Transportation planning in freight forwarding companies

Tabu search algorithm for the integrated operational transportation planning problem

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Summary. The integrated operational transportation planning problem extends the traditional vehicle routing and scheduling problem by the possibility of outsourcing a part of the requests by involving subcontractors. The purpose of this paper is to present the integrated planning problem and to propose an approach for solving it by a tabu search heuristic. Existing approaches from literature which discuss vehicle routing combined with outsourcing regard only one specific type of subcontracting. This paper describes and explores the complex situation where an own fleet and several types of subcontracting are used for request fulfillment. As the approach contains new aspects, unknown to the literature so far, tabu search is extended to special types of moves. On the basis of computational results the cost structure is analyzed in order to investigate the long-term planning question whether and to what extend it is profitable to maintain an own fleet.
Key words: freight forwarder, private fleet, subcontraction, tabu search, operational planning

1 Introduction

External procurement, also known as vertical division of work, means that a company purchases some items, such as vendor parts or services, from a third party (Grochla, 1980). However, the decision is not reduced to 'either-or' in the sense of 'make-or-buy' for each article or service within an isolated comparison by predetermined criteria. Instead, the traditional 'make-or-buy' decision evolves into a reference analysis among the items involved (Wellenhofer-Klein, 1999). A major impact of such an analysis is noticed in the level and the structure of costs in the outsourcing enterprise (Zäpfel, 2000).
In particular, the 'make-or-buy' decision also applies to the transportation branch. Most freight forwarding companies reduce the capacity of their own vehicle fleet far under the varying total demand limit. Additional outside carriers are involved in order to gain enough transportation resources for covering

the demand. In effect, freight forwarding enterprises have to plan the fulfillment of their requests not merely by routing and scheduling their own fleet but also by selecting transportation tasks to be sourced out by entrusting external independent freight carriers with their execution. Using own vehicles for the execution of tasks is called self-fulfillment, while involving an external carrier is called subcontraction. Together with engaging an external carrier, the rules of payment for its service (type of subcontraction) are defined. The problem investigated in this paper consists in constructing a fulfillment plan with the lowest fulfillment costs, assuming a fixed limited size of the own fleet and predefined types of subcontraction. This problem is called the integrated transportation planning problem (ITPP).
In this paper the ITPP, supported by a practical analysis is presented and a tabu search algorithm for problem solving is proposed. The problem has been tested for several sizes of the own fleet, in order to investigate long-term questions concerning the available vehicle capacity. Section 2 outlines the practical motivation for the problem. Section 3 briefly presents existing approaches to the problem. Section 4 introduces our approach to the problem and presents a mathematical model for the problem followed by the solution methodology in Section 5 and computational results in Section 6. Section 7 gives conclusions and recommendations for future research.

2 Operational planning in a freight forwarding company

We have analyzed a medium-sized freight forwarding company using its own vehicles and external subcontractors for its operations in several regions of Germany. The forwarding company receives less-than-truckload shipments from its clients. The analysis has shown that only about 30% of the requests are fulfilled by the company's own fleet (Kopfer, Krajewska and Jurczyk, 2006). Apart from the usage of the own fleet the company hires subcontractors on a long-term basis and forwards remaining requests to independent external carriers. The planning decisions are made hierarchically by the schedulers who are only supported by planning software for the pure vehicle routing problem without subcontraction. The manual planning process is performed in the following way:
At first the most attractive requests are assigned to the own vehicles. The attractiveness of a request is estimated on the basis of its proportionate profit contribution. For the own vehicles, stationed in one depot, round routes are constructed, which contain pickup and delivery locations of the requests. The costs of the own fleet consist of two blocks: variable costs and fixed costs. The variable costs depend on the tour length. They are calculated on the basis of a constant cost rate per travel unit. Fixed costs contain amongst others amortization costs, taxes, and the payment for drivers. These costs are outstanding (Figure 1a), while the marginal variable costs for a request are considerably low. Thus, it is aimed to utilize the own fleet to a maximal extent.

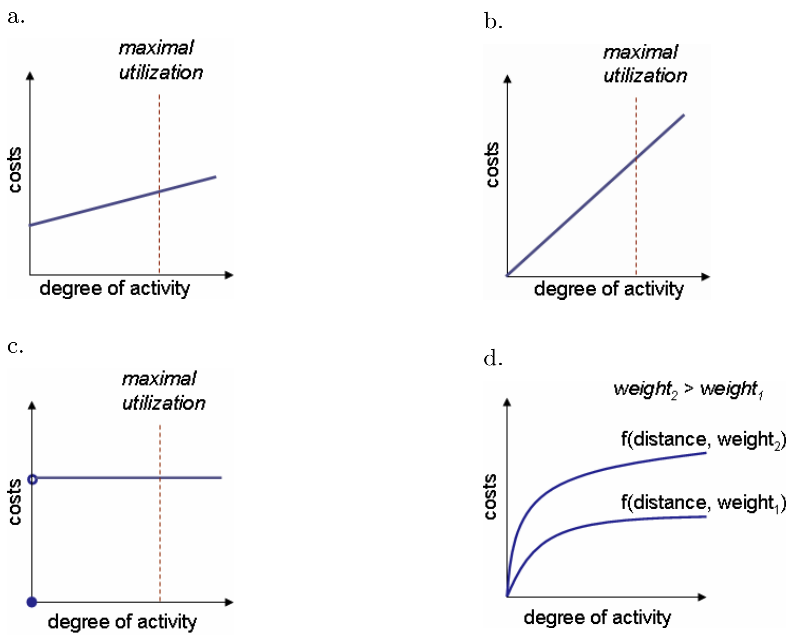

Fig. 1. Fulfillment costs for: (a) a vehicle from own fleet;(b) a vehicle from subcontractor paid on tour basis;(c) a vehicle from subcontractor paid on daily basis; (d) requests forwarded to an independent carrier.

Next, the requests which are not planned to be performed by self-fulfillment are forwarded to subcontractors. There are subcontractors which are frequently engaged by the forwarder and are nearly exclusively employed by him. Clusters of requests, which build complete tours can be shifted to these subcontractors. Consequently, the exclusively employed subcontractors receive full-truckload shipments from the forwarder. The set of exclusively employed subcontractors is split into two groups with different types of subcontraction. For the first group the payment for a tour with a full-truckload shipment is calculated on tour basis using an agreed tariff rate per travel unit and the length of the transferred tour. The tariff rate per travel unit is higher than the corresponding cost rate of an own vehicle as it covers a part of the fixed costs of the subcontractor (Figure 1b). For the forwarder, there are no fixed costs connected with the shifting of tours. The advantage of this type of subcontraction is that costs only arise when a vehicle is really used, and that the costs are proportional to the amount of its utilization.
The second type of subcontraction is applied for the second group of exclusively employed subcontractors. It consists in paying freight carriers on a daily basis. In this case an external carrier can be occupied up to an agreed limit for travel distance and time. He gets a daily flat rate and has to fulfill all the received requests of a transferred tour. The costs for the forwarder are con-

