishing time of trip k which derives from moving trip k on the time-axis when matching it with another trip n;
- q_k is the starting time of trip n, which is defined in the following;
- h_k is the deadline of trip k.
- P_n^o is the opening time of the terminal/company where trip n starts;
- $\acute{P}_n^o$ is the closing time of the terminal/company where trip n starts;
- P_n^d is the opening time of the terminal/company where trip n ends;
- $\acute{P}_n^d$ is the closing time of the terminal/company where trip n ends.

Fig. 5 provides a sketch of the time window framework.

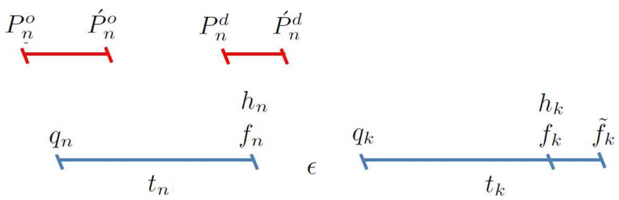

Fig. 5. The time window framework.

More specifically, it is assumed that, when combining two trips, the first one (trip n) is organized in order to respect its deadline q_n, while the second one (trip k), depending on the finishing time of the first trip (f_n) and by the repositioning distance (ϵ), could violate its deadline h_k (Fig. 5). In other words, coupling the trips can mean delaying the second trip with the consequence that its deadline q_k is not anymore respected. In this case, the finishing time of trip k has to be recomputed.

So, another pre-processing phase is necessary in order to calculate the time delay in relation to second trips deadlines. If trips n and k are combined, the new finishing time of trip k, $\tilde{f}_k$, is given by (1).

$$\tilde{f}_k = f_n + \epsilon + t_k \qquad \forall (n,k), n,k \in \mathcal{N}^R, n \neq k \tag{1}$$

On the contrary, if trips are not combined, $\tilde{f}_k$ is given by (2).

$$\tilde{f}_k = t_k + q_k \qquad \forall (n,k), n,k \in \mathcal{N}^R, n \neq k \tag{2}$$

Then, the delay cost C_{nk}^d is given by (3).

$$\begin{cases} c^d(\tilde{f}_k - h_k) & \text{if} \quad \tilde{f}_k > h_k \\ 0 & \text{if} \quad \tilde{f}_k < h_k \end{cases} \tag{3}$$

As it can be noticed, we compute a cost only if the second trip is delayed in respect to its deadline, while if it arrives in advance, no additional costs are considered. In reality, it may happen that, especially for big terminals and companies, if a truck arrives in advance in respect to its deadline, it should wait till its turn, so incurring in a time waste. Consequently, in this case an advance arrival should be minimized as well. If also eventual time advances are to be taken into account, C_{nk}^d has to be calculated as $|\tilde{f}_k - h_k|$.

The decision variables of the first optimization problem are represented by $y_{nk}^r \in (0,1)$, $(n,k), n,k \in \mathcal{N}^R$, which assume value equal to 1 if trips n and k have to be combined and served by carrier r, and 0 otherwise.

The mathematical formulation of the first optimization problem follows.

Problem 1.

$$maxU = \sum_{n \in \mathcal{N}^R} \sum_{k \in \mathcal{N}^R, k \neq n} \sum_{r \in R} S_{nk}^r y_{nk}^r \tag{4}$$

s.t.

$$t_{nk} y_{nk}^r \leq T \qquad \forall (n,k), n,k \in \mathcal{N}^R \qquad \forall r \tag{5}$$

$$C_{nk}^r = c^r(d_{nk} + \varepsilon) + \delta_n^r(1 - z_n^r)d_n + \delta_k^r(1 - z_k^r)d_k \qquad \forall (n,k), n,k \in \mathcal{N}^R, n \neq k \qquad \forall r \tag{6}$$

$$S_{nk}^r = 2d_n \sum_{r \in R}(c^r z_n^r) + 2d_k \sum_{r \in R}(c^r z_k^r) - (C_{nk}^r + C_{nk}^d) \qquad \forall (n,k), n,k \in \mathcal{N}^R \qquad \forall r \tag{7}$$

$$\sum_{k \in \mathcal{N}^p} y_{kn}^r + y_{nk}^r \leq 1 \qquad \forall n \in \mathcal{N}^R \qquad \forall r \tag{8}$$

