PICKUP AND DELIVERY SELECTION WITH COMPULSORY REQUESTS

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ABSTRACT

The operational planning decisions of a carrier consist of accepting transport requests of customers and constructing daily vehicle routes. Several customers may have less-than-truckload requests to be transported between two specified locations: these customers are consolidated into vehicle tours by the carrier. However, a carrier has only a limited capacity within his own vehicle fleet. Therefore he can only serve a selection of clients. Transport requests of clients are only accepted if they contribute to a higher total profit. A paired pickup and delivery selection problem is hardly investigated in literature. Due to long term contract or for other commercial reasons, some of the requests cannot be neglected, even if they do not contribute fully to profit. This practical aspect is modeled with the Pickup and Delivery with selection of customers. A mixed-integer programming formulation is given. It is indicated how the problem is solved by means of a meta-heuristic, more specifically a tabu-embedded simulated annealing algorithm.

INTRODUCTION

Road transport is performed in two modes: the 'own account' mode and the 'hire and reward' mode. In the 'own account' mode, the owner of the vehicles and of the moved goods are identical. But many companies outsource their transport activities to reduce overhead costs. Logistics service providers are hired to execute the transport. Such companies are called freight carriers, which operate in the 'hire and reward' mode. Operational planning problems relate to decisions as: crew scheduling (assignment of crews to vehicles or transshipment facilities); empty balancing (preparation of the operations for the next planning period, and vehicle routing and scheduling (scheduling of the services for the pickup and delivery phases).

Pickup and delivery planning problems comprise the allocation of resources for fulfilling the tasks within a region for a given planning period. A transportation plan many times is solved as a vehicle routing and scheduling problem. But, in fact, before the problem is solved, the carrier has to decide whether a certain transport request is accepted for completion and, if yes, also the mode of completion (own equipment or another carrier who receives a charge) is selected.

The request selection is evaluated by means of corresponding revenues and costs. The cost evaluation of a request requires the determination of a transportation plan (routing). In some cases, it is possible to decide for each transport request whether it is fulfilled by the carrier or by a third party LSP. But sometimes contracts prohibit to outsource specific transport requests to a LSP. The customer requires fulfillment of the transport request by the carrier. Such a request is called a 'compulsory request'.

Several actors are involved with the transport of goods. To model freight transport, the actors involved in the decision making process have to be represented. In Maes et al. (2011) a conceptual framework is presented to model freight transport. The key actors in the framework include firms, carriers, and forwarders. These actors allow the model to work on an activity-based level, focusing on the different activities of each actor. The decision making process of carriers is one of the key aspects in modelling logistic decisions in a behaviour based transportation model. When modelling at an activity-based level, the behaviour of carriers needs to be taken into account. One of the decisions a carrier has to make is whether or not to accept transport requests he receives. Furthermore, he needs to plan the sequence of pickups and deliveries to optimize the use of vehicles given time and capacity limitations.

A carrier faces the daily problem of optimally scheduling his transport orders. Each day a carrier receives transport requests from his clients, which have to be executed within a certain time period. To obtain a maximal profit, the carrier has to group certain orders and create an optimal sequence of paired pickup and delivery tasks. In literature, this problem is called a pickup and delivery problem (PDP). Within a PDP mostly it is assumed that all requests have to be fulfilled. In reality a carrier may refuse a transport order, when he believes the order is not profitable. Sometimes non-profitable orders are accepted, due to reasons of competition or long-term commitment to a client. In such a case a carrier accepts the transport order which is less or non profitable, because it will generate other requests with a profit sufficiently high to offset the loss of the first transport order. In our conceptual framework only current requests are taken into account and the
possible loss of future requests is ignored. Actors take decisions for one simulation period at a time. If a request is accepted, it will generate revenue when the transport is completed. When a carrier has to decide whether to accept a certain request, the problem is defined as a Pickup and Delivery Selection Problem (PDSSP). This problem has been introduced by Schönberger et al. (2002).

