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Horizontal Cooperation in Vehicle Routing Problems with Backhauling and Environmental Criteria

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Abstract

Horizontal cooperation in logistics refers to how two or more companies can cooperate in order to achieve a common objective, which is usually related to minimization of global distribution costs. This paper discusses backhaul-based horizontal cooperation in road transportation and supports the relevance of this praxis as a way of reducing both routing costs as well as costs due to CO_2 emissions. After describing the problem context and reviewing some related work, the paper examines different numerical examples in order to quantify the savings in routing and emissions costs that can be attained throughout backhaul-based horizontal cooperation. Both cooperative and non-cooperative scenarios are discussed and compared against each other. These considerations raise the value of the global objective function, permitting a realistic analysis of the importance of horizontal cooperation in the control of the environmental impact of road transportation.

Keywords: Horizontal Cooperation in Transportation; Backhauling; Vehicle Routing Problem; Environmental Criteria; Heuristics.

1. Introduction

Road transportation is the predominant way of transporting goods in many world regions. Due to high oil prices, congestion problems, greenhouse gas emissions, and safety issues associated with this transportation mode, some developed countries are trying to empower rail versus road transportation. However, according to the European Commission (2011), road transportation accounts for 47% of total transportation of goods in the European Union,

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32% in USA, and 64% in Japan. Overall, it is estimated that world freight transportation will raise about 50% between 2000 and 2020 (European Commission, 2006).

In the road transportation sector, the increasingly fierce competition among companies and the growing expectations regarding the quality and level of service by customers, require small and medium enterprises (SMEs) to be more efficient in the management of their distribution operations. In effect, the continuous increase in diesel fuel prices and taxes has taken a toll on the ability of many SMEs to deliver products cheaply. As a result, most SMEs in the road transportation sector suffer from pressures to raise their distribution prices, thus reducing their competiveness. Unlike SMEs, large companies often have access to cost efficient and highly productive transport networks. One strategy that SMEs can follow to become more competitive is to collaborate with other companies (horizontal cooperation), allowing the use of economies of scale, increase resource utilization, and cost reduction. Bahinipati et al. (2009) define horizontal cooperation as "a business agreement between two or more companies at the same level in the supply chain or network in order to allow ease of work and co-operation towards achieving a common objective". One of the aims of horizontal cooperation in logistics is to contribute to reduce empty backhauls or deadheading (return trips with no load). In Europe empty backhauls represent about 25% of road transportation activities (European Commission, 2011). Therefore, regulations exist so that haulers crossing foreign countries during their return trip home can pick up loads in countries where the vehicle is not registered. This practice, called "cabotage", helps to optimize the use of capacity of the hauls (European Commission, 2006). The left part of Figure 1 shows a typical non-cooperative scenario where each service provider (square node) designs its own set of routes to deliver its own customers (set of nodes represented by a common symbol). In contrast, the right part of Figure 1 shows the same routing problem in a cooperative scenario, where backhauling strategies are considered –i.e. some routes are merged in order to increase the actual utilization of vehicles during a roundtrip. The comparison of both figures provides a first intuitive idea regarding the benefits, in terms of routing distances and number of necessary vehicles that can be reached throughout horizontal cooperation.

Although the main goals of horizontal cooperation are to reduce shipping costs and also to provide a faster distribution service to customers, other important benefits are related to a reduction of the environmental impact of distribution activities. In the European Union, about 18% of the greenhouse gas emissions are due to road transportation (Hill et al., 2012). For instance, in France, transport emissions are as high as 35% of the total (Ballot and Fontane, 2010). Thus, collaboration among partners in the transportation industry can help reducing environmental footprint as it can reduce the number of necessary trips and increase the efficiency of the haulers.

In most developed countries, governments are promoting policies towards green logistics in general, that many times includes an approach to horizontal cooperation. Thus, for instance, the French Ministry of Economics, Finances and Industry suggests that horizontal cooperation can be seen as an opportunity for the logistics system, and shows the way to achieve new sustainable logistic practices in some real-life cases (Salmon, 2011). Similarly, the Spanish Ministry of Transportation encourages the use of better practices in logistics such as horizontal cooperation to increase turnover and improve the companies' competitive position inside the European transport market (Ministerio de Fomento, 2010).