stant irrespectively to the amount of vehicle utilization (Figure 1c) and they only arise if a vehicle of the subcontractor is used at all. The related costs are relatively high, therefore, the break-even point cannot be reached unless the daily limit is actually utilized. In practice, this subcontraction type is used to execute requests which do not fit into efficient vehicle routes or run into directions where no favorable clustering is possible.
The third type of subcontraction is applied for independent subcontractors which are not employed exclusively. This type of subcontraction is called freight consolidation. For freight consolidation the amount of payment depends on the service of the external carrier and not on the usage of its resources. This is appropriate for subcontractors who usually combine less-than-truckload shipments of different shippers to a single tour. Each shipper pays the subcontractor on the basis of the flow of cargo induced by his own requests and not on the basis of travel distance, because the length of the entire tour resulting from the requests of different shippers is not known to a single shipper. Such a freight calculation on the basis of freight flows had to be applied in Germany at the time of the state-controlled price regulation until 1994 and remains of highest practical relevance till now (Kopfer and Krajewska, 2007). Similar to vehicle routing, the costs for executing requests by means of freight consolidation are determined for each vehicle separately. This causes a grouping of requests which is analogous to the clustering of requests in vehicle routing. To make the difference between vehicle routing and freight consolidation more distinct, the subsets of requests for freight consolidation are called bundles instead of clusters. Instead of routes of a cluster, flows of a bundle are considered for freight calculation. As in vehicle routing, the entire transported loading must not exceed the vehicle capacity, because the requests of one bundle are intended to be transported by a single vehicle. Bundling reflects the cost savings which can be achieved by assigning several requests of one shipper to one vehicle of a carrier. A bundle of requests forwarded on the basis of freight consolidation usually yields a less-than-truckload shipment, but a large bundle may also constitute a full-truckload shipment. The flows of one bundle must ensure that the cargo of each request of this bundle gets from its source (pickup location) to its sink (delivery location). The flow of cargo of a single request can be diverted to locations of other requests of the same bundle and then be combined with them to joint flows on common arcs, while the cargo of each request must reach its sink by a suitable flow. Thus, for each request r_i there must exist a path $P_i(i^+, i^-)$ from the pickup location of r_i to the delivery location of r_i. The path P_i identifies the arcs which are used by the flow of goods of r_i on their way from the pickup to the delivery location. The flow on one single arc consists of the cargo of all requests whose path use that arc. Freight consolidation denotes the process of building bundles and constructing admissible flows for each bundle while the total freight has to be minimized. The calculation of the amount of the freight is performed on the basis of the flows on single arcs. For each arc between two locations the fee is computed in dependence of the length of the arc and the amount of goods

flowing on this arc.
The total freight of a bundle of requests corresponds to the sum of the fee of all arcs which are needed to bring the cargo of the bundle from the source locations to the sink locations. In case of a simple Vehicle Routing Problem (VRP) (comp. e.g., Bräysy and Gendreau(2001)), minimizing the costs of a single bundle consists in finding a minimal spanning tree of the complete graph containing all nodes of the bundle. Spanning trees are the only admissible solutions, because the node of each customer must be connected to the depot and there can be only one single path from the depot to each customer since the freight function is concave. Each spanning tree represents a solution for the problem of determining flows of cargo from the depot to the customer locations of all involved requests, while the weighting of each arc is given by its freight fee. Determining a spanning tree with minimal freight costs is a complex task which cannot be solved by a simple algorithm like e.g. the Kruskal algorithm, since the resulting freight fee of an arc depends on the structure of the considered spanning tree itself. There usually exist agreed freight tariffs under non-linear consideration of length and weight of the joint flows of an arc. Considering the distance between the nodes, the sum of the lengths of the arcs of the spanning tree is a lower bound for the length of a route which is neccessary to fulfill the requests of the customers. But in freight consolidation the weighting of the arcs of the spanning tree is not given by their length but by the freight fee. The freight fee for an arc accounts for the utilization ratio of the vehicle on this arc and depends on the flow, while its amount per distance unit is higher than applying a usual cost rate for travel distance, since the vehicle has to perform empty mileage in order to fulfill the next request. In case of a pickup-and-delivery-problem-with-time-windows (PDPTW), the situation is more complex than for a VRP. For a PDPTW the optimization problem resulting from freight consolidation consists in a generalized minimum cost flow problem. The flow is represented by a graph connecting each pickup location with its corresponding delivery location and combining flows on joint arcs in order to decrease the resulting freight. Freight consolidation means forwarding requests to independent carriers and does not imply any additional specification for the execution of the requests. Time windows must be met by the carriers but they do not influence the amount of freight paid in case of freight consolidation. The distribution of the freight function $f(distance, weight)$ in Figure 1d shows the declining shape of the tariff function. With respect to the solution of the entire ITPP freight consolidation is beneficial for the remaining requests which have not been profitably planned into any of the routes for own or hired vehicles yet, as this fulfillment method is relatively expensive.
There are two main advantages of the combined usage of the own fleet and subcontraction. First, freight forwarders face great demand fluctuations regarding transportation volume (Chu, 2005). As the quantity of requests varies in short time periods, a flexible capacity of transportation resources avoids fixed costs of an under-utilized own fleet. Secondly, positive synergy effects

arise through the usage of subcontracting. The set of requests can favorably be split among the clusters including self-fulfillment and different subcontraction types. This leads to a reduction of global fulfillment costs. Empty vehicle movements are minimized and better capacity utilization is achieved in the vehicle tours, while non-compatible requests are sold on the basis of freight calculation in less-than-truckload bundles.

3 Literature review

There exist only a few approaches which refer to vehicle routing extended by subcontracting. Each of them considers the requests to be independent shipment contracts, associated with less-than-truckload loadings, splitting of which is not permitted. All approaches focus on minimizing the fulfillment costs of a given set of requests.
For self-fulfillment the existing approaches introduce the usage of a homogenous (Pankratz (2002), Schönberger (2005)), alternatively heterogenous (Chu (2005), Greb (1998), Savelsbergh and Sol (1998), Stumpf (1998)) vehicle fleet. The fleet is stationed in one depot (except in Greb (1998)) and each vehicle has a predefined maximal capacity. As a result of vehicle routing and scheduling the round routes for all vehicles are constructed which, while traversed, generate fulfillment costs. The fixed costs are mostly omitted. Only Chu (2005) sums up the fixed costs of all vehicles. Stumpf (1998) assumes that only a part of the fixed costs is assessed, depending on the utilization ratio of the vehicles that have been used. The variable costs depend in all approaches on the tour length according to the distance criterion. Additionally, in Greb (1998) and Pankratz (2002) the time criterion for the tour length is included. The costs for self-fulfillment are then calculated on the basis of a constant tariff per distance (and time) unit.
Each of the existing approaches introduces only one single type of subcontraction. It is always assumed that the external freight carriers are homogenous. All of them quote the same conditions as well as the same tariffs for request execution. The approaches differ concerning the applied type of subcontraction. Different types of subcontraction reflect different levels of complexity. Some of them are associated with pure calculation of freight costs while in other cases an optimization process inside the subcontraction cluster is involved.
Bolduc et al. (2007) and Chu (2005) perform simple shifting of requests which represents the most straightforward method of subcontraction: a sale of a single request to an external freight carrier independently from all the other requests. The requests are forwarded on uniform conditions, based on a constant fee per distance unit, regarding the distance between the pickup and delivery location of a request.
Some approaches assume that complete tours are shifted to subcontractors (Savelsbergh and Sol (1998), Stumpf (1998)). This situation is of practical

relevance, if an entire vehicle is rented from the subcontractor. The method of freight calculation is based on variable costs and corresponds to that in case of self-fulfillment. Considering the fixed costs, vehicles can be hired on different terms. In Stumpf (1998) it is assumed that the vehicles of a third party are hired on a short-term basis if they are needed. Thus, fixed costs are covered partially according to the working time of the vehicles and drivers. In Savelsbergh and Sol (1998) a part of the vehicles is rented permanently. These vehicles cannot be returned, while the other part of vehicles is hired at a short notice. In both cases fixed costs are not involved, but the number of hired vehicles is minimized as a consequence of the applied cost structure.

