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Approaches for Modelling and Solving the Integrated Transportation and Forwarding Problem

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Approaches for Modelling and Solving the Integrated Transportation and Forwarding Problem

In line with the rising importance of 3rd and 4th party logistics the traditional routing and scheduling in freight forwarding companies is extended to a more complex integrated operational transportation planning problem. The extension consists in the additional possibility of forwarding requests to subcontractors on different terms.
Different types of theoretical approaches based on metaheuristics have been applied to the extended problem: from the savings algorithm up to tabu search and a comprehensive memetic algorithm. Those approaches also diversify with respect to different types of integration: from hierarchical to simultaneous planning. However, they have not been introduced into practice as yet.
We present an overview and a comparison of existing approaches, regarding the assumptions for modelling, the applied solution methods, and additional features of the approaches. Finally, we discuss the reasons for the gap between theory and practice.

1 Introduction

Freight forwarding companies have to face the fluctuating demand on the transportation market. Each day a variable number of requests is received from customers at a very short notice. On the other hand, the fixed costs of the own vehicle fleet, consisting e.g. in the wages for the drivers and amortisation costs, force a maximal utilisation of the fleet. Thus, the number of own vehicles is reduced and only a part of requests is fulfilled by the own fleet. All the other orders are outsourced. Using own vehicles for the execution of tasks is called self-fulfilment, while subcontracting means involving an external carrier.
However, the decision for each request is not reduced to "either-or" in the sense of an isolated "make-or-buy" decision supported by adequate comparison methods. Instead, the complex "make-or-buy" decisions evolve into the reference-analysis among the items involved [Wellenhofer-Klein 1999]. A major impact of such an analysis is noticed within the level and the structure of costs in the outsourcing enterprise [Zäpfel 2000]. The process of constructing a fulfilment plan with the highest possible quality corresponds to solving the integrated operational transportation and freight forwarding problem.
Caused by the tendency to outsource a part of the transportation tasks to external freight carriers, the need for covering the integrated operational planning problem in practice is soaring. In theory there exist only a few approaches that handle this

problem. We compare those approaches analysing their general assumptions and solution methods. Then, we discuss the discrepancy between theory and practice.
Section 2 presents the theoretical assumptions of the integrated operational transportation planning problem. In section 3 the metaheuristics used for the solution of the problem are analysed. Section 4 describes further features for solving the problem. Section 5 introduces the practical aspects of the problem. In the end, some conclusions are outlined in section 6.

2 Modelling the integrated operational transportation problem

Existing approaches for solving the integrated problem are totally different with respect to some assumptions, while other assumptions are common for all or most of the approaches. Particularly four main aspects should be considered: the attributes of requests that must be fulfilled by a freight forwarder, the main objectives of the transportation company expressed by the objective function, the definition of the planning problem for self-fulfilment, and the types of subcontracting that occur in the integrated problem. In the following sections the above mentioned aspects are discussed for different existing approaches.

2.1 Requests

In all known approaches for the integrated operational transportation problem a customer request is assumed to be a delivery request describing a single transportation demand, which results in a direct transportation process without transhipment, i.e. carrying a less-than-truckload packet beginning with the pickup operation and ending with the delivery operation. Splitting the loading is not permitted unless the volume of a single request is higher than the maximal vehicle capacity. The location of pickup and the location of delivery are specified as well as the quantity to be moved. In almost all approaches known from literature the location for pickup and the location for delivery of a request are different. Only in [Chu 2005] a simplified form of requests is modelled, in which all pickup operations take place in the depot (starting and ending location for all vehicles of the own fleet) and the goods are transported from the depot to their destination. Furthermore, time window constraints for the loading and unloading operations are incurred. All the approaches assume hard time windows, i.e., no delays are allowed. Then, a single request *i* can be characterised as

$i = (q_i, rev_i, p_i^+, p_i^-)$
where:
q_i quantity to be transported

rev_i	revenue for the request execution
p_i^+, p_i^-	pickup (p_i^+) and delivery (p_i^-) operation, which is defined as:

$p_i = (l_i, b_i, e_i, s_i)$

where:

l_i	location of the operation
(b_i, e_i)	time window for the operation
s_i	time duration of the operation

2.2 Objective functions

The aspired goal of the freight forwarder is to maximise the difference between the transaction volume and his costs. The related decisions are to be made on three planning levels: the operational, tactical and strategic level. The amount of the turnover from the request execution mainly results from the constant long-term tariffs for the customers and thus belongs to the tactical or strategic planning. Similarly, most mid- or long-term decisions concern the available resources, associated e.g. with the number of owned vehicles. The planning of the execution of the requests, which is the subject to discussion in this paper, takes place on the operational level. The main objectives are to find a partition which splits the request portfolio into fulfilment clusters (self-fulfilment as well as different types of subcontracting) and to solve the planning problems inside the clusters, so that the total execution costs are minimised [Kopfer, Pankratz 1999]. Thus, global cost-oriented objective functions that minimise the sum of the costs are considered. The different functions used in the analysed approaches are presented in table 1. The used variables are defined in table 2. The functions and the variables are discussed in detail in the following two sections.