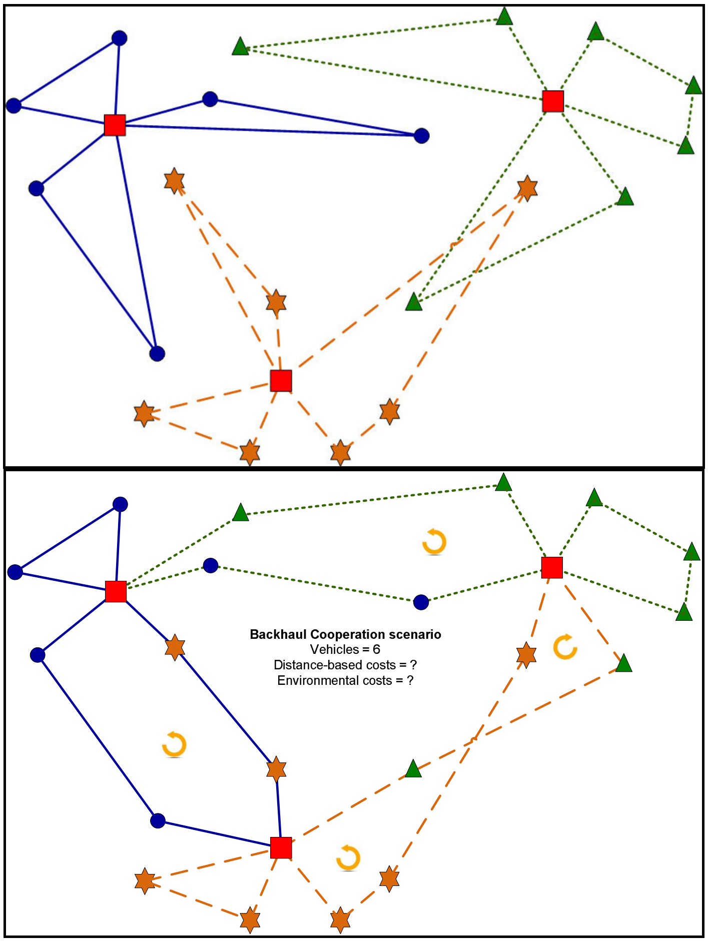

Fig. 1. Non-cooperative (above) vs. Cooperative (below) scenarios.

One of the many aspects to analyze in horizontal cooperation is trusting between entities, as many of them are competitors (Özener, 2008). The problem of uncertain deliveries to final destination customers can be tackled, at least partially, by using horizontal cooperation (Hsu and Wee, 2005). Another key aspect when promoting horizontal cooperation practices among firms is the consideration of the magnitude of the costs reduction associated with cooperation strategies. Unfortunately, however, it is not easy to estimate quantitatively those costs, which constitutes a serious obstacle for the development of this praxis. This paper aims at providing some insights on this issue by analyzing how routing costs vary between non-cooperating and backhaul-driven cooperating scenarios. Thus, different examples are examined in order to quantify the savings in route costs that can be attained throughout horizontal cooperation when backhaul strategies are employed.

2. Related Work

A good example of horizontal collaboration is the case of the less-than-truckload (LTL) carriers that operate together in cooperation (Liu et al., 2010; Wang and Kopfer, 2011). Thereby, the partners hope to achieve synergy effects in terms of area coverage, optimization of travel times and service quality. Logistics and Transportation (L&T) on the landside is a complex transportation network problem, which begins at the manufacturing plant of the supplier. The shipments from the plant move on, first, to the warehouses, later to one or several intermediate hubs, reconsolidated if necessary, and lastly are transferred to the distribution centers before reaching the final clients (Lyons et al., 2012). There are some papers that solely focus on just a sub-problem of the whole complex transport network in between the warehouses and distribution centers, that is, in the network of several intermediate hubs. For example, Ballot and Fontane (2010) consider reducing transport CO_2 emissions through pooling warehouses and/or distribution centers together, which led to a reduction in the number of current deliveries between the warehouses and the distribution centers in their real case study of merging two supply chains in France. Their research concerns just the intermediate hubs. Similarly, Rieck and Zimmermann (2010) study a typical LTL shipment and model the logistic network problem faced by a LTL carrier as a simultaneous pick-up and delivery problem with docking constraints. In most real cases, vehicle drivers leave the depot in the morning to perform the deliveries and pick-ups at no more than 50 customer locations in the local area and they return in the early evening. Cruijssen and Salomon (2004) study just one aspect of the whole transport network by considering more the retailer side of the supply chain as opposed to the industrial side of the supply chain. In their paper, a number of transportation companies each have their own set of orders delivering from the same depot and each have an unlimited number of trucks to make those deliveries. They further assume that no pick-ups take place, i.e. all orders are deliveries. Likewise, they perform sensitivity analyses to investigate the effect of order sharing in a number of scenarios among transportation companies who individually solve their own Vehicle Routing Problem (VRP) (local optimization). With order sharing, the problem will be tackled globally (global optimization). Other key references about horizontal cooperation are Cruijssen et al. (2007a; 2007b; 2010).

