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Planning truck carriers operations in a cooperative environment

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Abstract: This paper proposes a heuristic approach for planning the activity of multiple carriers cooperating with the goal of eliminating empty truck trips while maximizing the cost saving resulting from their collaboration. 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 into account compensation mechanisms among carriers, allows to combine two by two trips belonging to different carriers in order to decrease the number of empty movements. In this second phase, the importance of customers is explicitly taken into account by assigning to each trip a preference value. Finally, in the third step, a second optimization problem enables assigning, for each carrier, trucks to trips with the goal of minimizing their travel costs. The proposed heuristic approach has been tested on some instances and the results obtained are analyzed and discussed in the paper.

1. INTRODUCTION

Today, the issue of negative externalities related to freight road transportation is one of the major concerns. In this perspective, empty movements of trucks must be minimized. This can be done by properly planning and optimize demand 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 players 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. Some works about the first type of problem related to a single carrier date 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] have solved the problem both for static and dynamic cases and by 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, will have 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 order which are 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.

Shippers collaboration was first introduced by Ergun et al. [2007], who 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 minimum cost set of constrained cycles is found to cover a subset of arcs (delivery lanes) in a directed Euclidean graph. In another study, Ozener and Ergun developed cost-allocation schemes in similar shipper alliances Ozener 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 for analyzing the framework.

This paper is an extension of Caballini et al. [2013] where an optimization scheme aiming at maximizing cost savings for a single carrier has been proposed. In comparison to Caballini et al. [2013], the present study enlarges the context to multiple carriers and considers trips combination in a different way, by getting more balanced trips. More specifically, the goal is to maximize balanced trips (which will be called "re-used" trips in the paper) in order to gain economic and social 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 simplified case study and, finally, some concluding remarks are reported in Section 5.

2. PROBLEM DESCRIPTION

Road transportation keeps representing the most used transportation mode to cover short distances. However, the frequent 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 possibly belonging to different carriers with the goal of minimizing empty truck 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 container is imported (from sea to land) or exported (from land to sea). So, it can be assumed that the origin or destination of the trip is constituted by the port node. However, this is not a strong assumption because the same approach can be applied to land-land transportation.

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 from the port;
(2) it travels with the full container to the importer company or to where it is unstaffed/stripped, for instance in a consolidation centre or warehouse (link C-A);
(3) it brings the empty container to the depot of empty containers pointed out by the shipping company, which is 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 (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) it travels to the exporter company or to a consolidation centre where the container will be staffed/filled (link C-B);
(3) it 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", leads to a lack of efficiency because it implies empty movements of trucks on the network; in fact one of the two trips is a not value added one because the truck travels empty (without a cargo payload) or with an empty container. The use of these kind of trips, which represent the most common type of trip in the majority of cases, is due to technical and commercial reasons, which may bring back to the following ones:

- lack of planning tools or skills by carriers;
- unwillingness of giving trips to other carriers for fearing 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).

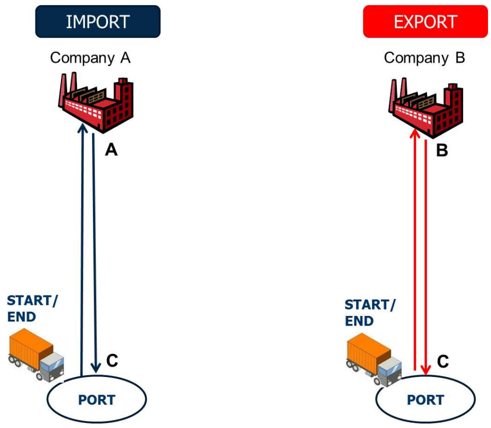

Fig. 1. Scheme of a typical sea-land "round-trip" (import and export)

So, starting from the consideration that the more balanced the transport is, the best is both from the economic and environment standpoints, the goal of this study is to maximize the number of the so-called "re-used" trips by sharing portions of carriers demands and to minimize the travel distance covered by trucks on the network. Of course, only trips having the same origin-destination nodes area can be combined.

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) it travels with the full container to the importer company -or in a consolidation centre- and strips the container (link C-A);
(3) it travels with the empty container to the exporter company -or in a consolidation centre- for staffing the container for the export cycle (link A-B);
(4) it travels with the full container to the port for release it and leave it continue its journey by ship (link B-C).