Table 1: Objective functions

Approach	Objective function
[Chu 2005]	$\sum_k cf_k + \sum_i \sum_j \sum_k cd_k * d_{ij} * x_{ij}^k + \sum_i ce * y_i * d_{i+i-}$
[Schönberger 2005]	$\sum_i \sum_j \sum_k cd_k * d_{ij} * x_{ij}^k + \sum_i ce * y_i * d_{i+i-} * \gamma_1$
[Stumpf 1998]	$\sum_i \sum_j \sum_k cd_k * d_{ij} * x_{ij}^k + \sum_k w_k * p_k + \sum_{dr} w_{dr} * p_{dr}$
[Pankratz 2002]	$\sum_i \sum_j \sum_k cd_k * d_{ij} * x_{ij}^k + \sum_k ct_k * t_k + \sum_i \sum_j cfr_{d_{ij}, q_{ij}}$
[Savelsbergh, Sol 1998]	$\sum_{i, i \neq l_k} \sum_j \sum_k cd_k * d_{ij} * x_{ij}^k + \sum_k \sum_j (cd_k + F) * d_{l_k j} * x_{l_k j}^k$

[Greb 1998]

$$\sum_i \sum_j \sum_k cd_k * d_{ij} * x_{ij}^k + \sum_k ct_k^t * t_k + \sum_i ce * y_i * d_{i+i-} * \gamma_2$$

Table 2: Variables used

k	a vehicle
dr	a vehicle driver
cd_k	tariff rate per distance unit of the vehicle k
ct_k	tariff rate per time unit of the vehicle k
cf_k	fixed costs of the vehicle k
ce	tariff rate per distance unit if a request is charged by an external carrier
$cfr_{d_{ij}q_{ij}}$	freight rate dependent on the distance and quantity of a bundle transported between accordant locations of operations i and j
d_{ij}	distance between accordant locations of operations i and j (i^+ refers to pickup and i^- to delivery location of i, and k^+ to starting location of a vehicle k)
q_{ij}	the quantity of a bundle transported between accordant locations of operations i and j
t_k	time length of the route for vehicle k
x_{ij}^k	binary variable, which equals to 1 if the path between accordant locations of operations i and j is used by the route of vehicle k, 0 else
y_i	binary variable that equals to 1 if request i is satisfied by an external carrier, 0 else
γ_1, γ_2	adjustment parameters
w_k, w_{dr}	per diem allowance for the vehicle and the driver
p_k, p_{dr}	basement rates for the percentage of per diem allowance paid dependently on time consumption
F	a large number for penalty costs

2.3 Self-fulfilment cluster

The own fleet may be a homogeneous or a heterogeneous set of vehicles. In case of a homogeneous fleet, the tariff rate per distance or time unit as well as the fixed costs per vehicle (accordingly cd_k, ct_k, cf_k) are equal for all vehicles; all vehicles are stationed in the same depot (l_k is constant) and have the same predefined maximal capacity Q_k. This is the case for [Schönberger 2005] and [Pankratz 2002]. For all the other approaches, a heterogeneous fleet is assumed. The parameters that are subject to differentiation are illustrated in table 3.

Table 3: Differentiation criteria for the heterogeneous vehicle fleet

Approach	Parameters that differ for different vehicles
[Chu 2005]	Q_k, cf_k, cd_k
[Stumpf 1998]	Q_k, cd_k, fixed costs (dependent on w_k, p_k (and w_{dr}, p_{dr} for the associated drivers))
[Greb 1998]	Q_k, cd_k, ct_k, l_k (split into different starting and ending locations l_k^+, l_k^-)
[Savelsbergh, Sol 1998]	Q_k, l_k , availability in the time intervals

Own vehicles are associated with fixed costs. In fact these costs do not belong to the operational planning level but they may result in additional constraints that force the maximal capacity utilisation of the fleet. Otherwise such costs are involved into the objective function in some approaches. Only [Chu 2005] sums up the fixed costs, cf_k, of all vehicles. The approach in [Stumpf 1998] assumes that only a part of the fixed costs (consisting of per diem allowance for a vehicle and associated drivers) is paid, corresponding to the part that the vehicle has de facto been used. This assumption is of practical relevance if the fleet is exploited in combination with other transportation entities under the condition that fixed costs are also shared among the transportation entities. Therefore, it is not necessary to aspire a high degree of utilisation of the vehicles. Otherwise, in [Savelsbergh, Sol 1998] the goal of reaching the maximal capacity utilisation of the own vehicles is included in the objective function of the model. The usage of a vehicle is connected with penalty costs F which assure that the number of vehicles is minimised and thus their utilisation is maximised.