LITERATURE REVIEW

The PDP is a generalization of the vehicle routing problem (VRP), which is a generalization of the traveling salesman problem (TSP) (Mitrovic-Minic, 1998). All of these problems have been widely investigated and numerous extensions have been developed. In a VRP generally all trip requests either originate or terminate at a single depot. In a PDP the trip requests are made between two locations that are outside the depot. In this section the division between paired and unpaired pickup and delivery points is used as in Parragh et al. (2008). Pickup and delivery vehicle routing problems are characterised with unpaired pickup and delivery locations. In this case an identical load is considered, and each unit picked up may be used to serve a delivery request. A classic pickup and delivery problem on the other hand, has paired pickup and delivery locations. Every request is associated with a paired origin and destination location and a specified load.

The focus of the literature review is on a specific case of the PDP, the pickup and delivery selection problem. In a PDSP not all transportation requests have to be fulfilled. A carrier receives transportation requests during the entire day. When additional requests are received, a decision has to be made whether the carrier will take the responsibility of the transport or not. The PDSSP is NP-hard as it is a generalization of the travelling salesman problem. In literature this problem is not often investigated, but several variations on the problem exist. Two main bodies of routing literature are relevant for the PDSSP. On the one hand the VRP with profits and on the other hand literature concerning PDP. The PDP is more relevant to the problem presented, however profit maximization has been more applied to VRP. In the next subsection first several vehicle routing problems with profits are presented, as the PDSSP may be seen as a variation of these problems. Next, techniques used on the PDP are discussed which might be useful for the PDSSP. To end this section the available literature on PDSP and variants of the problem are given.

VRP with profits

Feillet et al. (2005) give an overview of the TSP with profits. A distinction is made between three problem types, depending on the objective function. A first problem is called the profitable tour problem (PTP), which has as objective to simultaneously find a tour that minimizes travel cost and maximizes the collected profit. The problem studied in this paper, the PDSSP, may be situated in this category. The second problem, the orienteering problem (OP), has as objective to maximize the collected profit while travel costs do not exceed a preset maximum cost. The last problem is known as the prize-collecting TSP (PCTSP). Here the collected profit is defined as a constraint, ensuring that the profit may not be smaller than a preset value.

Also vehicle routing problems exist for which it is not necessary to visit every node on the graph. The VRP with profits is the extension of a TSP with profits to multiple vehicles. Aksen and Arras (2005) study the single-depot capacitated VRP with profits and time deadlines (VRPPTD), in which it is not necessary to visit all customers. Their objective is to find the number and routes of vehicles to maximise the total profit.

The Multiple Tour Maximum Collection Problem (MTMCP) of Butt and Ryan (1999) is closely related to the VRP with profits. Due to limited availability of time not all nodes may be visited. Only nodes which give the highest contribution in terms of profit are selected. An optimal solution procedure for the MTMCP is described. This procedure is based on a generalized set-partitioning formulation and uses constraint branching and tour storage techniques to improve solution time.

Pickup and delivery problem

The pickup and delivery problem is used to find optimal routes, for a fleet of vehicles, to satisfy a set of transportation requests. Almost every practical PDP problem is restricted by several time constraints (Mitrovic-Minic, 1998). First, time windows determine when a load may be picked up or delivered at a certain location. Next, drivers of vehicles are restricted in their use by time windows. In most countries drivers may only drive a certain amount of time and are obligated to respect rest moments. In this section the main characteristics of paired or one-to-one pickup and delivery problems are presented. This means that each request originates at a single location and is meant for another destination (Cordeau, 2008).

Pickup and delivery problems may be divided into dynamic and static problems (Savelsbergh and Sol (1995). In a dynamic problem not all request are known in advance, but may be received during the entire simulated period. Routes are constructed with the requests known at that time. When a new transportation request becomes available at least one route has to be adjusted. In a static problem all requests are known when the routes are constructed and no later adjustments to the planning are required. In this chapter the PDSSP is defined as a static problem, with all requests known in advance.

Within the PDP various objective functions are used, depending on the purpose or criteria of the research. In Savelsberg and Sol (1995) an overview is given. The most common objective functions used by single vehicle problems are mainly related to minimizing duration, completion time, travelled time or client inconvenience. Problems with multiple vehicles mostly try to minimize the number of vehicles or maximize profit, this while minimizing the distance travelled or the travel time. This is also the case in Li and Lim (2001) their objective function exists of four elements. First the number of vehicles is
minimized, than total travel cost and total schedule duration and finally the drivers’ total waiting time is minimized. The maximization of profit, leads us to the pickup and delivery selection problem, which is only rarely applied within PDP.