$$\sum_{r \in R} y_{nk}^r \leq 1 \qquad \forall (n,k), n,k \in \mathcal{N}^R \tag{9}$$

$$q_k y_{nk} + M(1 - y_{nk}) \geq f_n + \epsilon \qquad \forall (n,k), n,k \in \mathcal{N}^R, n \neq k \tag{10}$$

$$P_k^o \leq \tilde{f}_k y_{nk} \leq \acute{P}_k^o \qquad \forall k \in \mathcal{N}^R \tag{11}$$

$$P_k^d \leq (\tilde{f}_k - t_k) y_{nk} \leq \acute{P}_k^d \qquad \forall k \in \mathcal{N}^R \tag{12}$$

$$y_{nk}^r \in (0,1) \qquad \forall (n,k), n,k \in \mathcal{N}^R, n \neq k \tag{13}$$

□

The resulting problem is a mixed-integer linear programming problem in which the objective function (4) is a sum of the cost savings of all the combined trips.

Constraints (5) ensure that the time required by a truck for performing a certain number of trips is not exceeding the total time availability of the truck. Constraints (6) define the cost of executing the generic couple of combined trips (n, k) by carrier r taking into account the compensation mechanisms among carriers; in fact, if a carrier performs a trip belonging to another carrier it has to pay a cost proportional to the distance of the trip and to a constant δ that considers the trip value. Constraints (7) define the cost saving of each carrier obtained from combining a pair of trips (n, k) as the sum of the costs of the two single trip performed individually by the carriers which own them and the two trips executed together by carrier r. Constraints (8) make sure that each trip is not combined more than once, while constraints (9) grant that each pair of combined trip is executed only by one carrier.

The respecting of timing when combining two trips is assured by constraints (10), while constraints (11) and (12) are related to terminals and companies time windows.

Finally, constraints (13) define the decision variables of the problem.

By solving Problem 1, for each carrier a new set of combined trips (re-used ones) that maximize its truck capacity usage is achieved (let us denote this set with $\tilde{\mathcal{N}}_U^r$) but some round trips may remain uncombined (denoted with $\tilde{\mathcal{N}}_R^r$).

3.3 Phase 3: second optimization problem

The goal of the second optimization phase is to minimize the cost of assigning trips to trucks for serving each carrier demand. Considering each carrier singularly, this assignment is made on:

- its previous set of trips belonging to its re-used trip network ($\mathcal{N}_r^U$);
- a new set of re-used trips that has been assigned to it by the first optimization problem ($\tilde{\mathcal{N}}_r^U$);
- the round-trips resulting from the first optimization problem which has not been combined ($\tilde{\mathcal{N}}_r^R$) ;

Then, the considered set of trips for each carrier is given by $\tilde{\mathcal{N}}_r = \mathcal{N}_r^U \cup \tilde{\mathcal{N}}_r^U \cup \tilde{\mathcal{N}}_r^R$, being $\tilde{N} = \text{card}(\tilde{\mathcal{N}})$.

Besides, let us denote with:

- $m = 1, \ldots, M$ is the number of trucks available by carrier r;
- T_m, $m = 1, \ldots, M$ the time availability (expressed in minutes) for truck m;
- t_n, $n = 1, \ldots, \tilde{N}_r$, is the travel time for serving trip n (expressed in minutes), which depends on the distance to be covered and on the average speed v of the truck ($t_n = \frac{d_n}{v}$);
- c_m, $m = 1, \ldots, M$, is the unitary cost of truck m which takes into account costs related both to the truck and the driver;
- C_{nm}, $n = 1, \ldots, \tilde{N}_r$, $m = 1, \ldots, M$, is the cost of assigning trip n to truck m on the basis of the travel distance to be covered. Note that $C_{nm} = c_m d_n$, where d_n is the distance to be covered for performing trip n.

The decision variables of Problem 2 are defined by $x_{nm} \in (0, 1)$, $n = 1, \ldots, \tilde{N}$, $m = 1, \ldots, M$, assuming value equal to 1 if trip n is assigned to truck m, and 0 otherwise.

The problem statement, resulting in a mixed integer programming structure, follows.