The variable costs for the own fleet depend in all approaches on the tour length measured by the distance criterion. In [Greb 1998] and [Pankratz 2002], the time criterion for the tour length is additionally included. The costs for the usage of own resources are calculated on the basis of a constant tariff per distance (and time) unit (accordingly cd_k and ct_k).

The tour length results from routing and scheduling of the vehicles. The research for the planning of direct delivery requests is mostly focused on the pick-up-and-delivery-problem-with-time-window-constraints (PDPTW). All the approaches, except [Chu 2005] which is based on vehicle-routing-problem-with-time-window-constraints (VRPTW), consider the PDPTW. Additionally, in [Greb 1998] so called service operations are defined for the own fleet. After a certain period of time each vehicle has to come to its home location for the execution of these service operations. In [Greb 1998] there exists no depot, all the routes start and end with the service operation, which are associated with certain locations (accordingly l_k^+, l_k^-).

2.4 Sub-contraction cluster

In contrast to the self-fulfilment cluster, there exist no standardised ways to calculate the costs for the external execution of requests in the sub-contraction cluster. The different ways for the calculation of the costs of incorporating an external freight carrier reflect different levels of integration and complexity. It can be differentiated between types that lead to a mere calculation of the freight costs and types where an optimisation process is involved. In each existing approach only one single form of subcontracting is introduced, i.e., no approach combines different ways of freight calculation for different freight carriers.

The easiest form of sub-contraction is a simple shifting of requests, which means selling a single request independently from all the other requests to an external freight carrier [Chu 2005]. The requests are forwarded on uniform conditions, based on a linear, distance-dependent function. The price for the fulfilment of one request is calculated by the usage of the fixed tariff ce per distance unit for the distance d_{i+i-} between the pickup and the delivery location (l_{i+},l_{i-}) of the request i.

Other approaches assume complete tours to be shifted to subcontractors [Savelsbergh, Sol 1998, Stumpf 1998]. This situation is of practical relevance, if an entire vehicle is hired from the subcontractor. Vehicles can be hired on different terms. In [Stumpf 1998] it is assumed that the vehicles of the third party are rented in the short term if they are needed. Thus, a variable number of vehicles is possessed. In [Savelsbergh, Sol 1998] a part of the vehicles is rented permanently, i.e., they cannot be returned, while the other part is hired at short notice and sent home if the number of requests decreases.
The cost calculation for the hired vehicles is in both cases the same as for the own fleet. The costs depend on the routes that have been built. The routes are built during the process of assigning and sequencing the requests. In [Stumpf 1998] the fixed costs of the hired vehicles are covered partly according to the working time of vehicles and drivers and the variable costs are based on the tariff rate cd_k per distance unit. In [Savelsbergh, Sol 1998] only the variable distance-dependent costs are summed up but the minimal number of hired vehicles is aimed by the usage of penalty costs F.

The approach of parametrised sub-contraction, introduced by [Schönberger 2005] and [Greb 1998], improves simple shifting by adjusting the freight using different criteria, either weight or distance.
In [Schönberger 2005] an additional route for an artificial vehicle is constructed. All requests that are assigned to the sub-contraction cluster are planned into this route. Next, the distances between the pickup location and the delivery location d_{i+i-} are

calculated for each request i in the sub-contraction cluster as if the requests were forwarded to the subcontractor separately on uniform conditions (simple shifting). Then, an adjustment parameter is calculated [Schönberger 2005]. Let k^* be the artificial vehicle. Then, the adjustment parameter equals to: $\gamma_1 = \frac{\sum_i \sum_j d_{ij} * x_{ij}^{k*}}{\sum_i d_{i+i-} * y_i}$, which is the quotient of the driven distance of an artificial route and the sum of all distances in pairs between the pickup and the delivery locations for all the requests in the sub-contraction cluster. In order to get the fulfilment costs for involving an external freight carrier, the amount of costs for the simple shifting is multiplied by the adjustment parameter. If the pickup and delivery locations of different requests are close together, then the route of the artificial vehicle is relatively short, i.e. the selected requests fit together to form an attractive bundle of requests. Then it holds $\gamma_1 < 1$, and the freight costs decline in comparison with the simple shifting method. If the requests do not fit together, then $\gamma_1 \geq 1$ and the costs for subcontracting increase.