The approach of parameterized subcontraction combines the two aforementioned possibilities. Here, freight cost calculation results from isolated price assessments for each request on the basis of a predefined tariff, multiplied with an adjustment parameter which is defined using different criteria such as distance (Schönberger, 2005) or weight (Greb, 1998). In order to calculate the value of the adjustment parameter, an additional route of a dummy vehicle is constructed.

Freight consolidation on a basis of a nonlinear freight function is considered by Pankratz (2002). The problem is modeled as a multi-commodity network flow problem: the less-than-truckload requests are bundled and a least cost flow through a given transportation network is searched. The freight minimization problem itself is a combined non-linear network flow problem and assignment problem. It is an NP-hard optimization problem. Costs are calculated separately for each bundle, on the basis of a function that depends on two variables: distance of transportation and the amount of transported goods.

Several optimization methods have been proposed to solve the problem of vehicle routing extended by subcontracting: from a modified savings algorithm in Chu (2005) and a perturbation metaheuristic in Bolduc et al. (2007), a set partitioning in Stumpf (1998) and branch-and-price algorithm in Savelsbergh and Sol (1998) up to tabu search in Greb (1998) and Stumpf (1998), simulated annealing in Stumpf (1998) and a memetic algorithm in Schönberger (2005) (for a broad comparison of the approaches see Kopfer and Krajewska (2007)).

4 The integrated transportation planning problem

Our approach investigates the solution of the ITPP, which means the combined optimization problem of a forwarder applying self-fulfillment and the three different subcontraction types presented in Section 2. We concentrate on the transportation problem and do not consider additional packing constraints.

4.1 Planning framework

Assume a set R of n requests that have to be served. Each request r_i is characterized by q_i which is the quantity to be transported, as well as pickup operation i^+ and delivery operation i^-, which form a predecessor-successor pair (ps-pair) (Nanry and Barnes, 2000). The sets P^+ and P^- denote the sets of pickup operations respectively delivery operations to be served, and $P = P^+ \cup P^-$ is the set of all $2n + 2$ operations including 0^+ and 0^- for the start operation and return operation at the depot. Each operation from a ps-pair is described by three parameters: location of the operation l_i, time window for the operation (b_i, e_i), and time duration of the operation s_i. The Euclidian distance d_{ij} between each two locations l_i and l_j can be calculated. The set L denotes the $2n + 2$ locations of the ITPP, including all locations of the operations of P. Assume $u, v \in L$ to denote locations of the ITPP, i.e., $u = l_i$ and $v = l_j$ for $i, j \in P$.

The usage of the own vehicle fleet and the application of three subcontraction types are assumed for the execution of requests. For the self-fulfillment of requests a homogenous and limited vehicle fleet is available. The own fleet is represented by a set V holding m equal vehicles ($m = |V|$). Each vehicle k can be loaded up to a maximal capacity Q. All vehicles are stationed in the same depot l_0. A cost rate c_d per travel unit of a vehicle tour is used to calculate the variable costs. Additionally, each own vehicle is associated with fixed costs defined as c_f. Fixed costs arise for each vehicle in the own fleet irrespectively to its utilization, even if a vehicle stays idle. As the number of vehicles in the own fleet cannot be changed on the operational planning level, these costs do not influence the short-term planning process. However, as we do not only investigate the operational planning but later on also analyze the overall cost structures for request execution, the block of fixed costs remains of importance. Thus, these costs are included in our further assumptions for cost modeling.

Long-term agreements establish the terms and conditions of the services of exclusively employed subcontractors. Entire vehicles can be hired from these subcontractors and can be arbitrarily planned. These vehicles are equal to the own vehicles of the forwarder with respect to type and capacity. The maximal number of available vehicles is bounded in the agreements, which limits the size of the disposable fleet of the subcontractors in advance. However, not all of the available vehicles have to be exploited. Thus, payment is made only for those vehicles that have actually been used. Moreover, it is assumed that within one type of subcontraction all carriers are homogenous considering their tariffs.

From subcontractors paid on tour basis the set V' consisting of m' vehicles ($m' = |V'|$) is disposable. All vehicles are stationed in l_0 and can be loaded up to a maximal capacity Q. The tariff rate per travel unit of a vehicle $k \in V'$, corresponding to the cost rate c_d for the own fleet, is characterized by c'_d. The fixed costs of the subcontractor are not covered directly, but partially settled as $c_d' > c_d$.

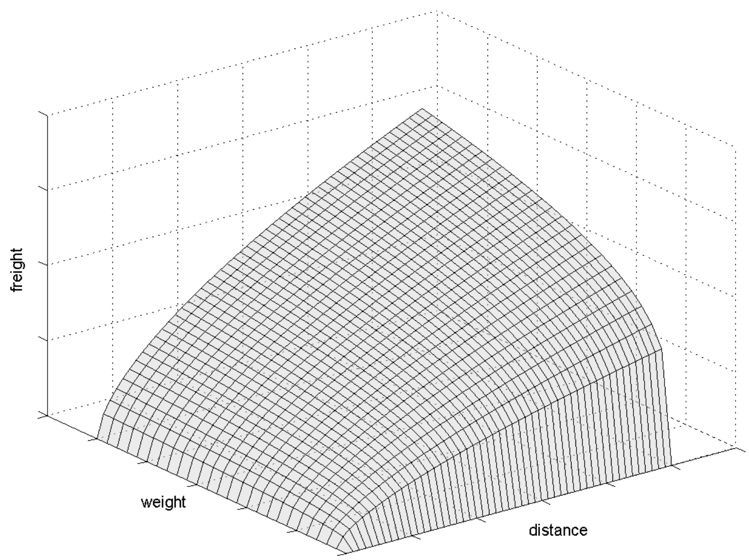

Fig. 2. Distribution of the freight charge function $fr(d_{uv}, q_{uv})$

Subcontractors paid on daily basis offer a set V'' of m'' vehicles ($m'' = |V''|$) which can be utilized. Again, these vehicles are stationed in l_0 and can be loaded up to a maximal capacity Q. Considering terms of payment, only a flat rate c_f'' per day is associated with any actually used vehicle from V''. The maximal tour length of any vehicle from V'' is d''_{max}. As v is the standard travel speed of any vehicle $k \in V \cup V' \cup V''$, its travel time t_{ij} between two locations l_i and l_j can be calculated.

The third subcontraction type consists in forwarding some requests or bundles of them to independent freight carriers and paying on the basis of their rendered services. The payment is determined by freight consolidation. The used freight function depends on two variables: length of the used arcs and weight of the flows on the arcs. It is non-linear and strictly monotonic increasing. Assuming q_{uv} as the weight of cargo flowing between locations u and v, the freight function is given by $fr(d_{uv}, q_{uv}) = cfr \cdot (d_{uv} \cdot (q_{uv})^{\lambda})^{1-\lambda}$ where cfr is a constant tariff rate and $\lambda \in (0,1)$. The principle shape of the function fr is shown in Figure 2.

4.2 Mathematical model of the integrated problem

The optimization problem which is investigated in this paper consists of several subproblems. The entire problem considers four fulfillment modes (self-fulfillment, subcontraction on tour basis, subcontraction on daily basis, and freight consolidation). It can be divided in a subproblem for freight consolidation and a subproblem for vehicle routing which in turn consists in three subsidiary subproblems with different types of vehicle routing. All three subsidiary subproblems have the same structure with respect to the constraints of the problem, but they differ with respect to the objective function. The subproblem of freight consolidation yields a flow problem with the property that the weight (costs) of an arc results from the evaluation of the above non-linear freight function. Since the entire problem combines the optimization of the costs of routes and flows simultaneously, it cannot be solved as a PDPTW with a heterogenous fleet.