Problem 2.

$$\min Z = \sum_{m=1}^{M} \sum_{n=1}^{\tilde{N}} C_{nm} x_{nm} \tag{14}$$

s.t.

$$\sum_{n=1}^{\tilde{N}} t_n x_{nm} \leq T_m \qquad \forall m = 1, \ldots, M \tag{15}$$

$$\sum_{m=1}^{M} x_{nm} = 1 \qquad \forall n \in \tilde{\mathcal{N}} \tag{16}$$

$$x_{nm} \in (0, 1) \qquad \forall (n, m), n \in \tilde{\mathcal{N}}, m = 1, \ldots, M \tag{17}$$

□

Constraints (15) avoid that a truck overcomes its time availability while performing the trips which are assigned to it. Constraints (16) make sure that each trip is served by one truck. Finally, constraints (17) determine the nature of the decision variables.

The solution of Problem 2, which is run for each carrier, provides the assignment of all the trips of one carrier to its trucks by minimizing its operating costs for performing them.

4. EXPERIMENTAL RESULTS

In order to test the effectiveness of the proposed heuristic, the optimization framework described in Section 3 has been implemented in Visual Studio 2012 ♯by using Cplex 12.3 as MILP solver.

A real case study has been analyzed, regarding the daily trips from port of Genoa in Italy. A total of 20 trips are chosen which are carried out by four carriers. The demand of each carrier, splitted in RT and RU networks, is shown in Fig. 6 for all the four carriers. As it can be seen, it is assumed that each of them is serving the same area composed of 8 nodes (which are spread in the North-West of Italy, near Milan). Node 5 represents the port, while the other ones refer to companies. The number of trips to be served is specified near each arch and is expressed in terms of containers.

Firstly, the pre-processing phase has been carried out: the original networks have been divided into four re-used networks, composed of links where the demand is balanced in both directions (the truck runs the link at full load in both directions) and four round-trips ones, made up of links with only one-way trip to carry out. Each carrier shares its round-trip network assigning a different importance to its shared trips (δ values).

Table 1 shows the input data related to the trip characteristics, and more specifically the trip number, the

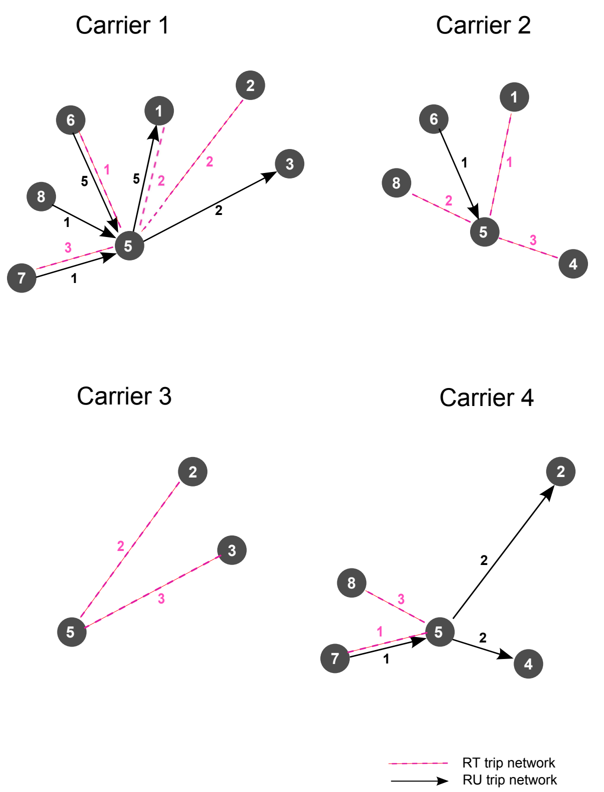

Fig. 6. An example

distance to be covered in order to execute it, the origin and destination nodes, and the carrier that owns the trip.

Table 1. Data

Trip (n)	Distance (d_n)	O-D	Carrier
1	189	5- 1	1
2	189	5- 1	1
3	189	5- 1	1
4	189	5- 1	1
5	159	5- 2	4
6	159	5- 2	4
7	133	5- 3	1
8	133	5- 3	1
9	172	5- 4	4
10	172	5- 4	4
11	159	5- 1	1
12	166	6- 5	1
13	166	6- 5	1
14	166	6- 5	1
15	166	6- 5	2
16	166	6- 5	1
17	158	7- 5	4
18	158	7- 5	1
19	180	8-5	1
20	166	6- 5	1

Table 2 provides all the features related to the nodes of the network considered.