In [Greb 1998] an adjustment parameter for freight calculation is defined as the quotient of the volume transported and the average vehicle capacity of the own fleet. If K refers to the number of vehicles in the own fleet, then $\gamma_2 = \frac{q_i * K}{\sum_k Q_k}$. As in the previous approach, the parameter is then multiplied by the costs resulting from simple shifting. As $q_i < \frac{\sum_k Q_k}{K}$, it is always true that $\gamma_2 < 1$. Using the parameter γ_2, the freight calculation takes into account the percentage of the vehicle capacity that is used by the request volume.

The most complex way to incorporate an external logistics service provider results from the so called freight flow consolidation [Kopfer 1984, Kopfer 1990, Kopfer 1992]. This way of freight calculation is based on the service that is fulfilled by the freight carrier. It is the most suitable way for the incorporation of independent carriers who combine the received requests with requests of other forwarders and perform a transportation planning on their own. The integration of this type of subcontracting into the operational transportation planning is introduced in [Kopfer, Pankratz 1999] and an approach for solving the integrated problem is presented in [Pankratz 2002]. The problem belongs to the multi-commodity network flow problems: the less-than-truckload requests are bundled and a least cost flow through a given transportation network is searched for each bundle which is transferred to a subcontractor.

The approach of [Pankratz 2002] builds bundles of requests which are transferred to carriers and are subject to freight calculation and optimisation. For each bundle of

requests a directed spanning tree representing a minimal cost flow of goods from the pickup locations to the delivery locations of all involved requests is searched. Time window constraints are omitted in the approach for freight calculation in [Pankratz 2002]. Freight flow consolidation in presence of time windows has been presented in [Schönberger, Kopfer 2005] by the determination of origin/destination paths; this has not been applied to the integrated problem as yet. The freight flow consolidation problem itself is a combined non-linear flow and assignment NP-hard optimisation problem. There are no fixed costs connected with this type of subcontracting, only the variable costs $cfr_{d_{ij}q_{ij}}$ that depend on two variables: distances and amounts of transported goods. Typically, the costs are degressive with respect to increasing capacity of the bundled goods, which results in a non-linear freight function.

3 Solving the integrated operational transportation problem

There are several approaches for solving the integrated problem with different types of integrating the sub-contraction and the self-fulfilment cluster. The integration types presented in 3.1 do not occur in the pure form, but they also depend on the used solution method. The methods themselves and their comparison are presented in the section 3.2.

3.1 Integration of the clusters

The integrated operational transportation problem comprehends three sub-problems: splitting the requests into fulfilment clusters, cost optimisation in the self-fulfilment cluster (i.e. assignment of requests to vehicles as well as vehicle routing and scheduling), and cost optimisation (or calculation) in the sub-contraction cluster (with possibly different types of subcontracting). Different methods of combining these three sub-problems in a solving procedure result in different forms of integration of the self-fulfilment and the sub-contraction cluster. There are three main types of integrating: hierarchical, semi-hierarchical and simultaneous integration. The types of integration are outlined in figure 1.
In case of hierarchical integration (multi-stage planning), the request portfolio is split into two subsets that are assigned to the clusters by applying a rule which does not take into account the subsequent optimisation in the subsets. After that the cost optimisation (possibly cost calculation for the sub-contraction) takes place inside the clusters. Such an approach is presented by [Chu 2005]. Due to the tariff rate *ce* used in [Chu 2005], the costs for sub-contraction are always higher than the costs for the self-fulfilment. As the volume of requests exceeds the available capacity of the own fleet, while time window constraints prevent the extension of the routes,

subcontractors have to be involved. Thus, the main idea of hierarchical planning is in this case to choose as many requests as possible for the own fleet, on the basis of a costs assessment, and then to optimise the routes. Afterwards, the costs of sub-contraction are just calculated.