Regarding horizontal cooperation in landside logistics, Caputo and Mininno (1996) examine various policies such as the use of standardized computerized documents, standardized pallets and cartons, multi-supplier warehouses and coordinated route planning in the Italian grocery industry. These authors further discuss the aggregation of suppliers to the same courier. Fair cost allocation is an important issue that has been studied recently by many authors in the literature, see e.g. Audy et al. (2012), Dai and Chen (2012). There are other authors who pay attention to the vehicle consolidation and load scheduling to develop a horizontal cooperation program (Özener et al., 2011). Very few papers have discussed horizontal cooperation by using multi-criteria decision making models (Bahinipati et al. 2009). Cruijssen et al. (2007b) study the potential benefits and impediments for horizontal cooperation between logistics service providers in Flanders. They provided empirical evidence on the level of savings that can be attained by joint route planning and how these savings depend on specific market characteristics. In a parallel way, Rieck and Zimmermann (2009) develop methods and algorithms for vehicle routing problems for medium-sized forwarders considering heterogeneous vehicles, time windows, simultaneous delivery and pick-up at customer locations and use of multiple vehicles within forwarding cooperation. Similarly, Krajewska et al. (2008) analyze the profit margins resulting from horizontal cooperation among freight carriers and the possibilities of sharing these margins fairly among the partners, using the Shapley value. Likewise, Dahl and Derigs (2011) studied the effectiveness of a decision support system that allows for cooperation among carriers, increasing the utilization of vehicles. There are many contributions that show optimization models for one of the aspects of horizontal cooperation, such as fulfilling a collaborative carrier's or shipper's delivery request on its backhaul route. Adenso-Diaz et al. (2012) develop a GRASP algorithm to solve the problem of designing conjoint delivery routes in road transportation. Also, Bailey et al. (2011) develop two models and solve them by using two solution methodologies, revealing that the percentage of cost savings for empty backhaul routes after shipment delivery (i.e. deadheading) can reach 27%.

One important externality of the implementation of horizontal cooperation in the logistics management of the distribution fleets of a set of firms or companies is the reduction of the environmental impact caused by transportation, mainly related to CO_2 emissions and which is difficult to estimate (Lera-Lopez et al., 2012). The main reason of this reduction is the decrease of the fleet size and a better use of the available resources due to cooperation. This situation involves that one of the most effective policies in green logistics is transport cooperation and particularly, horizontal cooperation (Dekker et al., 2012; Jabali et al., 2012). The optimization of routes considering environmental criteria has built the Pollution-Routing Problem (Bektas and Laporte, 2011) and the Green Vehicle Routing Problem (Erdogan and Miller-Hooks, 2012), playing an important role in the control of the CO_2 emissions done by the distribution processes associated to logistic activities. Moreover, it is important to highlight that horizontal cooperation is one of the easiest ways to improve the environmental impact associated to road transportation. For instance, Ubeda et al. (2011) study the resolution of a green logistics problem in a Spanish retailer integrating the pick-up and delivery activities in conjoint routes of the same fleet vehicles.

