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A matheuristic for routing real-world home service transport systems facilitating walking

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ABSTRACT

This paper provides a solution procedure for a state-dependent real-world routing and scheduling problem motivated by challenges faced in the urban home service industry. A transport service delivers staff members of different qualification levels to clients and picks them up after completion of their services. The possibility to walk to clients, interdependencies, time windows, assignment constraints as well as mandatory working time and break regulations are considered. The introduced matheuristic consists of two stages, identifying potential walking-routes and optimising the transport system. The presented numerical studies are performed with real-world based instances from the Austrian Red Cross, a major home health care provider in Austria. The results show that implementing walking and pooling of trips in solution procedures decreases the number of required vehicles substantially.

1. Introduction

Urbanisation causes various challenges like congestions and limited parking spaces for home service providers. This paper is motivated by a project performed with the Austrian Red Cross, a major home health care (HHC) provider in Austria; however, similar challenges occur in various home services such as appliance repair, routine maintenance and private tutoring. These services offer high social benefits for clients; nevertheless, they only contribute little to environmental sustainability (Halme et al., 2006). While public transport can be utilised in urban areas (e.g. Hiermann et al., 2013; Rest and Hirsch, 2013), it often lacks the flexibility of privately owned vehicle fleets due to infrequent service times and limited storage capacities for required equipment. As a result, most nurses operate separate vehicles, which leads to high fixed and operating costs as well as low vehicle utilisations, especially when facing long client service times. Additionally, a growing number of nurses are without driver's permits or reluctant to drive. Consequently, with HHC demand drastically increasing (Rest et al., 2012), novel sustainable concepts are required. This is further stimulated by stricter environmental regulations and the desire to decrease companies' ecological footprints. To achieve this, non-technology driven approaches are crucial (Moriarty and Honnery, 2013).

Motivated by these challenges, we introduce a solution procedure for the daily planning of HHC providers that operate multiple vehicles to deliver nurses to clients' homes and to pick them up after service is provided. Additionally, nurses can walk to clients. The presented work helps service providers to reduce their fleet and to lower fixed expenses while at the same time service quality is less impacted by the availability of parking spots. The pooling of trips as well as the option of walking can potentially decrease the environmental impact of the home service industry. The model is tested with instances based on real-world data. The contribution of this paper is twofold, namely describing this innovative real-world problem and providing a solution procedure to overcome current challenges. This supports decision-makers to investigate the impact of implementing transport systems, which facilitate both walking and trip pooling.

The remainder of this paper is organised as follows: Section 2 discusses related work. Section 3 defines the problem. Section 4 describes the two-stage solution procedure. Computational results are presented in Section 5 and concluding remarks in Section 6.

2. Related work

The introduced case has similarities with a broad range of problems such as the dial-a-ride problem (DARP), the truck and

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trailer routing problem (TTRP) and various real-world applications. DARPs, a special version of the pickup and delivery problem, occur in taxi and ambulance operations among others and deal with the transportation of customers from a pickup to a delivery location. Transport requests are predefined, which is a major difference to our problem where assignments are part of the optimisation. In most cases, the objective is to reduce the vehicles' drive times under maximum ride times, a user convenience constraint; however, a broad range of variants and extensions are found in the literature. For an overview of DARPs, refer to Cordeau and Laporte (2007), and Parragh et al. (2008).

Compared to the TTRP introduced by Chao (2002), where vehicles are uncoupled en-route as certain customers cannot be reached otherwise, sub-routes in our problem do not have to end at their start, but can end at any job. Furthermore, they can be continued on other vehicles and vehicles and nurses move individually at the same time. Lin (2011) introduces a two-stage heuristic for a real-world courier problem containing heavy resources, which carry lighter resources. These lighter resources, e.g. a courier, can pickup and deliver items independently after being unloaded by the heavier resource, which itself can serve clients. In contrast to our problem, the lighter resource can only re-join the heavier one at the last stop of the tour before returning to the depot. This also indicates that a lighter resource can only perform one sub-route. Compared to an independent strategy, lower average total costs and lower usages of heavy resources are achieved under certain conditions.