**Pickup and delivery selection problem**

Few research articles investigate ‘Paired pickup and delivery problems’ in which profits determine the acceptance of an order. The PDSP adds complexity to the traditional PDP as it requires selecting which subset of nodes in the graph to visit, as well as determining the order of visits in each tour. Another difficulty is added when the nodes are constrained by time windows. Schönberger et al. (2002) considers the PDP in which not all nodes have to be visited to maximize profit. In this problem orders may be less-than-truckload. A hybrid algorithm is presented to solve the problem. The hybrid algorithm is composed of a genetic algorithm that is seeded by a parallel route construction heuristic. The construction heuristic generates a feasible solution by assigning requests to vehicles based on their order on a time axis. Requests that violate the capacity or time window restrictions are removed from the routes. After the construction heuristic, improvements are made using a genetic algorithm. Schönberger (2005) divides requests into two categories: tactical requests and operational requests.

‘Tactical request’ acceptance problems require a general decision about the future acceptance of different requests. Mostly, this type comprises all requests of a certain customer. Due to the long-term acceptance of certain requests, it may be necessary to require medium- or long-term investments for additional transport or transshipment resources. The general acceptance is recommended only if the agreed revenues cover the sum of necessary investment and operation costs.

‘Operational request’ acceptance problems require that the carrier company has to decide about the acceptance of particular requests, which are not part of long-term contracts. Such a request is accepted if expected revenues cover expected additional costs caused by this additional request. If a carrier refuses a customer demand, it may be expected that also all other requests of this customer are lost for this carrier. According to Schönberger (2005) lost revenues cannot be adequately incorporated into the calculation of the profitability of a request. In Arda et al. (2008) a profitable PDP with time windows is presented. The authors study orders of full truckload and try to maximize global profit while respecting time windows. To solve this NP-hard problem genetic algorithms are used. First a parent of an ordered set of transportation orders is made. A feasible solution can be extracted by choosing successively the first order that fits the time windows constraints. Schönberger et al. (2002) and Arda et al. (2008) use homogenous vehicle fleets and propose static models. They do not take into account a fixed cost of using an additional vehicle. Also Frantzeskakis and Powell (1990) investigate the PDSP. In their case a dynamic aspect is added and only full truckloads are considered. The carrier decides which loads he will accept or refuse and how many vehicles to relocate in order to maximize the total expected profit over a planning horizon.

Verweij and Aardal (2003) study in their merchant subtour problem the selection of optimal locations to buy and sell products. A selection is made so that the merchant may optimize his profit. The problem is a variation of the PDSP, in which only a single vehicle is considered.

Kleywegt and Papastravou (1998) propose a problem in which transport is done between terminals in long haul shipments. Vehicles are either at a terminal or en route between two terminals. The selection of clients happens at a terminal after which their loads are consolidated into vehicles and direct transport to a terminal is conducted. This leads to a full truckload problem in which clients are concentrated at terminals and not spread out in the area.

In Ting and Liao (2012) a selective pickup and delivery problem (SPDP) is formulated. This may be seen as a variant of the PDSP in the case of ‘unpaired pickup and delivery nodes’. In the SPDP the constraint that all pickup nodes must be visited is relaxed. The objective is to find the shortest route for visiting all delivery nodes, without necessarily visiting all the pickup nodes as the nodes are not paired and only a single commodity is taken into account. The problem is solved using a memetic algorithm that allows to simultaneously deal with the selection of pickup nodes and the visiting order of nodes.

Another option within the PDP instead of not visiting all nodes is to outsource some of the requests to a third party logistic player. Schönberger (2005) investigates the possibility to make use of a logistic service provider (LSP). In this case all requests are divided between either the own vehicle fleet or the LSP. Routes have to be established for the own vehicles and the sum of charges to be paid for all externalized requests has to be minimized. Krajewsk and Kopfer (2009) also study a PDP where the carrier has the possibility to outsource transport requests. They use a tool search algorithm to solve their Integrated Transportation Planning Problem (ITPP). The main difference with other studies that include outsourcing is the use of three different outsourcing types instead of one. A first group of subcontractors works nearly exclusively for the carrier and is paid on tour basis. The second group of exclusively employed subcontractors is paid on a daily basis. The last group consists of independent subcontractors which are not employed exclusively.

