

The Collaborative Carrier Vehicle Routing Problem for Capacitated Traveling Salesman Tours

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Abstract: This paper concentrates on a new framework for a post-market reassignment of requests in a Collaborative Carrier Network (CCN). While the framework was applied to a pickup and delivery scenario in [BB07] we now use it for the vehicle routing of a carrier network offering LTL pickup services leading to a set of interdependent capacitated traveling salesman tours.

1 Introduction

Forming networks of collaborating carriers is well known in practice as well as in research on freight transportation. Collaboration has become a strategic instrument to gain efficiency in face of decreasing profit margins observed in many transportation markets. While large carriers can generate economies of scope on their own, smaller companies usually need to search for load complementing the current operations in order to balance their capacities. In the scientific literature, various aspects of carrier collaboration have been investigated, including sub-contracting decisions, negotiation and auction mechanisms, profit sharing, and communication platform design [SR05, KK06, LKM07]. In these studies the influence of individual operation costs on the reallocation of requests in the network has been pointed out.

In contrast to this previous research, our approach relies on true operation costs by integrating algorithms for transportation planning within an auction-based exchange mechanism. This allows collaboration strategies in transportation markets to be assessed on a numerical basis.

2 A Collaborative Carrier Vehicle Routing Problem

A CCN consists of a set of independent carrier companies that offer a standardized freight transportation service to shippers. We assume that every carrier has contracted a set of requests which have to be served within a certain period. The operations planning of the carriers is performed on a periodic basis with regard to individual depots and a homogeneous fleet. The framework for the collaboration of the carriers consists of a mechanism to exchange requests between carriers and a corresponding cash flow model for the decision to self-fulfill or sub-contract requests. Moreover, the framework includes a calculation scheme for the determination of revenue, cost, and profit which provides the

basis for incorporating the underlying vehicle routing problem.

The goal of the CCN is to maximize the total network profit. Consider a situation where Carrier i has contracted a transportation request at charge r_j from a shipper. Assume furthermore that another Carrier k can serve this request at lower marginal cost. To improve the network profit Carrier i can sell the request and receive a compensation price v_j from Carrier k which serves as an internal transfer price in the network. The charge r_j for the request is then transferred to Carrier k . A floor price expressing the minimum compensation price accepted by the offering carrier i is bounded by his marginal profit.

Starting from an initial request-to-carrier assignment the optimization problem of the CCN is to find a reassignment of requests such that the total profit of the CCN is maximized, provided the carriers perform an optimal routing of their vehicles. Under complete information transparency, this optimization problem corresponds to a multi depot vehicle routing problem. In a competitive environment, however, carriers are not willing to disclose private information such as customers, marginal cost, and profit. In the absence of information transparency, the distribution of requests is therefore unknown and the problem under consideration cannot be solved centrally. At least, we can assume carriers to be rational, i.e. we expect them to be willing to sell a customer request, provided they obtain an acceptable compensation price.

Let M denote the set of all carriers in the network, N the set of all transportation requests to be fulfilled within one period, and $N_i \subseteq N$ a subset of requests initially assigned to Carrier $i \in M$. The goal of the CCN is to reassign the requests $j \in N$ with respect to the paid compensation prices such that the period profit is maximized. Using the binary decision variable x_{ij} , which indicates whether Request j is reassigned to Carrier i , the Collaborative Carrier Vehicle Routing Problem (CCVRP) is formulated as follows:

$$\max P = \sum_{j \in N} r_j - \sum_{i \in M} C_i \quad (1)$$

$$\text{s.t. } 1 = \sum_{i \in M} x_{ij} \quad (\forall j \in N) \quad (2)$$

$$C_i = \sum_{j \in N} \beta_1 x_{ij} + L(\{j \in N \mid x_{ij} = 1\}) \beta_2 \quad (\forall i \in M) \quad (3)$$

$$\hat{P}_i \leq \sum_{j \in N} r_j x_{ij} + \sum_{j \in N_i} v_j (1 - x_{ij}) - \sum_{j \in N \setminus N_i} v_j x_{ij} - C_i \quad (\forall i \in M) \quad (4)$$

$$x_{ij} \in \{0, 1\} \text{ and } v_j \in \mathbb{R} \quad (\forall i \in M, \forall j \in N) \quad (5)$$

The objective function (1) maximizes the period profit of the CCN as the total revenue of all requests minus the total cost of all carriers. Since the total revenue is invariant, we can alternatively minimize the total cost alone. Constraints (2) ensure that every request is assigned to exactly one carrier. The transportation costs of the carriers are computed in constraints (3) with respect to a request-to-carrier assignment. Here, β_1 denotes the stopping cost per request and β_2 denotes the transportation cost per kilometer. Note that the constraints of the involved capacitated TSP also nest inside (3) because the overall tour length $L(\cdot)$ is computed for the carriers. Constraints (4) ensure that the profit of the carriers does not deteriorate through an exchange of requests. For every carrier, the original

profit \hat{P}_i is pre-processed from the request set N_i . The new profit is composed from the revenues and compensation prices obtained by a carrier minus the compensation prices paid and the transportation cost incurred from the reassignment. Also the compensation prices are decision variables in the model, but they reflect only internal transfer prices and do therefore not occur in the objective function.