Objective function

The task of the ITPP consists in establishing a feasible fulfillment plan with minimal execution costs. The objective function (K) comprises the costs for self-fulfillment (K_v) and the costs for subcontraction according to the following types: payment on tour basis (K_r), payment on daily basis (K_d), and payment according to freight consolidation (K_f):

$$\min K = K_v + K_r + K_d + K_f \tag{1}$$

In order to describe detailed costs in each cluster, the following variables are introduced:
x_{ij}^k is the binary variable such that $x_{ij}^k = 1$ if and only if any vehicle $k \in V \cup V' \cup V''$ travels between locations of the operations i and j.
x^k is a binary variable such that $x^k = 1$ if and only if the vehicle $k \in V''$ of a subcontractor paid on daily basis is used.
The costs K_v arising for the self-fulfillment of requests consist in the variable costs for each used vehicle and the fixed costs of the available vehicles.

$$K_v = c_d \cdot \sum_{k \in V} \sum_{i \in P} \sum_{\substack{j \in P \\ j \neq i}} d_{ij} \cdot x_{ij}^k + c_f \cdot m \tag{2}$$

The costs for subcontraction with payment on tour basis consist in the sum of the variable costs of the used vehicles $k \in V'$.

$$K_r = c_d' \cdot \sum_{k \in V'} \sum_{i \in P} \sum_{\substack{j \in P \\ j \neq i}} d_{ij} \cdot x_{ij}^k \tag{3}$$

In case of subcontraction on daily basis only fixed costs are considered. They arise if a vehicle $k \in V''$ is used.

$$K_d = c''_f \cdot \sum_{k \in V''} x^k \tag{4}$$

For freight consolidation the function $fr(d_{uv}, q_{uv})$ is used to assess the costs. The freight charge is summed up for all cargo flows on any arc (u, v).

$$K_f = \sum_{u \in L} \sum_{v \in L} fr(d_{uv}, q_{uv}) \tag{5}$$

Altogether, the objective function is given by:

$$\begin{aligned} K = c_d \cdot \sum_{k \in V} \sum_{i \in P} \sum_{\substack{j \in P \\ j \neq i}} d_{ij} \cdot x_{ij}^k + c_f \cdot m + c'_d \cdot \sum_{k \in V'} \sum_{i \in P} \sum_{\substack{j \in P \\ j \neq i}} d_{ij} \cdot x_{ij}^k + \\ + c''_f \cdot \sum_{k \in V''} x^k + \sum_{u \in L} \sum_{v \in L} fr(d_{uv}, q_{uv}) \end{aligned} \tag{6}$$

Constraints

The feasibility of the entire fulfillment plan is assured if each request is assigned to exactly one fulfillment mode and if the constraints for each fulfillment mode are maintained. A request is either assigned to any type of vehicle routing or to the fulfillment mode of freight calculation. An additional binary variable is needed for modelling the splitting between vehicle routing and freight consolidation. Let x_i be the binary variable such that $x_i = 1$ if and only if the request r_i is assigned to be fulfilled by freight consolidation. Equation (7) postulates that each operation i of the ps-pair of any request r_i has to be served either by a vehicle of the own fleet or by a vehicle paid on tour basis or by a vehicle paid on daily basis, or it has to be fulfilled by freight consolidation.

$$\sum_{\substack{j \in P \\ j \neq i}} \sum_{k \in V \cup V' \cup V''} x_{ij}^k + x_i = 1, \forall i \in P \tag{7}$$

For the purpose of constraint analysis, the vehicles of the own fleet and hired vehicles can be considered together, as only the objective function differs, while all restrictions are alike. In fact, for all own and hired vehicles k (with $k \in V \cup V' \cup V''$) round routes from and back to l_0 are constructed according to a usual PDPTW. Models for the PDPTW can for instance be found in Dumas, Desrosiers and Soumis (1997), Mitrovic-Mitnic (1998), Nanry and Barnes (2000), and Lau and Liang (2001). Any formulation of the PDPTW using the decision variable x_{ij}^k as a binary variable denoting that a vehicle $k \in V \cup V' \cup V''$ travels from operation i to operation j, can be used as a submodel of the entire model for the ITPP. The constraints of the PDPTW are linked by the equation (7) to the objective function (1). Additionally, equation (7) provides the integration of the restrictions of the PDPTW to the remaining restrictions of the entire model of the ITPP. For the connection of the objective function (1) to the usage of subcontraction on daily basis the variable x^k is defined for each vehicle $k \in V''$. Equation (8) describes the relation of the value of x^k to the values of the variables x_{ij}^k which are applied for the construction of the routes, the capacity constraints, and precendence conditions in the formulation of the underlying PDPTW. Equation (8) postulates that $x^k = 1$ if the vehicle $k \in V''$ leaves the depot.

$$\sum_{j \in P} x_{0j}^k = x^k, \forall k \in V'' \tag{8}$$

The maximal tour length of a vehicle paid on daily basis must not exceed d''_{max}.

$$\sum_{i \in P} \sum_{j \in P} d_{ij} \cdot x_{ij}^k \leq d''_{max}, \forall k \in V'' \tag{9}$$

The flow between two locations u and v is caused by forwarding a bundle of requests on the basis of freight consolidation. In order to describe the flow conditions, the variables x_{uv}^i are introduced. For any request r_i and any pair of locations u, v the variable x_{uv}^i has the value of the weight of the cargo of r_i, if the goods of r_i flow from location u to location v. Thus, $x_{uv}^i = q_i$, if the arc (u,v) is used by the path $P_i(i^+, i^-)$, and $x_{uv}^i = 0$ otherwise. The constant q_{ui}^+ has the value of q_i, if $u = l_{i^+}$ (i.e., u is the location of the pickup operation of r_i), and $q_{ui}^+ = 0$ otherwise. Respectively $q_{ui}^- = q_i$, if $u = l_{i^-}$ and otherwise $q_{ui}^- = 0$.
Locations that do not take part in freight consolidation, because they are served by an own or hired vehicle on a round route, cannot be used as a consolidation point of flows in freight consolidation. This is assured by the equation (10) which postulates that only flows to locations v that are not served in a round route can have positive values.

$$\sum_{i \in R} \sum_{u \in L} x_{uv}^i \leq M(\sum_{i \in R}(q_{vi}^+ \cdot x_i) + \sum_{i \in R}(q_{vi}^- \cdot x_i)), \forall v \in L \tag{10}$$

In (10) M stands for a large constant with $M \geq \sum_{i \in R} q_i$. Equation (11) postulates that for each location and each request participating in freight consolidation the ingoing and outgoing flows must be balanced. If the location u is neither a location of a pickup nor of a delivery operation of r_i, the difference between ingoing and outgoing flows of u must be zero with respect to the request r_i, because $q_{ui}^+ = 0$ and $q_{ui}^- = 0$. That means that with respect to r_i there is either no flow at u or that there must be one ingoing and one outgoing flow with goods of r_i. If u is the location of the pickup operation of r_i ($q_{ui}^+ = q_i$), there is one outgoing flow with goods of r_i at location u. Otherwise, if u is the location of the delivery operation of r_i ($q_{ui}^- = q_i$), there must be one ingoing flow with goods of r_i at location u.

$$\sum_{\substack{v \in P \\ v \neq u}} x_{uv}^i - \sum_{\substack{v \in P \\ v \neq u}} x_{vu}^i = (q_{ui}^+ - q_{ui}^-) \cdot x_i, \forall u \in P, i \in R \tag{11}$$

The entire flow q_{uv} between two locations u, v consists in the sum of the flows of all requests r_i whose goods flow on the arc from u to v.

$$q_{uv} - \sum_{i \in R} x^i_{uv} = 0, \forall u, v \in P \tag{12}$$

The quantity of goods flowing between two locations must not exceed the standard vehicle capacity.

$$q_{uv} \leq Q, \forall u, v \in P \tag{13}$$

An example for least cost flows is shown in Figure 3. In this example 14 requests must be fulfilled. The pickup locations for request r_i range from $l_i = 1^+, ..., 14^+$ and the corresponding delivery locations are l_i with $i = 1^-, ..., 14^-$ (Figure 3a). In case, each request is shifted to the subcontractors separately, the flows are established by direct arcs from the pickup to the delivery location for each request (Figure 3a). If bundling without capacity constraints is regarded, the least cost flows are shown by the connected graph in Figure 3b. For bundling with capacity constraints several connected components are established (Figure 3c), which enable the flows from the pickup locations to corresponding delivery locations.