An export-import "re-used" is analogous to the import-export 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 made 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.

So, in this paper, effective collaboration among carriers is pursued. Each carrier has a certain amount of orders (pickup/delivery of containers) to be fulfilled; it owns some trucks having different time availabilities and costs and it is characterized by different internal management costs. The basic idea of collaboration among carriers lies on the fact that each carrier may take care of orders belonging to other carriers or, vice versa, may leave some of its trips to other hauliers, in order to maximize total re-used trips. However, carriers may not be willing to give some of their trips to other carries due to the fear of loosing customers in a competitive market: this issue is considered in the paper

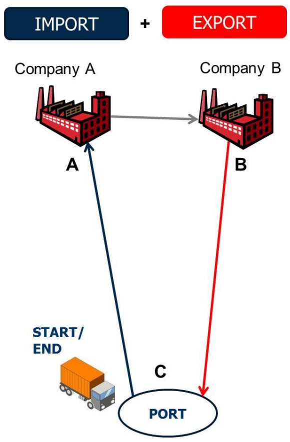

Fig. 2. Scheme of a typical sea-land "Re-Used" Trip

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. 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). Moreover, time windows in relation to trips are neglected (i.e. trips can start and finish at any moment without time constraints). Besides, only two types of costs are considered: the transportation costs (which are dependent on the distance covered by vehicles, i.e. trucks) and the costs arising from compensating carriers which "borrow" their part of demand to other carriers (this aspect will better explained in the next section). It would also be possible to consider resource costs (i.e. driver and truck) and container repositioning costs Powell [1987], but in the current work they are not taken into account. Finally, it is assumed that trucks starts their trips near to their origin, so the distances that would be covered by them in order to get to the origin of the trip can be neglected (this is also a very realistic assumption).

In order to formalize the problem properly, 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 included in the re-used trips networks.

For better clarification, let us take into account the simple network provided in Fig.3, composed of 4 nodes and 10 trips to be performed. The demand for each trip is expressed in number of containers and is shown on each arc.

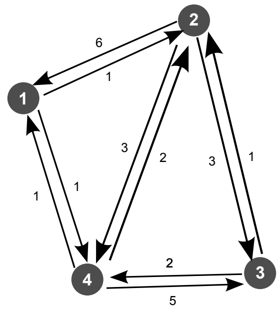

Fig. 3. Example of a generic container demand over a network of 4 nodes

Fig. 4 provides an example of decomposition of the simple demand network shown in Fig.3. As it can be noticed, the demand on links belonging to the "re-used trips" network, i.e. balanced orders on the same tracts of the network. On the contrary, the "round-trip" network is composed of trips which do not have the same demand on both links connecting the same origin and destination.

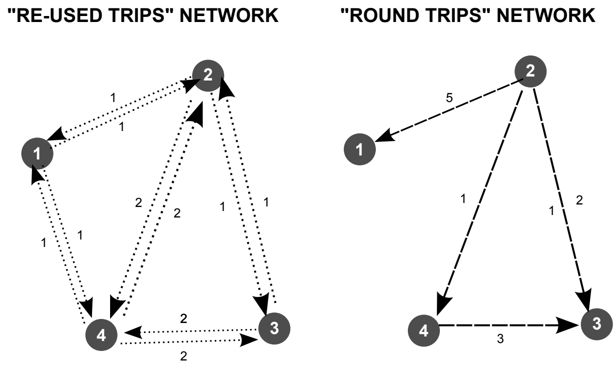

Fig. 4. Example of decomposition of demand network proposed in Fig.3

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 (*phase a*), in which trips belonging to the RT networks should 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 must take into account the disadvantage of the carrier that "loses" its order.
(3) a second optimization phase (*phase b*) in which trucks are assigned to trips (trips belonging to the the re-used network plus the ones combined and the

remaining trips which have not been combined) so as to minimize travel distance costs.

Fig. 5 reports the proposed optimization scheme.