3. Considering Backhaul Strategies in Vehicle Routing Problems

In today's highly competitive economic context, we are interested in analyzing how horizontal cooperation among transportation firms can help to reduce delivery or routing costs in different scenarios. In this paper, we assume that the carriers and shippers are directly controlled by the same companies –i.e., the shippers own the fleet of vehicles. In this context, we will analyze an ideal routing scenario, in which backhaul-based horizontal cooperation among companies takes place. In this cooperative scenario, companies are incentivized to share trucks and routes in order to improve their individual turnovers by reducing transportation costs and number of necessary vehicles. The goal is to minimize distance-based costs throughout the use of backhaul strategies and, as a direct consequence, to reduce the environmental impact of the delivery activities as well. This cooperative scenario is then compared against a non-cooperative scenario in which each company manages its own clients without taking benefits of backhauls strategies. This second scenario can be assimilated to several individual capacitated vehicle routing problems, where each individual firm or depot tries to minimize its individual routing costs –i.e., a multiple (capacitated) vehicle routing problem. We will consider that the customers of each firm are geographically scattered as regards as the firms' positions, so that backhaul policies will have a significant impact on the costs. This can be observed in Figure 2, where each firm depot is represented by a square symbol and all customers of the same firm are represented by the same non-square symbol.

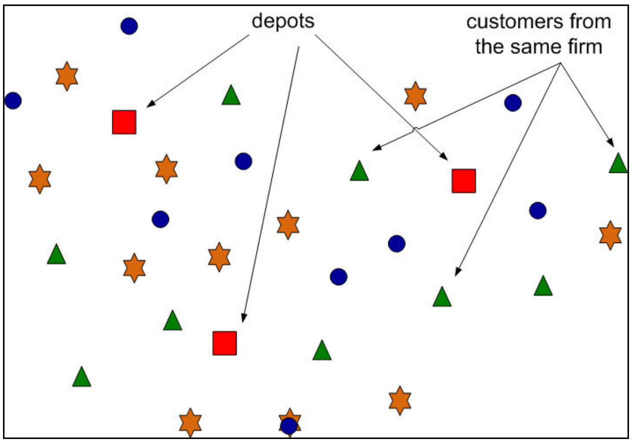

Fig. 2. Scattered topology –worst case for a non-cooperative scenario.

Then, the following scenarios are considered and evaluated: *(a)* cooperative scenario, in which all companies are willing to cooperate –i.e. if convenient, customers' services can be reassigned to other companies (depots) throughout backhaul strategies in order to reduce global routing and environmental costs; and *(b)* non-cooperative scenario, in which customers are never shared by firms and each firm is just trying to minimize its own routing costs.

Methodologically speaking, our modeling approach is based on the mathematical program formulation done by Goetschalckx and Jacobs-Blecha (1989) when they designed their model for the Vehicle Routing Problem with Backhauls, based on the VRP analysis performed by Fisher and Jaikumar (1978). Nevertheless, we have developed our own metaheuristic which will be presented in the following section.

4. Numerical Experiments

In order to perform some numerical tests, we have designed three benchmark instances. For the routing decisions in both collaborative and non-collaborative scenarios, the SR-GCWS-CS algorithm (Juan et al., 2011) is employed to solve each of the Capacitated Vehicle Routing Problems that arose in a given problem. A standard personal computer, Intel® Core™2 Duo CPU at 2.4 GHz and 2 GB RAM was used to perform all tests. The top part of Figure 3 shows a non-cooperative solution for a routing problem with 32 customers plus 4 depots. On the contrary, the bottom part of Figure 3 represents a feasible solution for the same instance when backhauling cooperation strategies are considered.

We have developed a metaheuristic algorithm to solve each of the cases mentioned above. A Java application has been implemented in order to incorporate the previous procedure giving solution to the selected tests. Thus, in algorithmic terms, we have firstly combined a 'priority-assignment' list of potential depots to customers, employing the classical savings heuristic (Clarke & Wright, 1964) and an Iterated Local Search (ILS) process suggested by Lourenço et al. (2010). Finally, we use the SR-GCWCS-CS algorithm developed by Juan et al. (2011), so that we improve the general routing costs.

Results of these tests, comparing the collaborative scenario using backhauling policies with the non-collaborative ones are summarized in Table 1. The table shows the details of each instance, that comprises the following: *(i)* instance number; *(ii)* number of customers, *n*, number of depots, *d*, and maximum load capacity of any vehicle, *Q*; *(iii)* the best solution found –in terms of distance-based costs– for the non-cooperative scenario (BS-NC); *(iv)* the estimated emissions costs associated with BS-NC, which have been computed according to Ubeda et al. (2011); *(v)* the number of vehicles associated with BS-NC; *(vi)* the best solution found –in terms of distance-based costs– when backhauling cooperation is allowed; *(vii)* the estimated emissions costs associated with BS-C, computed in a similar way as before; *(viii)* the number of vehicles associated with the BS-C; *(ix)* the gap between costs; and *(x)* the gap between emissions.