4.3 Example for integrated planning

In order to illustrate the ITPP an exemplary fulfillment plan is presented. It is assumed that the 14 requests, $R = \{1, ..., 14\}$ of Figure 3 are subject to execution. The vehicle capacity Q amounts to 40 units of weight. The locations of ps-pairs of these requests are shown in Figure 3a.
In our example, the own fleet consists of two vehicles, k_1 and k_2. Subcontraction on route basis is performed by one vehicle k_3 and subcontraction on daily basis is performed by one vehicle k_4. Thus, four vehicles are available, supplemented by the possibility of freight consolidation.
Figure 4 shows a fulfillment plan for these requests. All own vehicles k_1 and k_2 as well as the vehicles k_3 and k_4 of subcontractors are used for request fulfillment. One bundle of requests is forwarded on the basis of freight consolidation. Solid lines denote tours of the own fleet (Figure 4a) and flows of freight consolidation (Figure 4b). Dashed lines denote tours of hired vehicles (Figure 4a and Figure 4b).
The round tours of the own and hired vehicles are shown in Table 1. As the costs of vehicle k_4 are independent of the tour length, the longest tour is assigned to k_4. The vehicle k_3 is assigned the shortest tour as its tariff rate per travel unit is higher than that of the own fleet.
Furthermore, four requests are fulfilled using the fulfillment mode of freight consolidation. The associated costs of the flows of the bundled requests are presented in Table 2.

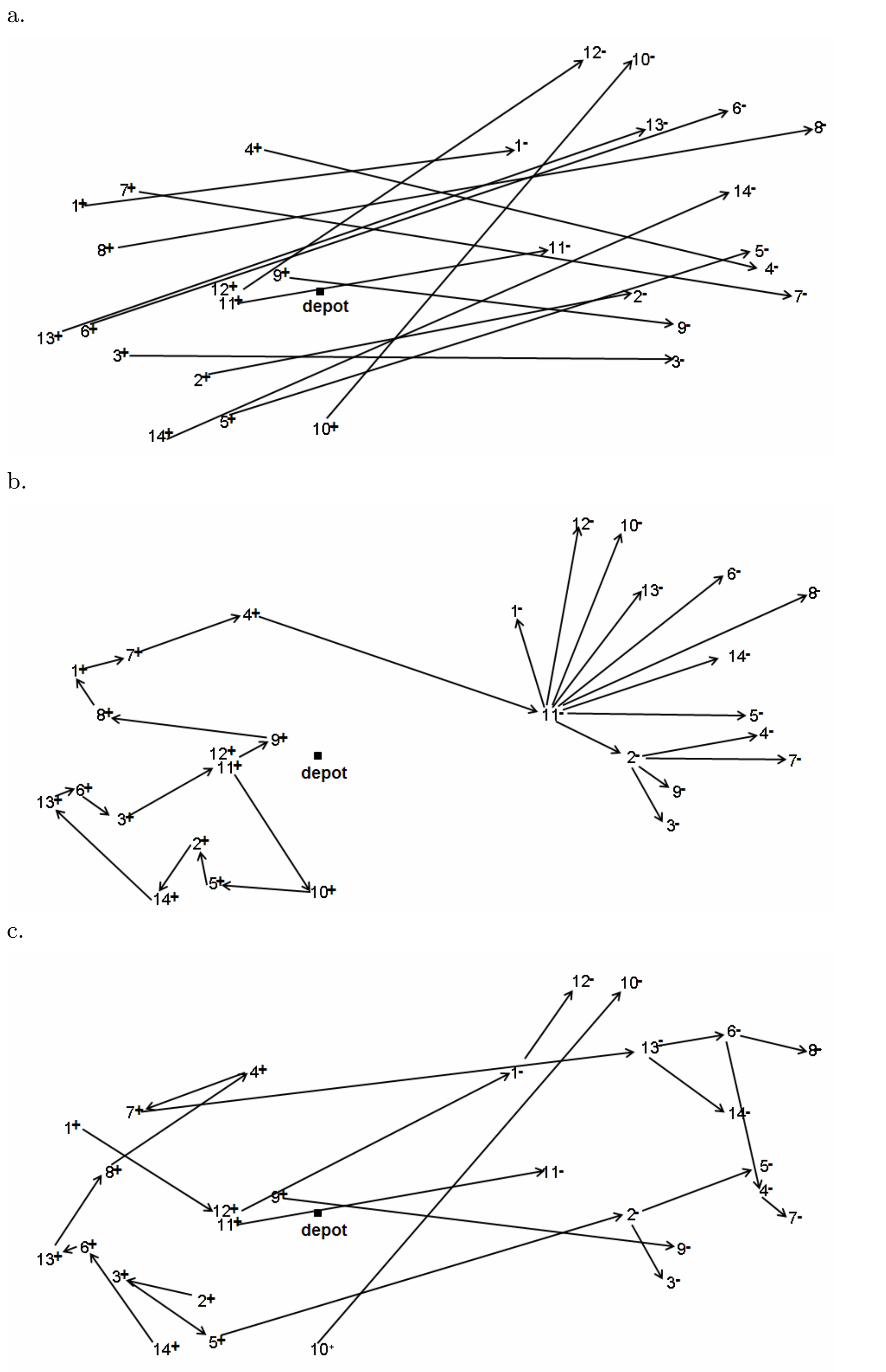

Fig. 3. Freight flow consolidation: (a) if each request is shifted separately (without bundling); (b) if bundling without capacity constraints is considered; (c) for capacitated bundling.

a.

b.