This paper offers the following novelties compared to existing research. The traditional PDP is extended to a PDSP by allowing a selection of transportation requests. This leaves the carrier with the option to discard transportation requests which lead to a lower total profit. Next to the planning and scheduling of vehicles into routes as in a classical PDP, a selection within the transportation requests has to be made. The problem at hand considers more than one commodity and paired pickup and delivery are unpaired. Furthermore, multiple vehicles are considered and transport loads are less-than-truckloads.

In the study of Verweij and Aardal (2003) only a single vehicle is assumed and in the work of Arda et al.
(2008), Frantzeskakis and Powel (1990) and Kleywegt ad Papastravou (1998) full truckloads are investigated. The paired pickup and delivery locations, together with the multiple vehicles and less-than-truckload requests make the PDSP very hard to solve. The only paper that studies a PDSP with similar problem characteristics but in a different problem context is Schönberger et al. (2002). Their heuristic results are not compared to exact solutions or lower bounds and reported results are only briefly described. This hinders the comparison of computational results.

PROBLEM FORMULATION

In this section a mathematical representation of the problem is given. First, the key characteristics of a PDSP are described. Next, all symbols that are used are presented and the objective function and corresponding constraints are formulated. The problem is defined as a static PDSP problem. The formulation is an adaptation of the PDPTW formulation of Mitrovic-Minic (1998) and is extended to include the selection of requests.

Key characteristics of a PDSP

To represent logistic decisions within an activity based freight transportation model, the decisions of a carrier have to be modelled. First, the key characteristics related to this problem are presented. This allows formulating a PDSP model in the next subsection.

First of all, not all requests have to be accepted. Every fulfilled request leads to revenue. If a request is accepted, a reward is achieved when the transport is done successfully. For every request a time window is assigned to the pickup and delivery location. In the problem definition at hand, only hard time windows are considered. A request consists of less-than-truckloads. Furthermore, pickup has to occur before delivery of each request (Precedence constraint) and pickup and delivery have to be performed by the same vehicle (Pairing constraint). In our model multiple vehicles are used and it is assumed that capacity is the same for all vehicles. All vehicles depart from and return to a depot of the carrier. Finally, travel costs and travel times for each link are known and assumed to be constant.

Introduction of symbols

Requests A carrier receives a set $P$ of requests. Because the set of requests is equal to the number of pickup locations the same symbol is used in both cases. Each request $r \in P$ consists of a pickup location $p_r$, a delivery location $d_{in}$, a quantity to be shipped $q_r$ and a revenue $Rev_r$ if the request is completely satisfied. So each request is given as a quadruple. The quantity $q_r$ may either be a positive or negative number, depending on the type of operation, either a pickup or a delivery task.

Locations Three different types of locations may be distinguished, each with their own time window. A set of pickup locations $P=\{1,...,n\}$ and a set of delivery locations $D=\{n+1, n+2,...,2n\}$ are included, each with an earliest operation time $e_r$, a latest operation time $l_r$ and a quantity $q_r$ that needs to be shipped or delivered. A single depot $O$ is available, where each vehicle starts and ends his route. If this is a start location, the depot is denoted as node 0. For an end location the notation $2n+1$ is used for the node.

Network A network $G(A,N)$ is given, with $N = P \cup D \cup O$, the set of nodes and $A$ a set of undirected arcs. Within the network the distance between two nodes $i$ and $j$ is given as $d_{ij}$. The travel cost $ct_{ij}$ expresses the charge for travelling a single distance unit. The cost to travel a certain link is expressed as $ct_{ij}d_{ij}$. The last variable on the network is $f_{ij}$ which stands for the time needed to travel from node $i$ to node $j$.

Vehicles The carrier has a given homogenous fleet $K$ of own vehicles. Each vehicle $k$ has a maximum capacity of $Q_{max}$. Vehicles are bound in time by their driver, who is subject to legal driving time restrictions. Only the total amount of driving hours is checked, not the daily rest requirements. Making the assumption that a carrier has the same amount of drivers as vehicles, each vehicle has a start time $s_i$ and a finish time $f_i$. The difference between $f_i$ and $s_i$ may not exceed the legal driving time of the driver. To keep track of the content of the vehicle, so that it will not exceed the maximum capacity, load variables $L^k$ are introduced.