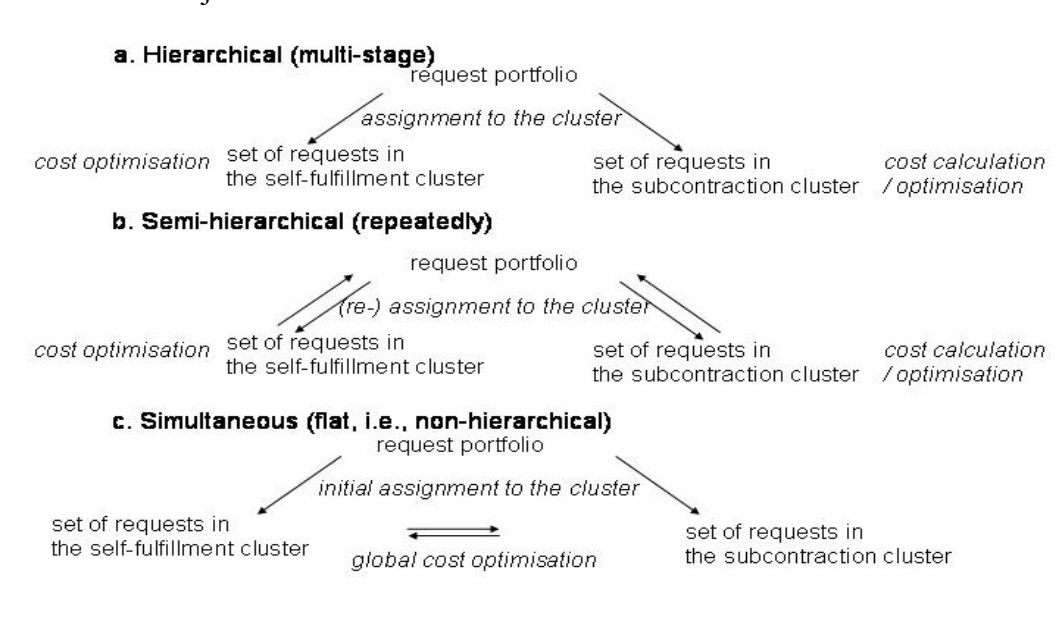

Figure 1: Different types of cluster integration

The semi-hierarchical approach, introduced by [Pankratz 2002], runs repeatedly. In the first step the procedure in [Pankratz 2002] builds sets of requests (bundles) which are to be handled in a common tour. Then these bundles are assigned either to the self-fulfilment cluster or the sub-contraction cluster. Next, the optimisation procedures run in the clusters for each bundle separately. They perform the sequencing and scheduling for each bundle in the self-fulfilment cluster and the flow optimisation for each bundle in the sub-contraction cluster. Afterwards, using a Genetic Algorithm new solutions are generated by reassigning the requests to the clusters. The bundles of these new solutions are also optimised and evaluated, and so on. The time consumption of these procedures is strongly reduced by performing independent computing of different division scenarios, i.e.: the costs for each division scenario are assessed for the round trips in the self-fulfilment cluster and the spanning trees in the sub-contraction cluster. Only the sets with the best assessments are chosen for modification to find the next possible division. As the optimisation tasks in both clusters cause high time-consumption, the semi-hierarchical planning approach allows changes concerning the division of the request portfolio into the clusters only on the basis of assessments and not of exact optimisations of the sub-problems of the two clusters.

The simultaneous (flat) integration, e.g. in the approaches of [Schönberger 2005] and [Greb 1998], tries to minimise the total costs of self-fulfilment and sub-contraction

holistically. The metaheuristics used in the presented flat approaches assume that the requests are initially assigned to one of both clusters. Then the cost optimisation procedure takes place by altering this initial solution in several iterations. In each iteration of the optimisation procedure, the integrated problem is not divided into different sub-problems which are solved by assessment, but there exists a problem representation with a complete implementation plan for each request. The modification of such a plan for the next iteration runs on the global level. In order to get the next modified plan the requests are shifted not only at other positions within one cluster, but also shifting from one cluster to a position in another cluster is possible. Consequently, a request can be planned out of the sub-contraction cluster and assigned to a route of an own vehicle. As both above mentioned flat approaches propose the parametrised sub-contraction method, the costs in the sub-contraction cluster have to be recalculated after each iteration.
In particular, [Stumpf 1998] and [Savelsbergh, Sol 1998] can be classified as simultaneous planning approaches, as there exists no difference between planning the own vehicles and the vehicles of subcontractors in those algorithms. The optimal routes are aimed and the requests are shifted between all the routes as well as within one particular route.

3.2 Solution methods

As the integrated operational transportation problem is NP-hard, finding the optimal solution for a greater number of requests is nearly impossible. Thus, sub-optimal solution methods have been proposed that use metaheuristics. An overview of the used metaheuristics is presented in table 4. We briefly outline the main characteristics of each metaheuristic.