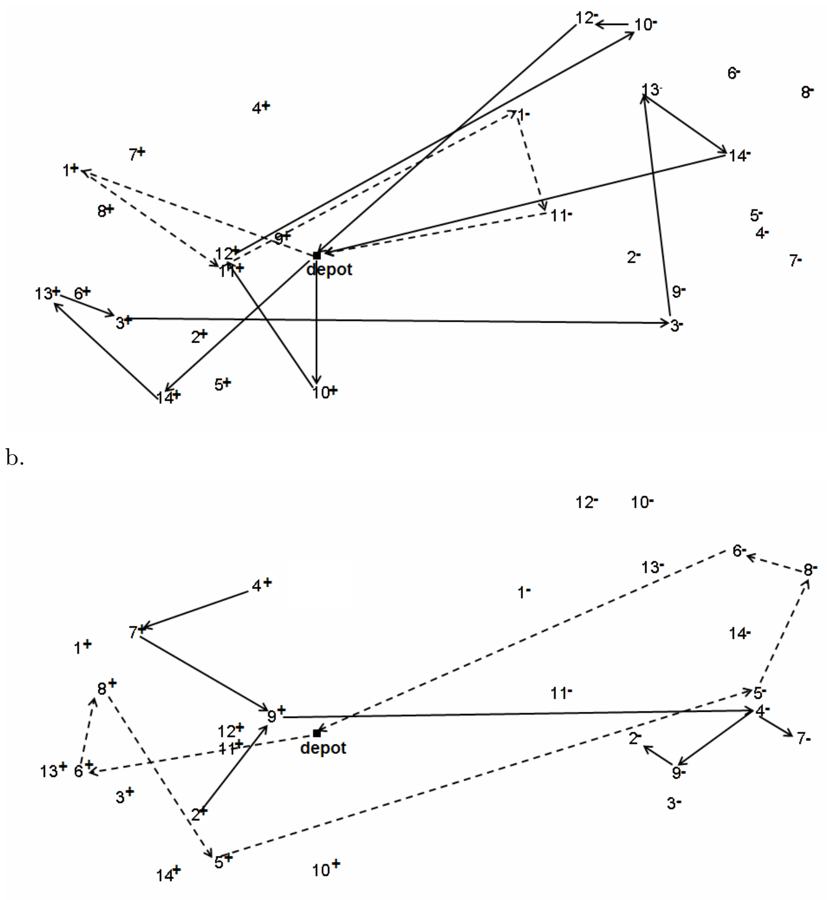

Fig. 4. Fulfillment plan with routes and flows for integrated transportation planning: (a) tours of own vehicles (solid lines) and vehicle paid on route basis (dashed lines); (b) tour of vehicle paid on daily basis (dashed lines) and freight flow consolidation (solid lines).

5 Solution methodology

We present a tabu search algorithm for the solution of the ITPP. The main advantage of tabu search is that it solves the problem simultaneously, as in one move a request can be shifted within or between different fulfillment modes. A second advantage is that good solutions can be obtained in a relatively short time. The tabu search theory can be found in many publications, e.g., Glover and Laguna (1997), and therefore we only describe how the tabu search principles have been applied in particular to solve the problem at hand.

Vehicle	Tour	Tour length	Costs
k_1	$l_0\ 14^+13^+3^+3^-13^-14^-\ l_0$	279	$c_f + 279 \cdot c_d$
k_2	$l_0\ 10^+12^+10^-12^-\ l_0$	211	$c_f + 211 \cdot c_d$
k_3	$l_0\ 1^+11^+1^-11^-\ l_0$	174	$174 \cdot c'_d$
k_4	$l_0\ 6^+8^+5^+6^-8^-5^-\ l_0$	289	c'_f

Table 1. Round tours of used vehicles

d_{ij}	q_{ij}	Costs
26	$q_2 = 13$	$cfr \cdot (26 \cdot 13^\lambda)^{1-\lambda}$
62	$q_2 + q_4 + q_7 + q_9 = 32$	$cfr \cdot (62 \cdot 32^\lambda)^{1-\lambda}$
17	$q_2 + q_9 = 22$	$cfr \cdot (17 \cdot 22^\lambda)^{1-\lambda}$
10	$q_2 = 13$	$cfr \cdot (10 \cdot 13^\lambda)^{1-\lambda}$
18	$q_4 = 5$	$cfr \cdot (18 \cdot 5^\lambda)^{1-\lambda}$
27	$q_4 + q_7 = 10$	$cfr \cdot (27 \cdot 10^\lambda)^{1-\lambda}$
7	$q_7 = 5$	$cfr \cdot (7 \cdot 5^\lambda)^{1-\lambda}$

Table 2. Freight consolidation

5.1 Initial solution

A feasible initial solution s_0 of the ITPP is constructed in a two-stage process. At first, as many requests from R as possible are planned into the routes of the m own vehicles, the m' vehicles paid on tour basis and the m'' vehicles paid on daily basis. Here, the simple insertion algorithm is used. It finds the best position for a request checking all feasible positions in all vehicle routes. In the second stage, each remaining request r_i that has not yet been assigned to the vehicles $k \in V \cup V' \cup V''$ (no feasible position is available) is planned as a flow on a path $P_i = (i^+, i^-)$ within freight consolidation.

5.2 Neighborhood structure

The neighborhood $N(s)$ of a current solution s is composed of all feasible solutions that can be obtained by applying to s one of the moves defined below. Four types of moves are used in the proposed tabu search approach: insert-into-vehicle-route, single-shifting, insert-into-flow and swapping-routes. Three of these moves operate on selected requests which are to be shifted and change their position concerning their integration in the total solution. The selection process aims to find the request whose shifting leads to the best enhancement of the solution and takes place on a restricted candidate set $\overline{R}$. In order to restrict $\overline{R}$, a frequency based memory saves the number ϑ_i of times each request r_i has been chosen as candidate. As $|\overline{R}| = n/2$, half of the requests with the lowest ϑ_i constitute $\overline{R}$.
An insert-into-vehicle-route move takes a request r_i out of its current location in a tour or out of a bundle and repositions it at its best position in a route

chosen from the routes of all vehicles $k \in V \cup V' \cup V''$.
A single-shifting move takes a request r_i out of its tour or its bundle and assigns it to be dispatched as a direct single flow at the arc (i^+, i^-) constituting $P_i = (i^+, i^-)$.
An insert-into-flow move consists in combining a request r_i existing as a single direct flow at the arc (i^+, i^-) with another path P_j building joint flows on commonly used arcs. So, it combines an isolated single flow with an existing bundle for freight consolidation.
A swapping-routes move swaps two complete routes between fulfillment modes which are based on routes. So, the assignment of routes to two vehicles k_i, k_j of different sets V, V', V'' is exchanged.
The above moves take out and insert requests of clusters for routing and of bundles for flow optimization at the same time.
The introduced moves constitute a new extended approach for tabu search algorithms in the area of operational transport planning, since they bridge the gap between vehicle routing and freight optimization. They overwhelm the great structural differences between sequencing at one hand and flow optimization at the other hand by applying moves which affect both types of costing. This demonstrates the strength of tabu search for simultaneously solving problems consisting of diverse subproblems. The presented moves are remarkable with respect to graph algorithms, as they are crossing the border between flow optimization and routing.

5.3 Tabu tenure and aspiration criteria

A tabu status is to be respected by each move which causes an insertion of a request to a route. It is defined in the following way: a request that leaves a route of any vehicle $k \in V \cup V' \cup V''$ cannot return to it during a given number of iterations θ_1. The numerical experiments have shown that due to the large number of possibilities for the insertion-into-flow moves it is not advisable to define a strict tabu list for this move. Moreover, the tabu list prohibiting the return of a request to a bundle excludes too many planning possibilities, which worsens the results. Thus, a proper means for avoiding the incorporation of a request twice in the same way into a bundle is achieved by random choice of one of the possibilities for integrating it in the bundle. This way of integrating a request into a bundle is defined by random choice from θ_2 best possible positions for a request in a bundle.
A tabu status of a move can be overruled if a solution is better than any feasible solution known so far.

5.4 Execution control and intensification through restart

In tabu search there are parameters for two ways of controlling the execution time: the maximum total number of iterations (σ_1), and the maximum number of iterations without improvement of the best known solution (σ_2). After the number of iterations has reached $\lambda_1 = \sigma_1$ and there have been $\lambda_2 = \sigma_2$ iterations without improvement of the so far best solution, the execution of the program is stopped. The execution is also stopped, when λ_1 doubles σ_1 (Brandao, 2006). Therefore, λ_1 is not known in advance and depends on the evolution of the search.