Operations A vehicle has to perform several operations on its route. Each pickup and delivery task takes a certain amount of operation time $ct_{ij}$ to perform per unit that needs to be handled. The total time a vehicle spends at the pickup or delivery location, can be found as follows: $ot_{ij}q_{ij}$. Due to the hard time windows applied at each pickup and delivery location, a vehicle cannot start his pickup operation until after time $e_i$. The vehicle is allowed to arrive earlier at the location, but must then wait until the start of the time window. A vehicle may never arrive to a location after the end of the time window $l_i$. Different waiting protocols may be defined depending on the solution heuristic used. It may be preferred to drive first and wait at the arrival location or to wait first at the previous location and then drive. The empirical study of Mitrovic-Minic and Laporte (2004) shows that the wait first strategy has the potential to build shorter routes compared to drive first in case of dynamic planning problems. Waiting at the starting positions results in more requests being known at the time they leave and a better potential to optimize the route. On the other hand the study revealed that the wait first strategy requires much more vehicles for the same set of locations. Therefore, a new waiting strategy (advanced dynamic waiting) was introduced. Here the drive first and wait first strategy are combined by serving locations in one service zone according to the drive first strategy and apply the wait first strategy between different service zones. This strategy was able to outperform the common used drive-first waiting strategy (Mitrovic-Minic and Laporte, 2004). For static vehicle routing, as the problem at hand, drive first is the most commonly used waiting strategy and will be used for the PDSP.

Variables For this problem two sets of binary variables are defined.

\[ x^k_{ij} = 1 \text{ if vehicle } k \text{ travels from } i \text{ to } j; 0 \text{ else} \]
\[ y^k_i = 1 \text{ if vehicle } k \text{ performs request } i; 0 \text{ else} \]

Next to these binary variables, two sets of continuous variables are introduced.
$T_i^k = \text{the time of vehicle } k \text{ after node } i \text{ is served}$

$L_i^k = \text{the load of vehicle } k \text{ after node } i \text{ is served}$

**Objective function**

The objective of the PDSP is to maximize the profit collected along the vehicle tours. Profit is defined as the sum of the total revenue collected on all the tours minus the total cost of performing the tours.

$\text{Profit} = \text{Revenue} - \text{Cost}$

For the revenue $Rev$ a table is created which stipulates the price of the transport order in function of the distance to be travelled. The total revenue is found by accumulating all revenues of the requests that are accepted and executed.

$$\text{Rev}_{\text{tot}} = \sum_{k \in K} \sum_{i \in N} \sum_{j \in N} \text{Rev}_{ij} \cdot Y_i^k$$

The total cost ($C_{\text{tot}}$) is calculated as the sum of the costs of each link travelled by a certain vehicle $k$. In this case the cost is only related to the distance being travelled. No fixed cost component is enclosed for the use of a vehicle. The assumption is made that a carrier has a fixed vehicle fleet at his disposition and no extra cost is imposed for the use of the vehicles.

$$C_{\text{tot}} = \sum_{k \in K} \sum_{i \in N} \sum_{j \in N} c_{ij} \cdot d_{ij} \cdot X_{ij}^k$$

The objective function which needs to be maximized is:

$$\max \{ \text{Rev}_{\text{tot}} - C_{\text{tot}} \}$$

**Constraints**

In this section the constraints to which the objective function is subjected are formulated. The constraints are grouped according to their function.