Moreover the following unit cost, expressed in $euro/km$, has been associated to each carrier:

- c_1=1.6;
- c_2=1.2;
- c_3=1;
- c_4=1.4.

Table 2. Data2

Node ♯	Opening time	Closing time	Type of node
1	8	16	company
2	8	16	company
3	8	16	company
4	8	16	company
5	6	16	terminal
6	8	16	company
7	8	16	company
8	8	16	company

In order to calculate repositioning kilometers, and consequently their costs, an O-D matrix has been elaborated and it is presented in the Appendix. Besides, the average truck speed has been set equal to 50 km/h for all the trucks and the unitary delay cost c_d has been set to 20 $euro/hr$.

Table 3 provides the results obtained from the first optimization problem in case of $\delta = 0$, i.e. no compensation costs are due. As it is clear, the carrier that is chosen to perform a certain combination of trips is the one that allows to maximize the cost saving S^r_{nk} (that reaches the value of 6053.6 euro), being characterized by the lowest unit cost.

Table 3. Results of phase two (first optimization problem). $\delta = 0$.

Combined Trips	Carrier	Total S_nk
3+19	3	763
4+20	3	698
5+12	3	607,4
6+2	3	543
8+15	3	480,8
9+17	3	468,2
10+14	3	473,2
11+16	3	612
13+1	3	781
18+7	3	627
		6053.6

When δ assumes values equal to 0.1, 0, 2 and 0, 3, the same combination of trips are selected as in case of $\delta = 0$, but the values of total cost saving is different: 5887, 5720.4 and 5553.8, respectively. This is due to the fact that by increasing delta, the compensation cost that must be payed to the trip owner also increases. In these cases it is still convenient to assign the combined trips to carrier 3, which is characterized by the lowest unitary cost, but the total cost saving is decreased by the compensation term.

Fig. 7 shows the total cost saving obtained from different values of the compensation cost δ. It can be seen that the highest cost saving is obtained when no compensation cost is due ($\delta = 0$) because this allowed to choose the carrier only on the basis of its operational costs (in this case all the trips are assigned to carrier 3 which has got the lowest unitary cost). However, by increasing the compensation cost δ, the total cost keeps increasing till a time in which it is preferable to assign trips to more expensive carriers in order not to incur in too high compensation costs. Note that the lowest cost saving is obtained when δ is equal to 0.7 (see Table 4). This is due to the fact that the high value of compensation cost (0.7) leads to assign some trips to the carrier which originally owns them (that is carrier 1) but that has an higher operational costs compared to the other players.

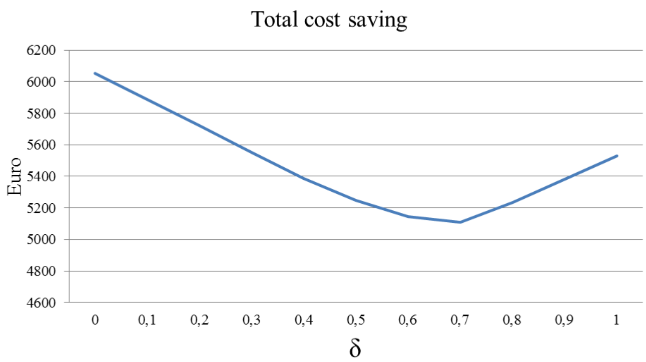

Fig. 7. Total cost saving by varying the compensation cost δ.

Table 4. Results of phase two (first optimization problem). $\delta = 0.7$.

Trips combined	Carrier	Total $S_n k$
4+19	1	679.7
13+2	1	699.6
18+7	1	544.8
8+15	2	438
1+14	3	425
+20	3	545
5+12	3	495.4
11+16	3	500
6+10	3	360.5
9+17	4	422.5
		5110.5

Moreover, Fig. 8 shows how many of the combined trips are assigned to the different carriers by varying the compensation cost δ. For example, carrier 3, due to its lower operating costs, is assigned most of the trips up to a δ equal to 0.4. This ratio, however, is decreased as the compensation cost increases, up to the case of δ equal to 1 where no trips are assigned to this carrier. More specifically, in this last case, the compensation cost is too high that it is more convenient to assign trips to the carriers to whom they belong even if their operational costs are higher.