Several insights can be derived from Table 1. First, notice that when comparing distance-based costs, the use of backhauling allows reducing distance-based costs in about 16% –average reduction value for the three cases considered in this paper. Likewise, environmental costs are reduced by almost 24% on the average. As pointed out before, the emissions costs associated with each solution are computed following the methodology described in Ubeda et al. (2011), who suggested a table of coefficients that allows the approach to the emissions costs according to the truck load and distances for partial routes between edges. Finally, it is also worthy to observe the remarkable reduction in the number of vehicles required to complete the delivering of the products when backhauling strategies are allowed.

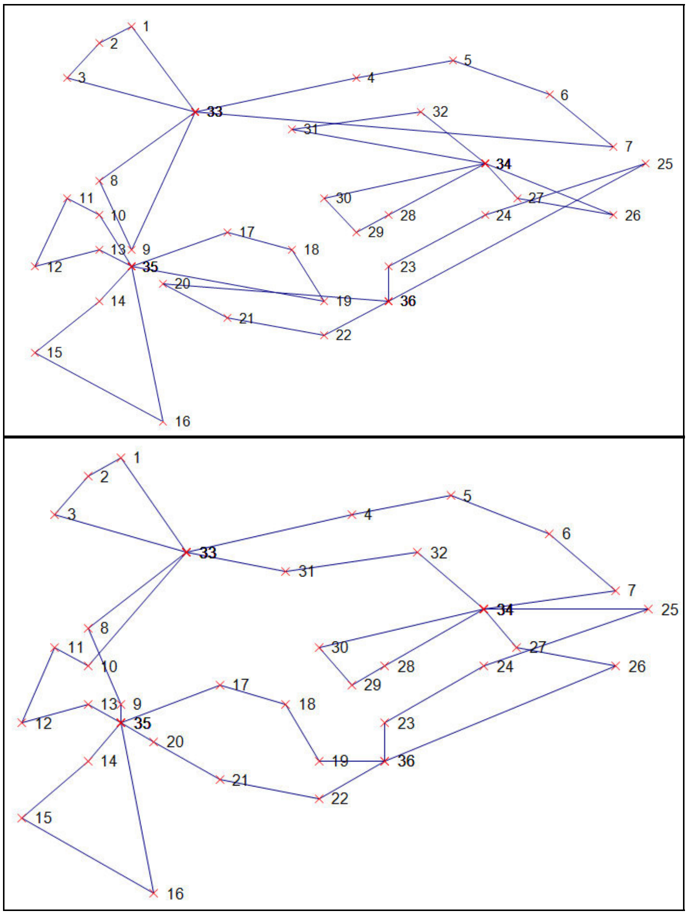

Fig. 3. Solving instance 2 without (top) and with (bottom) backhauling cooperation.

5. Conclusions

In this paper, we have discussed how horizontal cooperation throughout backhauling can represent an effective strategy to reduce distance-based costs as well as emissions costs during distribution activities in the transportation arena. Despite the exploratory character of the numerical experiments developed in this paper, results seem to clearly suggest that noticeable savings in both costs can be obtained by incorporating backhauling practices into logistics and transportation enterprises. As future work, we plan to develop a metaheuristic approach for efficiently deal with routing problems with backhauling and to test this approach using a larger set of benchmark instances.

Table 1. Comparative between cooperative and non-cooperative scenarios.

		BS-NC			BS-C (backhauling)				
Instance	**n-d-Q**	**Distance (1)**	**Emissions (2)**	**nVeh**	**Distance (3)**	**Emissions (4)**	**nVeh**	**Gap (3)-(1)**	**Gap (4)-(2)**

1	20-3-60	217.49	191.65	9	176.29	144.80	6	-18.9%	-24.4%
2	32-4-80	185.03	168.90	11	156.44	128.03	7	-15.5%	-24.2%
3	52-5-80	344.55	306.56	17	297.04	238.56	12	-13.8%	-22.2%
Averages								*-16.1%*	*-23.6%*

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