An optimal routing of vehicles found under information transparency is also optimal to the CCVRP. But in the absence of information transparency the way to solve the CCVRP must be different from the way algorithms for vehicle routing usually work. The problem can be hierarchically decomposed into a top level problem (CCVRP) and corresponding base problems which represent the routing problems of the carriers. The distribution of requests is transferred to the base level problems and the results of the routing problems are returned to the top level problem. This problem is virtually independent from the base problem, i.e. from the particular type of vehicle routing under consideration. Hierarchical systems generally require a coordination. In our approach this coordination is performed by a market-based exchange of requests between carriers which is controlled by a combinatorial auction.

3 Procedure for the Reassignment of Requests

Solving a CCVRP requires to provide a transfer procedure for reassigning customer requests. Starting from the initial distribution of requests, a reassignment of requests must be found, which increases the overall network profit. The used procedure should be confidential and effective in terms of implementing substantial incentives for the carriers to participate in the process. It is controlled by a combinatorial auction which significantly enhances the economic efficiency of an exchange market through bundled bids [dVV03]. Combinatorial auctions allow the participants to express preferences, like bidding on combinations of requests or bidding on a request provided that one of their own requests is sub-contracted to another carrier. In order to solve the CCVRP we propose a reassignment algorithm, described in five steps.

In the first step, the carriers evaluate their requests and select those with the lowest marginal profit as a candidate for being reassigned. For these requests it is most likely that other carriers can serve them at lower cost. The requests are posted to the central authority including the floor prices, the required transport capacities, and the geographical locations of the pickup points. The posted requests form a candidate set from which subsets are composed in Step 2. Provided the candidate set contains n requests, at most $2^n - 1$ subsets are composed, where the empty set is neglected. In Step 3, the carriers determine marginal profits for all of these subsets on the basis of the announced coordinates and capacities. The marginal profits serve as the bids of the carriers in the combinatorial auction. Note that even for small candidate sets an exponentially growing number of request combinations is generated. To determine the winner of the auction a Combinatorial Auction Problem (CAP) has to be solved in Step 4, see [dVV03]. The division of the gained profit takes place in Step 5. For this purpose the profit gain is computed by the central authority. The gain results from the winning bid values minus the floor prices of the requests contained in the associated selections. Afterwards, the profit gain is split up among the participating

carriers. We use a simple method for profit sharing, where the announced floor prices are directly assigned to the involved carriers. The remaining profit is divided perfectly among the participating carriers.

These five steps are iteratively repeated until no further improvement is possible. Steps 1 and 3 are autonomously performed by the carriers whereas Steps 2, 4, and 5 are centrally performed by the central authority.

4 Computational Study

For an illustration we consider a network with three LTL carrier companies operating from individual depots which are located within a common customer area. Therefore, a strong competition can be expected among carriers and collaboration should come along with considerable benefits. We aim at verifying this expectation by solving the resulting CCVRP. The proposed reassignment algorithm is compared with the optimal solution obtainable under information transparency. The corresponding optimization problem is known as the capacitated multi depot traveling salesman problem.

A set of ten test instances is derived from the Euclidean TSP benchmark *R101* of [Sol05]. Every single test instance assigns six transportation requests to each carrier which are randomly drawn from *R101*. The required capacity of the requests ranges between 1 and 35 units. The capacity of the used vehicles is set to 200 units. Due to the capacity restriction, no carrier is able to serve all requests of a period on its own.

In the computational study the average gap of the initial network profit, measured against the upper bound obtainable under information transparency, is reduced by 4 basis points. Improved request-to-carrier assignments are found in all cases. Our computations give evidence that collaboration pays off for carriers that offer pickup services.

References

- [BB07] S. Berger and Chr. Bierwirth. The Collaborative Carrier Vehicle Routing Problem. *Working Paper Series of the MLU Halle*, (63), 2007. Submitted for Publication.
- [dVV03] S. de Vries and R. V. Vohra. Combinatorial Auctions: A Survey. *INFORMS Journal on Computing*, 15(3):284–309, 2003.
- [KK06] M. A. Krajewska and H. Kopfer. Collaborating freight forwarding enterprises. *OR Spectrum*, 28(2):301–317, 2006.
- [LKM07] C. G. Lee, R. H. Kwon, and Z. Ma. A carrier’s optimal bid generation problem in combinatorial auctions for transportation procurement. *Transportation Research E*, 43(2):173–191, 2007.
- [Sol05] M. M. Solomon. <http://w.cba.neu.edu/%7Emsolomon/problems.htm> - last check of address 27.4.07, 2005.
- [SR05] J. Song and A. C. Regan. Approximation algorithms for the bid construction problem in combinatorial auctions for the procurement of freight transportation contracts. *Transportation Research Part B*, 39(10):914–933, 2005.