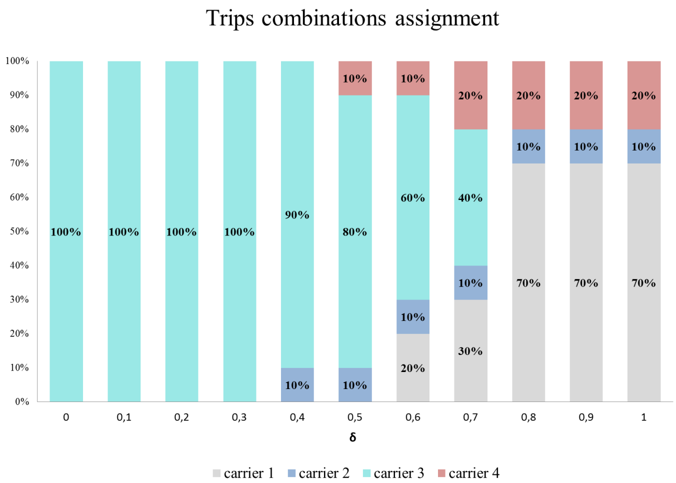

Fig. 8. Trip assignment by varying δ.

Finally, for each carrier, the second optimization problem (phase three) of the heuristic - whose goal is to assign trucks to trips - has been run considering:

- the combined trips (regarded as a single trip with a longer duration) which have been assigned to the carrier in the first optimization phase;
- the round trips which have not been combined during the resolution of the first optimization problem;
- all the trips belonging to the original re-used trip network of the specific carrier.

Each truck of the carrier is characterized by different unit costs (expressed in cost per Kilometer) and time availability (working time spans, expressed in minutes).

Table 5 shows all the trips of carrier 3 that must be assigned to its 15 trucks; as it can be seen, trips from 1 to 8 are the combination of trips resulting from the first optimization problem ($\tilde{\mathcal{N}}_r^U$), while trips from 9 to 13 belong to the original re-used trip network of carrier 3 (see Fig. 6). The table also shows, for each trip, the distance to be covered, the repositioning distance to get from one company to another, and the final distance as the sum of the previous two terms.

Table 6 provides the results obtained by solving Problem 2 for carrier 3 in case of $\delta = 0.5$. As it can be seen, some trucks are not activated (truck number 6, 8, 11 and 13), also due to their higher costs compared to similar trucks in terms of time availability.

Table 5. Pre-processing step for optimization problem 2.

Trip	Origin	Dist.(km)	ϵ(km)	Tot.Dist.(km)
1	$\tilde{\mathcal{N}}_r^U$: 3+20	355	69	424
2	$\tilde{\mathcal{N}}_r^U$: 4+19	369	12	381
3	$\tilde{\mathcal{N}}_r^U$: 6+1	159	507	507
4	$\tilde{\mathcal{N}}_r^U$: 9+14	338	68	406
5	$\tilde{\mathcal{N}}_r^U$: 10+12	338	68	406
6	$\tilde{\mathcal{N}}_r^U$: 11+16	325	69	394
7	$\tilde{\mathcal{N}}_r^U$: 13+2	355	0	355
8	$\tilde{\mathcal{N}}_r^U$: 18+7	291	0	291
9	$\mathcal{N}_r^U$	318	0	318
10	$\mathcal{N}_r^U$	318	0	318
11	$\mathcal{N}_r^U$	399	0	399
12	$\mathcal{N}_r^U$	399	0	399
13	$\mathcal{N}_r^U$	399	0	399

4.1 Computational Analysis

In order to test the efficiency of the proposed approach, a computational analysis has been carried out on a laptop having the following features: processor Intel(R) Core(TM) $i7-2640$ M, CPU @2.80 GHz (4 CPUs), memory 8192 MB RAM.

More specifically, the computational analysis has been performed to measure the time needed to obtained the solution by varying the number of carriers, trips and nodes (terminals and companies).

By fixing the number of trips to 20 and the number of nodes to 10 (as in the real case depicted above), an increase of the number of carriers from 4 up to the value of 30 does not have any impact on the computational times, which is definitely very low, i.e. between 0 and 0.02 seconds.

Table 6. Results of phase three (second optimization problem).