In [Chu 2005] the so called TL-LTL heuristic, based on the savings-algorithm, is introduced. If the total demand is higher than the capacity of the own vehicles, this algorithm selects of a group of customers who will be served by external freight carriers. Being greedy in the first step, the requests with the lowest freight costs are assigned to the sub-contraction cluster.
In the second step the possible savings resulting from consolidating the initial solution are considered. The consolidation is based on shifting some requests from the sub-contraction cluster to the routes of the own fleet with subsequent inter- and intra-route exchanges in the self-fulfilment cluster.

Table 4: Algorithms and metaheuristics introduced

[Chu 2005]	TL-LTL heuristic
[Schönberger 2005]	memetic algorithm

[Stumpf 1998]	local search techniques and set-partitioning algorithm
[Pankratz 2002]	hybrid genetic algorithm
[Savelsbergh, Sol 1998]	branch-and-price algorithm
[Greb 1998]	tabu search

The branch-and-price algorithm presented by [Savelsberh, Sol 1998] is based on a column generation scheme. An additional feature concerns the reduction of computational complexity, which is caused by the rising number of columns in the pool. Some threshold $D_{\max} \leq 0$ is defined. Before the pricing problem is resolved, the pool is cleaned. All columns with actual reduced costs higher than D_{max} are removed from the pool.
The efficiency of the algorithm is improved by modifying the computation scheme of the pricing problem. The basic idea is to solve the pricing problem approximately as long as it produces columns with negative reduced costs and only to solve the pricing problem optimally when solving it approximately fails to produce columns with negative reduced costs [Savelsbergh, Sol 1998] (it is expected that the optimal solution of the actual restricted problem also refers to the master problem). As an approximation technique, a cheapest insertion algorithm is used.

In [Stumpf 1998] three local search techniques are applied to find a solution: tabu search, threshold accepting and the deludge algorithm. Then the results are compared with the introduced set-partitioning algorithm.
All local search techniques need a starting solution. Here, two types of heuristics for seeding an initial solution are employed: savings algorithm and cheapest insertion algorithm. Three different types of neighbourhoods are used for local search. *S1*-neighbourhood results in switching a single request inside one tour or to swap it between tours. In *Sn*-neighbourhood *n* different requests are displaced inside and between the routes at once. As both neighbourhoods are used vicissitudinously, the *Kn*-neighbourhood combines them and defines the exchange moment between them.
In order to find an optimal solution of the set-partitioning problem, the column generation technique is used to generate the set of feasible routes. From this set, a subset is chosen, so that the fulfilment costs are minimal and each request is executed by exactly one vehicle. For the optimisation of the tours that belong to this subset, a heuristic based on the techniques of genetic search is used.
A tabu search procedure is proposed by [Greb 1998]. An insertion heuristic is used to find an initial solution. Two types of neighbourhoods are defined: swapping pairs of requests between two routes and shifting a single request from one route to another one. They correspond to *S1*- and *S2*- neighbourhoods defined by [Stumpf 1998].

In [Schönberger 2005] a memetic algorithm for the integrated problem is presented. In order to start the algorithm, an initial population has to be constructed at first. Here, a four-step construction procedure seeds an initial population.
An individual (chromosom) represents a complete solution, i.e., the assignment and sequencing of requests (incl. sequencing of the dummy route in the sub-contraction cluster) are coded in the representation.

In [Pankratz 2002] a hybrid genetic algorithm, combining a genetic algorithm with an insertion heuristic, is introduced. The genetic algorithm generates bundles of requests which are treated as tours for self-fulfilment or bundled orders for sub-contraction. For each bundle an insertion heuristic solves the resulting travelling salesman problem, respectively the resulting freight consolidation problem. The found solutions of the partial problems are combined to a total solution of the integrated operational transportation planning problem. Then the Genetic Algorithm searches for a better bundling of the requests.
As well as in the previously mentioned approaches [Greb 1998, Stumpf 1998], the cheapest insertion algorithm creates several individuals for the population. However, as the optimisation procedure for own-fulfilment as well as for the sub-contraction cluster is assumed, the cheapest insertion algorithm is extended so that the requests are planned into the round routes or into the spanning trees.
An individual of the Genetic Algorithm only represents an assignment of the set of requests to transportation entities, no sequencing is included. In order to evaluate the chromosomes (individuals), an assessed sequencing is applied. Thus, each individual possesses an additional data-structure containing the routes and spanning trees of a scheduling plan, constructed by the cheapest insertion algorithm. As it is not newly constructed but only adjusted to modified clusters, the main advantage of such a representation is that the computational complexity for decoding a genotype to a phenotype (while evaluating a complete solution) is strongly reduced.