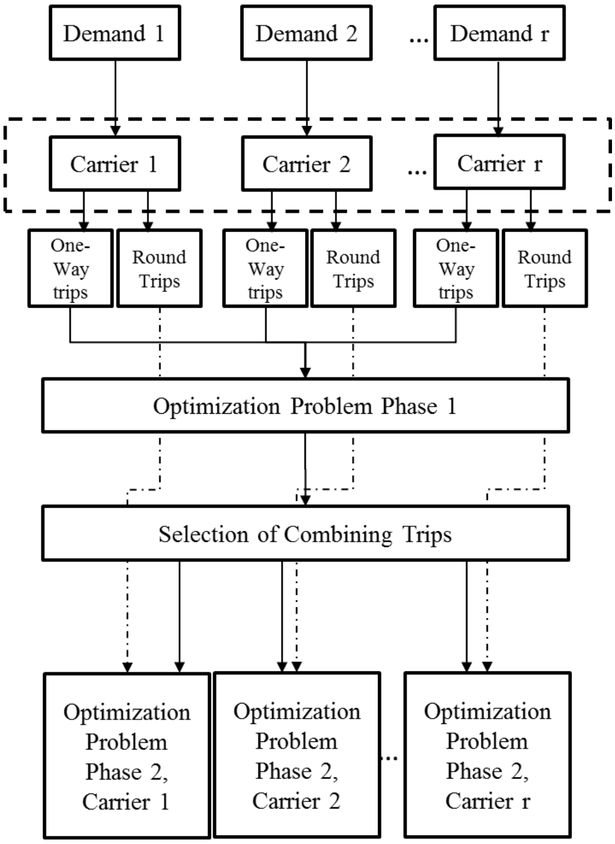

Fig. 5. The optimization Scheme

In the pre-processing phase, the original carrier demand networks are split into "re-used" trips networks, which refers to balanced trips that can be performed autonomously by each carrier, and "round" trip networks, in which half of each trip is performed empty so not fully exploiting trucks capacity; so the objective is to try to combine, two by two, the trips of the various "round trip" networks with the goal of minimizing empty trips and getting more balanced freight flows. 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 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 to the RT network and so it will be shared with the other carriers.

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;
- $m^r, m = 1, \ldots, M^r$, is the number of trucks available by carrier r;
- T_m, $m = 1, \ldots, M$, is the time availability (expressed in minutes) for truck m^r .
- t_n, $n = 1, \ldots, N$, is the travel time for serving trip n (expressed in minutes), which depends on the distance to be covered and on the average speed of the truck which is assumed to be 80 km/hr ($t_n = d_n/v$);
- d_n, $n = 1, \ldots, N$, is the distance to be covered to serve trip n;
- c_r, $r = 1, \ldots, R$, is the unit operative cost typical of carrier r;
- C_n^r, $n = 1, \ldots, N$, 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: $C_n^r = 2d_n c^r \forall n \in \mathcal{N}^p, \forall r$.

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

- t_{nk} is the time for serving the pair of trips (n,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;
- 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 get to another company (ϵ is supposed to be equal to 25 km);
- $z_n^r \in (0, 1)$, $n \in \mathcal{N}^p$, are quantities, known in advance, which assume value equal to 1 if trip n is performed by carrier r and 0 otherwise.

The decision variables of the first optimization problem are represented by:

$y_{nk}^r \in (0, 1)$, $(n, k), n, k \in \mathcal{N}^p$, which assume value equal to 1 if trips n and k must be combined and served by carrier r and 0 otherwise.

The statement of the first optimization problem follows.

Problem 1.

$$maxU = \sum_{n \in \mathcal{N}^p} \sum_{k \in \mathcal{N}^p, k \neq n} \sum_{r \in R} S_{nk}^r y_{nk}^r \qquad (1)$$

subject to

$$t_{nk} y_{nk}^r \leq T \qquad \forall (n, k), n, k \in \mathcal{N}^p \qquad \forall r \qquad (2)$$

$$C_{nk}^r = c_{nk}^r (d_{nk} + \varepsilon) + \delta_n^r (1 - z_n^r) + \delta_k^r (1 - z_k^r) \qquad \forall (n, k), n, k \in \mathcal{N}^p, n \neq k \qquad \forall r \qquad (3)$$

$$S_{nk}^r = C_n^r + C_k^{\acute{r}} - C_{nk}^r \qquad \forall (n, k), n, k \in \mathcal{N}^p \qquad \forall r, \acute{r} \qquad (4)$$

$$\sum_{k \in \mathcal{N}^p} y_{kn}^r + y_{nk}^r \leq 1 \qquad \forall n \in \mathcal{N}^p \qquad \forall r \qquad (5)$$

$$\sum_{r \in R} y_{nk}^r \leq 1 \qquad \forall (n, k), n, k \in \mathcal{N}^p \qquad (6)$$

$$y_{nk}^r \in (0, 1) \qquad \forall (n, k), n, k \in \mathcal{N}^p, n \neq k \qquad (7)$$