Truck	Cost	Time Avail.	Trips assigned
1	1.5	6	7
2	1	6	5
3	1.2	7	4
4	1.2	7	1
5	1.3	7	13
6	1.8	7	-
7	1.3	8	3
8	2	8	-
9	1.4	8	11
10	1.5	8	6
11	1.6	9	-
12	1.2	9	8+10
13	1.8	9	-
14	1.2	10	2+9
15	1.4	10	12

Analogous results are obtained by fixing the number of trips (20) and carriers (4) and by varying the number of nodes from 8 to 30. The only sensitive parameter towards the computational time is represented by the number of trips: the time needed to find the solution reaches the values of 0.09 and 0.19 seconds when the number of trips is equal to 100 and 140, respectively, but a perceivable increase is reached only when the number of trips is equal to 150. In this case, the solution is found after 30 minutes with a gap from the optimum equal to 0.03%.

So, considering the size of problems encountered in the real context, it can be stated that the computational performances of the proposed heuristic are satisfactory.

5. ENVIRONMENTAL IMPACTS

On average, trucking consumes more than 80% of freight transport energy and emits a considerable portion of green house gases, which categorizes it among the largest sources of pollutants (Ericsson et al. [2006]). According to the European Environmental Agency, over the period 1990-2008, in Europe the average carrying capacity of trucks has been utilized under 50% (Source: Load factors for freight transport (TERM 030), European Environmental Agency - EEA, 2010). This causes extra vehicle-kilometers determining excessive fuel consumption and emissions. Although minimization of energy consumption is not the specific focus of this study, the indirect implications of combining trips leads to reduce energy consumption as well as emissions. Thus, in this section, environmental benefits of combining trips is calculated in terms of energy consumption and greenhouse gas emissions. The calculations are made based on the formulas provided by "EcoTransIT" (Knoerr [2008]), which is an ecological transport information tool. The final energy consumption and vehicle emissions, related to the operation of vehicles, are taken into account.

Capacity utilization is one of the most important factors that influences the environmental impacts of road freight transport. In addition, the energy consumption of trucks has a direct relationship with the weight it is carrying. The payload capacity (CP) is defined as the maximum mass of freight allowed. In case of trucks, it can be defined as the difference between the maximum weight allowed and the empty weight of a vehicle. Since the data about the type of goods was not available for each trip, it has been assumed that the volume of the cargo fills the containers, and thus, the difference in the weight of containers comes from various cargo types.

The truck and container specifications used in this study are reported in Table 7.

Table 7. Truck and container specifications

Feature	Truck	Container (40')
Empty weight	14	3.78
Payload capacity	14	26.7
Total weight	40	30.48

The following definitions are used in the calculation of the final energy consumption. Load factor (LF) is defined as the weight of the container in relation to the payload capacity of the truck. The Empty trip factor (ET) is defined as the ratio between the unloaded and the loaded distance the vehicle runs. Thus, the capacity utilization (CU) is defined as in (18).

$$CU = \frac{LF}{1 + ET} \tag{18}$$

For calculation of emissions, the European standard is the mostly used; *EcoTransIT* world considers Euro-V standard (2008). The equation for the calculation of the final energy consumption is defined by (19).

$$ECF = ECF_e + [ECF_f - ECF_e]CU \tag{19}$$

where:

- ECF = Final Energy Consumption with the current load;
- ECF_e = Final Energy Consumption without load (empty);
- ECF_f = Final Energy Consumption with full load.

The data for energy consumption and emissions for full and empty trucks having a weight bigger than $24 - 40$ *tons* are assumed based on the Euro-V for motorway, average gradient for hilly countries as in table 8 (source: INFRAS 2010).

Energy savings and reduction of emissions have been calculated for all the values of the compensation cost δ. In all the analyzed cases, a reduction between 65 % and 67 % is obtained both in emissions and energy consumption, resulting from combining the trips. This value results from the fact that on the return leg of each trip, the vehicle carries the empty container which results in about 69% energy consumption in comparison to the full leg (depending on the weight of container in the full leg). Thus, by eliminating this unnecessary trip, a considerable amount of energy can be saved.

Table 8. Energy consumption and emissions for full and empty trucks.