As we have presented, different techniques are used to solve the variant problems of operational transportation planning. They differ regarding the complexity of the used method and the quality of the generated solution. There exists a trade-off between the metaheuristics used and the complexity of the problem formulation. I.e., in case of [Savelsbergh, Sol 1998] and [Stumpf 1998] the round routes that are introduced for the sub-contraction cause that the models of the integrated operational transportation planning are simplified to the PDPTW (with heterogeneous fleet and several depots). Therefore, the algorithms are based on the column generation technique that for mid-sized PDP-problems is able to produce better solutions than local search techniques or genetic algorithms. On the other hand, for complicated approaches regarding e.g. parametrised sub-contraction or freight flow consolidation, the mentioned heuristics are appropriate and deliver promising results of good quality.

It is impossible to compare the results directly because of the different problem definitions, test instances, and different cost structures of the approaches. However, all the approaches present comparisons of their results to existing benchmark instances that assure their high quality.

4 Further features of the presented solution methods

The existing approaches to the integrated operational transportation planning problem have not only focused on the core of the problem, which means searching for the request portfolio that optimises associated execution costs, but also introduced further features in the problem processing. We briefly present these features.

An interactive approach arises from the thesis, that a mechanic approach ignores the principle that computers are useful tools but they should not be relied on to make decisions automatically in complex situations. Human problem solvers are better at recognizing patterns, finding an acceptable balance between conflicting objectives, using past experiences of similar problems, applying imagination to find unusual solutions, overriding rigid constraints and generally applying subjectivity to a problem [Waters 1984]. Thus, an interactive approach allows an interaction of a human solver with the system solver. Modifications, which are done by the human solver in the established solution, are recognised and the interactive algorithm continues its optimisation task under consideration of the additional information and the problem specific hints given by the user [Kopfer, Schönberger 2002]. Such an approach to the integrated operational transportation planning problem is introduced by [Greb 1998]. A interactive computer based routing system is implemented and described in [Greb 2002]. The following features are included into the system: adding or cancelling a vehicle or a single request, assigning a request compulsory to the sub-contraction cluster as well as to a particular route, manipulating an initial or optimal plan (e.g. fixing the assignment of some requests or tours).

The need for a dynamic approach rises as the requests from the clients are usually sent to a freight forwarder short-dated and, on the other hand, fast request execution of high flexibility is awaited [Kopfer 2005]. In case of a dynamic approach the planning horizon is limited. The input data such as travel times or demands depend explicitly on time. From the entire set of constantly arriving requests only those are planed, for which the time window constraints are situated within the current planning horizon [Pankratz 2002]. A complete request portfolio is not known in advance. New requests come successively and irregularly. A dynamic algorithm continues the optimisation task considering additional information and the actual state of fulfilment. The dynamic approach presented by [Pankratz 2002] is based on rolling horizons.

Both mentioned approaches consist of a sequence of static partial problems. For the dynamic approach, a feasible solution for each of these static problems has to be found, which can be implemented immediately. Using the interactive approach, the real goal is not to find a solution for each partial problem. Only a reasonable solution of the overall problem has to be found making use of the solutions of the partial problems. The preliminary solutions are combined and adapted using the specific strengths of the human and the automatic problem solver [Kopfer, Schönberger 2002].

In [Schönberger 2005] some extensions of practical relevance have been introduced, in order to compare the resulting scenarios with the basic problem. At first, it is assumed that some requests are prohibited to be outsourced to subcontractors. Such requests have to be fulfilled with the own vehicles and are called compulsory. Secondly, constraints which are limiting the capacity of the own resources are added to the model. The added capacity restrictions refer to the limitation of the length of single tours, to the entire length of all tours, to the capacity of loading, and to the number of available drivers. [Schönberger 2005]. By modifying these restrictions, experiments concerning the amount of requests that have to be subcontracted can be performed. As a third feature, the possibility of postponing some requests to the next planning period is enabled. If a request is postponed, there exist no fulfilment costs for that request but also the turnover for the request execution is not yet realised. Thus, to evaluate the approach properly, the objective function is extended to the difference between the revenue from request execution and the variable fulfilment costs. The subset of requests from the overall set is wanted, such that the profit is maximal. Evaluating different modifications of the problem with additional restrictions and extensions of the above kind is useful for the analysis of the impact of changing the flexibility of the solution process.

5 Practical aspects

In practice, the complexity of the integrated operational transportation planning problem is even higher than in the presented theoretical models. Most freight forwarders apply several forms of paying for outsourced services alternatively. I.e. there are different types of sub-contraction that should be combined at a single blow by using different subcontractors. Till now, no theoretical approach proposes an integrated solution where several types of sub-contraction are combined. All theoretical approaches we have found in literature involve only one single type of sub-contraction. Moreover, the practical and theoretical types of sub-contraction are not always corresponding.