□

The resulting problem is a mixed-integer linear programming problem in which the objective function (1) is a sum of the cost savings of the combined trips. Constraints (2) ensure that the time required by a truck for performing a certain number of trips is not exceeding the total availability of the truck. Constraints (3) define the cost of executing the generic couple of combined trips (n, k) by carrier r taking into account the compensation mechanisms among carriers; constraints (4) define the cost saving of each carrier obtained from combining a pair of trips (n, k) as the sum of the costs of each single trip performed individually by each carrier and the two trips executed together by carrier r. Constraints (5) make sure that each trip is not combined more than once, while constraints (6) grant that each pair of combined trip is executed only by one carrier. Finally, constraints (7) 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 $\tilde{\mathcal{N}}^r_{RU}$) but some round trips may remain uncombined (let us denote this set with $\tilde{\mathcal{N}}^r_{RT}$).

The goal of the second optimization phase is to minimize the cost of assigning trips to trucks for serving each carrier demand. This assignment is made on the overall set of trips belonging to the re-used networks and on the ones composing the new round-trip networks. Then, the considered set of trips for each carries is $\tilde{\mathcal{N}}^r = \mathcal{N}^r_{RU} \cup \tilde{\mathcal{N}}^r_{RU} \cup \tilde{\mathcal{N}}^r_{RT}$, being $\tilde{N} = \text{card}(\tilde{\mathcal{N}})$.

Moreover, let us denote with C_{nm}, $n = 1, \ldots, \tilde{N}$, $m = 1, \ldots, M$ the cost of assigning trip n to truck m on the basis of its travel time (or travel distance). The decision variables of Problem 2 are defined by $x_{nm} \in (0, 1)$, $n = 1, \ldots, \tilde{N}$, $m = 1, \ldots, M$, assuming a 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.

$$\min Z = \sum_{m=1}^{M} \sum_{n=1}^{\tilde{N}} C_{nm} x_{nm} \qquad (8)$$

subject to

$$\sum_{n=1}^{\tilde{N}} t_n x_{nm} \leq T_m \qquad \forall m = 1, \ldots, M \qquad (9)$$

$$\sum_{m=1}^{M} x_{nm} = 1 \qquad \forall n \in \tilde{\mathcal{N}} \qquad (10)$$

$$x_{nm} \in (0, 1) \qquad \forall (n, m), n \in \tilde{\mathcal{N}}, m = 1, \ldots, M \qquad (11)$$

□

Constraints (9) avoid that a truck overcomes its time availability while performing the trips which are assigned to it. Constraints (10) make sure that each trip is served by one truck. Finally, constraints (11) 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 to each carrier available trucks by minimizing its operating costs.

4. EXPERIMENTAL RESULTS

In order to test the effectiveness of the proposed heuristic, a simple case study has been analyzed, in which the collaboration among three carriers has been tested. The demand of each carrier, split in RT and RU network, is shown in Fig. 4 for carrier 1 and in Fig. 6 for carriers 2 and 3. As it can be seen, it is assumed that each of them is serving the same area composed of 4 nodes. The number of trips to be served is specified near each arc and is expressed in terms of containers.