**Flow conservation constraints** This constraint is introduced to make sure that vehicles entering a location will also leave this location.

$$\sum_{j=1}^{N} X_{ij}^k - \sum_{j=1}^{N} X_{ji}^k = 0, \forall i \in N, \forall k \in K$$

**Vehicle constraints** Each vehicle starts and ends its tour in the depot $O$. If a vehicle is not used it stays at the depot. This is represented by the following constraints.

$$\sum_{j \in P} X_{ij}^k \leq 1, \forall k \in K$$

$$\sum_{i \in D} X_{(2n+1)j}^k \leq 1, \forall k \in K$$

Every request may only be executed by at most one vehicle. Let the index $^{\text{comp}}j_{\text{comp}}$ be used for the requests which are compulsory and $^{\text{ncomp}}j_{\text{ncomp}}$ for those which are non-compulsory. The constraints to express this are:

$$\sum_{k=1}^{K} Y_{ij}^{k_{\text{comp}}} \leq 1, \forall i \in P$$

$$\sum_{k=1}^{K} Y_{ij}^{k_{\text{ncomp}}} = 1, \forall i \in P$$

A next constraint states that a vehicle cannot load more freight than its maximum capacity.

$$l_i^k \leq Q_{\text{max}}$$

To keep track of the load of a vehicle at a certain moment, the following constraints are necessary. Each vehicle leaves and returns to the depot empty.

$$L_i^k - L_i^{k-1} - |q_{ij}| \geq M_1 \cdot (1 - X_{ij}^k), \forall i, j \in N \text{ and } i \neq j, \forall k \in K$$

**Time window constraints**

Each node has to be served within its time window. The start of the operation, as well as the end of the operation has to fall within the time window.

$$e_i + ot_i - |q_{ij}| \leq T_i^k \leq l_i, \forall i \in N \setminus O, \forall k \in K$$

To keep track of time, a time variable is introduced. To start, the time variable is set equal to the start time of the vehicle.

$$T_0^k = s_k, \forall k \in K$$

A vehicle may not exceed his finish time.

$$s_k \leq T_i^k \leq f_k, \forall i \in N, \forall k \in K$$

The time variable is increased after every operation. The time after service at a certain node, is found by adding the travelling time and operation time to the time variable after serving the previous node. Also the time windows have to be respected, so that the arrival time at a node may not precede the earliest operation time allowed on that location. This is specified in the following constraint:

$$T_i^k + \varepsilon_{ij} - T_j^k + ot_{ij} \cdot |q_{ij}| \leq (1 - X_{ij}^k) \cdot M_2, \forall i, j \in N, \forall k \in K$$

Due to the time window constraint on $T_i^k$, it is assured that the operation does not start before $e_i$.

**Pairing and precedence constraints**

If a request is performed, then vehicle $k$ has to finish its operations at the pickup location $i$ before it can visit the associated delivery location $n+i$. This is known as the precedence constraint, expressed as:

$$T_i^k + t_{(n+i)} - T_{n+i}^k \leq (1 - Y_{ij}^k) \cdot M_2, \forall i \in P, \forall k \in K$$

It is not allowed to split a request over multiple vehicles. A vehicle has to perform both the pickup and the delivery activity. This is known as the pairing constraint, expressed as:

$$\sum_{j \in N \setminus O} X_{ij}^k = Y_{ij}^k, \forall i \in P, \forall k \in K$$

and

$$\sum_{j \in N \setminus O} X_{j(n+i)} = Y_{j(n+i)}^k, \forall i \in P, \forall k \in K.$$
SOLUTION METHOD

The problem under study is solved by means of a metaheuristic. While this paper does not intend to explain detail the design of the metaheuristic, the experiments and the computational results, briefly a description is given.

The heuristic is based on the tabu-embedded simulated annealing algorithm of Li and Lim (2001). The algorithm starts with an insertion heuristic to create a first feasible solution. This solution is further improved by an improvement heuristic. Instead of repeating the tabu search until the procedure terminates, it is restarted from the current best solution after several iterations without improvement. At the same time the global annealing temperature is reset. After a number of restarts without improvement the algorithm is ended. The generation of new best solutions is done via a TABU Search algorithm. To avoid cycling, the visited solutions are recorded into a tabu list, which contains the total profit of a solution. As the probability of two different solutions having the same total profit is very small, it is sufficient to only keep track of total profit.

CONCLUSIONS

A variant of the Pick-up and Delivery Vehicle Routing Problem is investigated, in which the carrier can make a selection of customers to be served, depending on which transport requests offer profit. Furthermore a number of requests are compulsory and are not open to the question of selection. We have been able to formulate the optimization problems as a mixed-integer linear programming problem and have developed a meta-heuristic to solve the problem.

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