An analysis of the situation of forwarders has shown that for the sub-contraction of less-than-truckload request bundles between independent partners the freight flow

consolidation approach (without time window constraints) remains of highest practical relevance. There usually exist fixed tariffs under non-linear consideration of distance, weight of a bundle, and the type of goods that should be transported. The price for subcontracting is quoted on the basis of such tariffs, although it can be modified dependent on the driven direction.

In case of bundles with full-truckload there are two methods of sub-contraction which come into consideration. As already mentioned, complete tours can be shifted to subcontractors on a fixed tariff basis which is mostly dependent on the distance of the round route to be driven. There are no fixed costs connected with such usage of foreign vehicles, but the tariff rate for the variable costs is higher in comparison to usage of the own vehicle fleet as it covers a part of maintenance costs. The second possibility consists in paying the subcontractors on a daily basis. In this case an external freight forwarder gets a daily flatrate and has to fulfil all the received requests up to an agreed distance and time limit. Costs related to both sub-contraction possibilities and typical costs for self-fulfilment are shown in figure 2.

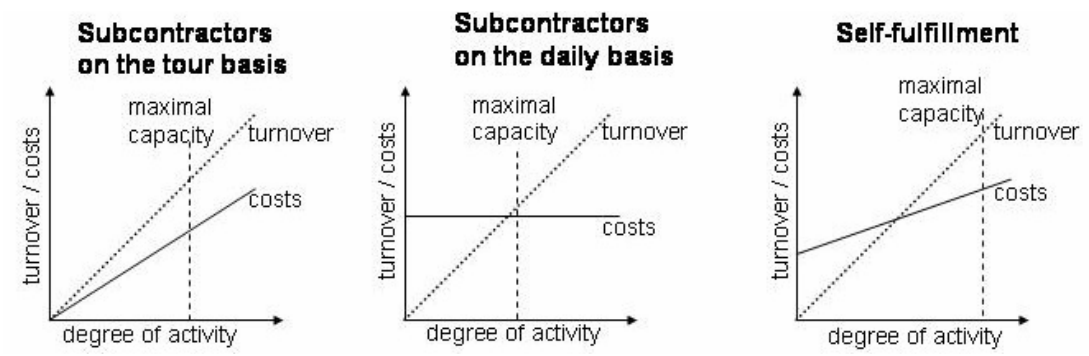

Figure 2: Comparison of costs for different types of sub-contraction and self-fulfilment [Compare Jurczyk, Kopfer, Krajewska 2006]

Solving the integrated operational planning problem in practice has to be done dynamically, because there is a constant flow of request orders to the freight forwarder during the planning period. Concurrently, because of several additional practical and volatile constraints, the interaction of a human and a system solver are inevitable. Thus, the existing dynamic and interactive approaches should be combined or a new interactive and dynamic approach should be developed.

Our analysis of existing operational transport optimisation software systems for freight forwarders has shown that the problem is underestimated. There is no suitable system for freight consolidation on the software market, and a system for the integration of the planning problems for self-fulfilment and subcontracting is not available anyway. Due to the lack of software, the problem of splitting the request

portfolio is solved manually, and there is only an appropriate support for the sub-problem in the sub-contraction cluster. But finding good solutions for the global superordinate problem may be even more important than generating high quality solutions for one sub-problem. In practice, planning of the integrated problem is made hierarchically (compare [Jurczyk, Kopfer, Krajewska 2006]). In the first place the requests with the highest contribution margin are planned into the self-fulfilment cluster. Here, schedulers can be supported by software that optimises the sub-problem of building round routes. Then the other types of sub-contraction are considered, also in a hierarchical order. The advantages of simultaneous planning are lost.

6 Conclusions

The above presented analysis of existing approaches shows that the integrated operational transportation planning problem is not defined uniformly. The theoretical approaches differ regarding the assumptions for the self-fulfilment cluster as well as in terms of sub-contraction. Specific metaheuristics, assuming different types of problem integration with different degrees of complexity as well as further features for the solution of the integrated problem have been developed. However, these theoretical approaches do not fully correspond to the practical issues of the problem and are not applied in practice. The integrated operational transportation planning problem reflects the core of today's operational planning in freight forwarding companies. As the logistic market gets more and more competitive and the possibilities to decrease costs are almost exhausted, freight forwarders discover that they cannot work efficiently without structural changes which include establishing computer-aided and efficient planning. The usage of systems offering support for the solution of the integrated operational transportation planning by producing high quality fulfilment schedules is becoming inevitable.

7 Literature

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