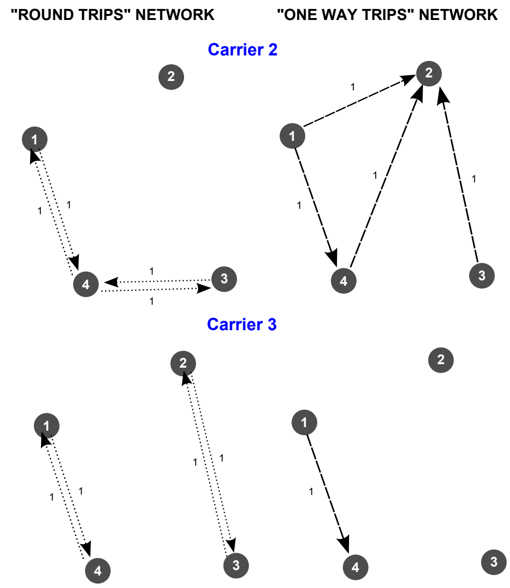

Fig. 6. Demand networks for carriers 2 and 3

Firstly, the pre-processing phase has been carried out: the original networks have been divided into three 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 three 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. Table 1 shows the round trips of each carrier, and the cost of combining the trips two by two sustained by each of them.

Table 1. Results of phase one

r	O	D	km	Duration	δ^r_n	Round-Trip Cost
1	2	1	200	150	20	480
1	4	1	250	188	30	600
1	2	3	300	225	15	720
1	2	4	350	263	10	840
2	1	2	200	150	90	520
2	1	4	250	188	70	650
2	3	2	300	225	80	780
2	4	2	350	263	50	910
3	1	4	250	188	30	800

Table 2 provides the results obtained by the first optimization problem: 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}. The born of a new couple of re-used trips means that, in spite of the compensation cost due to the carriers that initially owned the trips, still combining the trip is beneficial to both carriers. More specifically, trips $1-2$ and $2-1$ are combined and assigned to carrier 2, as well as trips $2-3$ and $3-2$, while the combination of trips $2-4$ and $4-2$ is assigned to carrier 1; trips $1-4$ and $4-1$ can be joined and assigned indifferently to carrier 1 or 3, having the same cost saving.

Table 2. Results of phase two

Combined trips	c_n^1	c_n^2	c_n^3	S_{nk}^1	S_{nk}^2	S_{nk}^3
$1-2+2-1$	595	565	-	405	435	-
$1-4+4-1$	695	705	845	555	545	555
$2-3+3-2$	825	820	-	675	680	-
$2-4+4-2$	915	945	-	835	805	-

Finally, the second optimization problem (phase three) of the heuristic, whose goal is to assign trucks to trips, is run per each carrier and considers the combined trips (regarded as a single trip with a longer duration) derived from the first optimization phase, plus the trips of the "round-trips" network which have not been combined and all the trips belonging to the carrier "re-used" trips networks.

Table 3 provides the results obtained by solving Problem 2, in which a different number of trucks is considered for each carrier (8, 4 and 2 for carrier 1, 2 and 3, respectively), each one having different time availability (working time spans, expressed in minutes) and different associated costs (expressed in cost per Kilometre). The assignment of trips to trucks is shown in the last column of Table 3. As it can be seen, some trucks are not activated (truck 1, 6 and 8 for carrier 1 and truck 1 for carrier 2), also due to their higher costs compared to similar trucks (in terms of time availability) belonging to the same carrier.

Table 3. Results of phase three

Carrier	m^r	Truck availab.	Truck cost	Link assign.
1	1	1100	8	-
1	2	1100	7	2-4;4-2;2-4;4-2
1	3	1050	7	2-3;3-2;2-4;4-2
1	4	650	6	1-2;2-1;1-4;4-1
1	5	600	6	3-4;4-3;3-4;4-3
1	6	450	5	-
1	7	450	3	1-4;4-1
1	8	500	7	-
2	1	530	6	-
2	2	650	4	1-4;4-1;1-2;2-1
2	3	480	5	2-3;3-2
2	4	300	3	3-4;4-3
3	1	480	5	2-3;3-2
3	2	400	4	1-4;4-1

5. CONCLUSIONS

In this paper a heuristic approach dealing with the collaboration problem among multiple road carriers is proposed. The goal of each carrier is to satisfy at minimum cost its demand in terms of trips, a part of which is balanced whereas the remaining part is not. In the absence of collaboration, carriers follow non-optimal policies incurring in sets of trips which are not optimized and do not exploit the trucks capacity resulting in higher costs. So, the main goal of this study is to decrease the number of empty trips and, more in general, 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. Finally, a second optimization phase permits to assign each carrier fleet to the trips it should serve with the goal of minimizing its operating cost. The proposed methodology has been tested and the results are satisfactory.

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