ECF	energy consumption (l/km)	emissions (g/km)
full	37.1	982
empty	22.7	601

Moreover, the percentage reductions in emissions and energy consumption nearly reach the same value because these indexes are both calculated based on the same parameters, i.e. the weight carried and the distance covered.

Finally, by varying δ, there is not a relevant changing in the results of the two indicators, being neither the weight carried nor the distance covered varied substantially.

6. CONCLUSION

In this paper a heuristic approach dealing with the collaboration problem among multiple road carriers has been proposed. The goal of each carrier is to satisfy at minimum cost its demand in terms of trips, by trying to maximize balanced trips.

In the absence of collaboration, carriers follow non-optimal policies incurring in trips which are not optimized and do not exploit trucks capacity so resulting in higher costs. So, the main goal of this study is to decrease the number of empty trips and, more in more general, this means to increase carrier assets utilization by maximizing the cost savings resulting from matching trips. To address this problem, a three-phase algorithm has been developed. In the first phase, the demand of each carrier is divided into two parts: a balanced flow network (re-used trips) and a not balanced one (round trips); then a first optimization allows to match trips two by two trying to maximize the saving and respecting some constraints, such as trips deadlines and time windows related to the network nodes. Finally, a second optimization phase permits to assign carrier trucks to the trips it should serve with the goal of minimizing its total operating costs.

The cooperative framework designed in the paper takes into account a compensation mechanism among carriers based on different weights associated to the trips shared by the various players involved.

The proposed heuristic has been successfully tested on a real case study related to trips to/from the port of Genoa and it demonstrated to be effective in serving all the required demand while minimizing the total costs. In fact, a better exploiting of trucks and a better planning of trips allow, on one side, to decrease the number of trucks used and, on the other side, to satisfy a higher number of trips keeping unchanged the number of trucks managed by each carrier. Moreover, in addition to economic benefits, an environmental analysis carried out on the results has indicated that a considerable amount of reduction of energy consumption and emissions can be gained by the trips combination.

Finally, also from a computational viewpoint, the proposed approach proved to give satisfactory results; in fact, computational times significantly increases only when the number of trips to be matches is very high (around 150 trips).

Future research will be devoted to take into account multiple combinations (more than two trips) as well as other constraints such as drivers working hours and places to deliver containers at the end of trips. Moreover, further efforts will be dedicated to improve negotiation mechanisms among carriers.

7. ACKNOWLEDGMENTS

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8. APPENDIX

Table 9. Repositioning distance ϵ (km)-part 1

O/D	1	2	3	4	5	6	7	8	9	10
1	189	189	189	189	189	189	189	189	189	189
2	189	189	189	189	189	189	189	189	189	189
3	189	189	189	189	189	189	189	189	189	189
4	189	189	189	189	189	189	189	189	189	189
5	159	159	159	159	159	159	159	159	159	159
6	159	159	159	159	159	159	159	159	159	159
7	133	133	133	133	133	133	133	133	133	133
8	133	133	133	133	133	133	133	133	133	133
9	172	172	172	172	172	172	172	172	172	172
10	172	172	172	172	172	172	172	172	172	172
11	189	189	189	189	189	189	189	189	189	189
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0

Table 10. Repositioning distance ϵ (km)-part 2

O/D	11	12	13	14	15	16	17	18	19	20
1	189	69	69	69	69	69	61	61	12	69
2	189	69	69	69	69	69	61	61	12	69
3	189	69	69	69	69	69	61	61	12	69
4	189	69	69	69	69	69	61	61	12	69
5	159	44	44	44	44	44	36	36	23	44
6	159	44	44	44	44	44	36	36	23	44
7	133	27	27	27	27	27	19	19	56	27
8	133	27	27	27	27	27	19	19	56	27
9	172	68	68	68	68	68	59	59	12	68
10	172	68	68	68	68	68	59	59	12	68
11	189	69	69	69	69	69	61	61	12	69
12	0	166	166	166	166	166	158	158	180	166
13	0	166	166	166	166	166	158	158	180	166
14	0	166	166	166	166	166	158	158	180	166
15	0	166	166	166	166	166	158	158	180	166
16	0	166	166	166	166	166	158	158	180	166
17	0	166	166	166	166	166	158	158	180	166
18	0	166	166	166	166	166	158	158	180	166
19	0	166	166	166	166	166	158	158	180	166
20	0	166	166	166	166	166	158	158	180	166