With the aim of intensifying the search around good local optima progressive ways are performed due to the long-term memory. Search is disrupted and restarted from the best known feasible solution s' if during a given number of iterations μ there is no improvement compared to s'. The restart is an approved means to constitute a type of long-term memory (Brandao, 2006). With the restart, the tabu list is emptied.

5.5 Global description of the tabu search heuristic

After generating an initial solution s_0 the tabu search heuristic alternatively performs α single-shifting moves and insert-into-flow moves followed by α combined applications of insert-into-vehicle-route moves, single-shifting-moves and insert-into-flow moves until one of the stopping criteria is reached. This combination of moves (see Table 3) has proven to be successful. Single-shifting and insert-into-flow moves are always performed adjacently, but the current solution s' is improved after each of them. An insert-into-vehicle-route move is not always successful. Limited capacity of the fleet, together with time windows, restrict the number of requests that can be assigned to vehicles. The tabu list provides an additional limitation. Thus, if a trial to assign a request r_i to any of the vehicles remains unsuccessful, single-shifting and insert-into-flow moves are performed for r_i.

In order to accelerate the search process, particular bundling conditions are used to exclude impossible flows at an early stage. Assume that there is a flow between the locations u and v. The following two conditions for arcs which are incident with pickup or with delivery locations must hold (Schönberger and Kopfer, 2004):

(i) if u is the location of the pickup operation of r_i ($u = l_i^+$) then the loading of r_i must be contained in a flow entering u;

(ii) if u is the location of the delivery operation of r_i ($u = l_i^-$) then the loading of r_i must be contained in a flow leaving the location u.

Each time when a request is shifted out of a bundle for freight consolidation by applying an insert-into-vehicle-route or single-shifting move, a repairing procedure is performed. Each request r_i that does not fulfill the conditions (i) and (ii) is deleted from all paths $P_1, ..., P_j \in P$ and planned with a single-shifting move as an exclusive path $P_i = (i^+, i^-)$.

If λ_2 has reached the value of the parameter μ at the end of the iterated application of moves, a restarting from the current solution s' takes place. Next, 2α swapping-routes moves are performed and the iteration counters are re-initialized.

```
PROCEDURE INSERT
    Repeat α{
        Apply insert-into-vehicle-route move;
        s' := new best solution;
        If (¬ insert-into-vehicle-route move){
            Apply single-shifting move;
            s' := new best solution;
            Apply insert-into-flow move;
            s' := new best solution
        }
    }
    If (λ_2 = μ)
        Restart from s'
END *INSERT*
```

```
Generate initial solution s_0;
Set the best solution s' = s_0;
Set the iteration counters λ_1 := 0 and λ_2 := 0;
While (λ_1 < 2σ_1) and (λ_1 < σ_1 ∧ λ_2 < σ_2) do{
    Repeat α{
        Apply single-shifting move;
        s' := new best solution;
        Apply insert-into-flow move;
        s' := new best solution;
    }
    INSERT
}
Restart from s';
Repeat 2α{
    Apply swapping-routes move;
    s' := new best solution
}
Set the iteration counters λ_1 := 0 and λ_2 := 0;
While (λ_1 < 2σ_1) and (λ_1 < σ_1 ∧ λ_2 < σ_2) do {
    INSERT
}
Repeat 2α{
    Apply swapping-routes move;
    s' := new best solution
}
```

Table 3. Outline of the tabu search heuristic

6 Computational results

The aim of the experimental study is to show that the proposed tabu search algorithm benefits from the enlargement of the solution space as a consequence of allowing subcontraction. The analysis investigates, whether it is possible to generate solutions for the ITPP which reduce the total fulfillment costs compared to pure self-fulfillment. Additionally, the experiments are used for an analysis of the adequacy of the size of the own fleet.
For computational analysis, 18 test problems (25- and 50-customer instances) of three problem classes (NC, NR, NRC) for the PDPTW created by Nanry and Barnes (2000) have been solved (Table 4, Table 5). We have also tested our approach on real-life data sets provided by Stute GmbH, a German freight forwarder operating mainly in northern Germany, between the Niedersachsen province and the Main area. We use the data provided by one of the company's subsidiaries in Neuwied. The depots of this subsidiary and the involved subcontractors are also located at Neuwied.
On the basis of previous experiments tariff rates are set. The cost rate per travel unit is set to $c_d = 1$ and the values of the other parameters are $c_f = 100$, $c'_d = 2$, $c''_f = 200$, $\lambda = 0.1$, $cfr = 10$ and $Q = 40$.

# Vehs	K for 25-customer Instances								
m	nc102	nc103	nc105	nr101	nr102	nr105	nrc101	nrc102	nrc103
0	547	509	543	928	1127	1209	746	595	563
1	556	474	567	982	1073	1122	722	609	615
2	604	562	569	1004	1071	1091	736	639	618
3	622	613	631	1035	1107	1055	818	639	685
4	720	671	746	1031	1128	1094	866	753	785
5	798	771	841	1106	1086	1074	966	839	885
6	898	871	951	1141	1145	1132	1101	939	985
7	998	971	1051	1247	1260	1232	1166	1053	1100
8	1098	1071	1141	1348	1326	1313	1266	1139	1191
9	1198	1171	1251	1437	1458	1413	1366	1253	1285
10	1298	1271	1341	1538	1526	1512	1470	1339	1400
11	1398	1371	1441	1647	1598	1632	1584	1453	1485
12	1498	1471	1551	1731	1758	1731	1684	1539	1585
13	1598	1571	1641	1847	1876	1831	1770	1653	1685
14	1698	1671	1741	1940	1958	1912	1870	1739	1794

Table 4. Results for 25-customer Instances

If n denotes the number of requests, the tabu tenures θ_1 and θ_2 of a move are experimentally approved to be at best if set as $\theta_1 = n/3$ (rounded up to the nearest integer) and $\theta_2 = 3$. The values of parameters σ_1, σ_2 and μ have been established in a way that allows them to adapt to the search process. Parameter σ_2 should be greater than μ to give time for improvement after a restart

# Vehs	K for 50-customer Instances								
m	nc101	nc102	nc103	nr101	nr102	nr105	nrc102	nrc103	nrc105
0	784	786	787	2418	2175	2229	1315	1269	1277
1	766	732	809	2293	2101	2187	1361	1370	1279
2	755	755	778	2279	2063	2060	1380	1269	1415
3	816	813	814	2222	2116	2117	1269	1276	1392
4	812	812	818	2206	1816	1952	1333	1295	1314
5	862	861	861	2254	2098	1949	1563	1355	1543
6	962	962	961	2182	1974	1922	1622	1405	1702
7	1062	1062	1062	2234	1919	1936	1616	1415	1655
8	1162	1161	1162	2188	2015	1912	1640	1486	1764
9	1262	1262	1262	2178	1919	1936	1740	1674	1883
10	1362	1362	1362	2179	2017	1979	1794	1676	1936
11	1462	1462	1462	2245	2039	2079	1920	1815	2057
12	1562	1562	1562	2207	2112	2169	2040	2005	2214
13	1662	1662	1661	2365	2217	2272	2140	2105	2320
14	1762	1761	1762	2414	2312	2377	2240	2093	2339

Table 5. Results for 50-customer Instances

# Vehs	K_2 for real-case Instances			K_4 for real-case Instances		
m	I1	I2	I3	I1	I2	I3
0	2927	3334	3892	1813	2610	2829
1	2352	2725	3432	1847	1961	2193
2	2163	2294	2739	1731	1643	1953
3	1800	2264	2388	1352	1493	1424
4	1509	1588	2135	1291	1413	1613
5	1448	1316	1822	1309	1582	1605
6	1377	1569	1618	1392	1511	1583
7	1472	1483	1705	1459	1515	1763
8	1572	1467	1779	1568	1542	1777
9	1655	1694	1830	1638	1748	1828
10	1768	1761	1945	1766	1803	1935
11	1868	2049	2028	1866	1948	2045
12	1968	2007	2128	1958	2048	2145
13	2056	2249	2235	2075	2148	2230
14	2165	2191	2379	2156	2142	2345

Table 6. Results for real-case Instances

Instance-class	δ	ϵ	Δ	η
25-customer Instances				
NC	0.36%	32.32%	0.33	5.14%
NR	1.54%	18.69%	1.67	15.32%
NRC	5.19%	26.62%	0.33	7.73%
50-customer Instances				
NC	0.00%	12.45%	1.67	1.31%
NR	0.00%	5.07%	7.00	14.02%
NRC	1.36%	23.01%	1.67	9.96%
real-case Instances				
$I(K_2)$	4.85%	14.95%	5.67	16.58%
$I(K_4)$	3.44%	18.31%	3.67	14.98%

Table 7. Results for comparison parameters

(Brandao, 2006). Moreover, continuing a restart from the same solution may hinder the search to advance to other parts of the solution space (Scheuerer, 2006). Therefore, the parameters were set as $\sigma_2 = 4/3 \cdot \sigma_1$, $\mu = \sigma_1/2$, which sets a limit of 2 as a maximum number of restarts from the same solution and 3 as a maximal number of restarts generally. Also $\sigma_1 = 25n$ and $\alpha = 10$ were experimentally found to be good values. In order to benchmark the developed heuristic, it has been run with the restriction of exclusive usage of own vehicles. The generated results of this version of the heuristic for the instances of Table 4 and 5 have been compared to the best known results for the used theoretical instances. Applying the cost rate *cd* to the best known solutions, the average worsening of results for the developed heuristic amounts to 4.8%. The number of vehicles of the own fleet as well as the maximal number of available subcontractors' vehicles are defined in advance. The volume of the requests that can be transferred using the fulfillment mode of freight consolidation is unlimited. As we analyze small academic problem instances, only one vehicle from a subcontractor paid on route basis ($m' = 1$) and one vehicle of a subcontractor paid on daily basis ($m'' = 1$) are available for these problems. Additionally, for the tested real-life instances $m' = 2$ and $m'' = 2$ are considered as reasonable values.

Fulfillment plans have been generated for different numbers of vehicles of the own fleet using the tabu search heuristic of Section 5. The remaining requests which are not fulfilled by using the own fleet are forwarded by the cheapest type of subcontraction for each of the remaining requests. The resulting total costs K for the academic instances are presented in Tables 4 and 5. The costs for real-life instances I with two and with four subcontractors' vehicles (accordingly K_2 and K_4) are presented in Table 6. Tables 4, 5 and 6 show that the number of own vehicles has a tremendous impact on the total costs and that a medium sized fleet should be aspired. Table 7 presents summarized results for achieved cost reductions by using a suitable number of own vehicles.

The improvement of the tabu search over the initial solution is calculated for each fixation of the number of vehicles for each instance. The relative improvement at an average for each problem class is denoted by η (Table 7). The values of η show that initially observed costs can be reduced by up to 15%.

The ITPP yields a lower bound for the PDPTW, since its search space contains that of the PDPTW. Next, the exclusive usage of own vehicles is postulated, while assuming enough transportation capacity of the own fleet. This leads to solving the tested examples as usual PDPTW-instances. Provided that the variable costs for the self-fulfillment of a set of requests are always lower than the costs for subcontracting the set, the solution of the PDPTW is identical to that of the ITPP. In this case the number of the used vehicles of the own fleet equals to the number of used vehicles in the optimal PDPTW solution. Planning scenarios with a higher number of vehicles are more expensive with respect to the entire cost structure, because the disposable request volume does not deplete the capacity of the own fleet while its fixed costs have to be covered. All planning scenarios with a lower number of vehicles are not solvable for the PDPTW and require subcontraction as the capacity of the own fleet is not sufficient.

Subcontracting might be cheaper than self-fulfillment due to special cost effects for the applied type of subcontraction. Let δ be the average reduction of the costs that the presented tabu search algorithm for ITPP achieves in comparison to the PDPTW with the same number of utilized own vehicles. The values of δ (Table 7) for each problem class show that the solution can only be slightly improved by a problem extension allowing subcontraction since the fixed costs of unused vehicles of the own fleet are included in the ITPP. These improvements mainly result from transferring some less-than-truckload requests or small bundles using freight consolidation or assigning a long route to subcontractors on daily basis. However, it causes that the own fleet is under-worked while its high fixed costs still have to be covered. Thus, reducing the number of own vehicles while assigning a part of the requests to subcontractors brings an essential saving of expenses. The saving has been calculated for each instance assuming the number of vehicles which yields the lowest costs for the ITPP. The average percentage of cost reductions is given by ϵ and Δ presents the average number of vehicles in the own fleet for the fulfillment plan with these lowest costs (Table 7). The values of Δ show that, while minimizing the total costs, the own fleet should be reduced but not eliminated, but Δ remains positive even for small 25-customer instances. Thus, from the perspective of cost minimization own vehicles should be used for some requests which can be profitably fulfilled in a vehicle tour. Due to the small number of own vehicles, their high utilization is then assured, so that fixed costs are covered and the break-even point is clearly overstepped. All other requests should be assigned to various subcontraction types.

Analysis of the real-case instances (K_4) with more available vehicles of subcontractors shows, that the fleet should be further reduced. It means that in the assumed cost structures subcontraction with payment on tour and on daily basis is mostly more expensive compared to the variable costs of the own fleet (as it occurs in a single planning process) but less expensive compared to the entire costs of own vehicles. In practice there are further, not cost-oriented aspects for and against an own fleet, e.g., service aspects and flexibility as important arguments to keep an own fleet.

7 Conclusions

The ITPP reflects practical situations of today's planning in freight forwarding companies. In this paper we have proposed a complex approach to vehicle routing extended by subcontraction, based on important assumptions of practical relevance. We have shown that combined usage of the own fleet and several subcontraction types indeed brings an essential cost reduction. Finally, we have found that the optimal number of vehicles in the own fleet can be approximated with respect to the total fulfillment costs. Thus, in the long-term planning of a freight forwarder, the size of the own fleet can be adjusted.

A key challenge for future developments is to analyze the dependence of the recommended portion of usage of the own fleet or particular subcontraction types on their relative cost levels. However, the cost structures are strongly dependent on the particular attributes of the solved problem instances. Anyway, the tabu search approach proposed in this paper yields good results for the ITPP in a reasonable time. Thus, the proposed solution method or similar approaches are useful in practice. But an analysis of existing optimization software for freight forwarders (Kopfer, Krajewska and Jurczyk, 2006) has shown that the problem is underestimated on the market. No software for vehicle routing and subcontraction not to mention advanced simultaneous optimization methods are offered at all. Thus, the complex process of planning in freight forwarding companies is still done manually (compare Jurczyk, Kopfer and Krajewska (2006)). Yet, as the logistic market gets more and more competitive, and the common possibilities to decrease transportation costs are almost utilized, freight forwarders slowly discover that they cannot work efficiently without structural changes. Amongst others, these include establishing fully automatic and efficient methods for the entire problem of operational transportation planning. Thus, algorithms solving this problem are becoming inevitable.

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