In the context of HHC, Trautsamwieser et al. (2011) consider different qualification levels, assignment constraints, working time regulations and mandatory breaks in daily planning, where each nurse operates a separate vehicle. An exact model and a variable neighbourhood search-based heuristic are proposed. Concerning working time regulations and mandatory breaks, related work is found in the context of various real-world applications. Nevertheless, despite their high importance in practice, only little attention is received in the literature. Goel (2009) proposes a large neighbourhood search to comply with European Community driving time regulations. Kok et al. (2010) show the significance of these regulations and the resulting increase in routes and durations. A restricted dynamic programming heuristic combined with a break scheduling heuristic is introduced.

Similarly, the impact of synchronisation and interdependencies on vehicle routing problems (VRP) is little analysed in the literature. Bredström and Rönnqvist (2008) describe real-world problems where including temporal synchronisation has a large impact on solution quality and feasibility. Solution approaches based on mixed integer programming are provided. To the best of our knowledge, Doerner et al. (2008) were the first to explicitly consider interdependent time windows in a real-world problem faced in blood transportation. As in our problem, a change in the sequence of one route can lead to infeasibility of all other routes. A mixed-integer programming model, three variants of heuristic solution approaches and a branch-and-bound algorithm are proposed. A survey by Drexl (2012) on synchronisation gives an extensive overview of its importance and the resulting challenges. Of special interest are VRPs with transfers or transshipments, where similar challenges are faced concerning feasibility testing and interdependencies as in our problem. Qu and Bard (2012) implement a propagation algorithm to check feasibility of insertions in an aircraft transport problem with transshipments. Masson et al. (2014) model the feasibility problem for a DARP with transfers as a simple temporal problem and use the Bellman-Ford-Cherkassky-Tarjan algorithm to solve it. None of these solution approaches consider mandatory break regulations or the additional option of walking to subsequent clients. Furthermore, both applications consider specific transfer locations and transfers are not mandatory. This is a major difference to our problem, where transfers occur at clients and have to be performed due to the time-lag between delivery and pickup.

In summary, a broad range of work has been done for related issues; however, published solution approaches are not directly applicable to our problem as various special characteristics are not considered.

3. Problem description

The problem is defined as an extended many-to-many multi-trip DARP. The following outlines the main differences to the classical DARP. (i) The objective is to minimise vehicles' drive times and working times over all nurses considering mandatory break and working time regulations. Service durations are constant and therefore excluded and breaks do not count towards working times. (ii) Transport requests are not predefined, but decided within the model. All jobs have to be served; however, individual requests depend on which nurse can be feasibly assigned at the lowest cost. Furthermore, this introduces interdependencies. The time at which a nurse has to be picked up from a job depends on when the nurse was delivered. (iii) Nurses can walk between jobs. Hence, not all jobs need to be visited by the transport service.

Input is a set J of n jobs ($i \in J$), each requiring a service with a certain qualification requirement q_i^J. To serve these jobs, the service provider has a set M of m nurses ($j \in M$), each associated with a qualification level q_j^M, and a set K of k vehicles ($h \in K$). Jobs can only be performed by a nurse of at least the same qualification level, i.e. $q_j^M \geq q_i^J$. To ensure employee satisfaction, the maximum deviation of qualification level and requirement is set to E, i.e. a nurse of level q_j^M can perform jobs of $[q_j^M - E, q_j^M]$. Additionally, the number of downgradings S, i.e. when an overqualified nurse performs a service, are limited. All jobs have to be started within a hard time window $[e_i, l_i]$, whereas e_i is the earliest and l_i the latest allowed start time. A service takes d_i time units; the service start time is denoted by B_i, while A_i^M and A_i^K denote the arrival time of the nurse and vehicle respectively.

The problem is defined on a complete graph $G = (V, A)$, where each job acts as a potential delivery and pickup location. As a consequence, the vertex set $V = \{v_0, v_1, \ldots, v_{2n+1}\}$ contains delivery vertices $D = \{v_1, \ldots, v_n\}$ and pickup vertices $P = \{v_{1+n}, \ldots, v_{2n}\}$ for all jobs. All tours start and end at a depot indicated by v_0 and v_{2n+1}. Each arc $(i, j) \in A$ is associated with a walking time $t_{i,j}^M$ and a driving time $t_{i,j}^K$. If utilised, the vehicle load Q_i is at least one, indicating the driver, who cannot serve any jobs. The maximum number of nurses on board is constrained by $C - 1$. Each vehicle can have multiple tours. Waiting of vehicles at any other place than the depot is not allowed and, as multiple drivers are available, the total time a vehicle can be utilised is not constrained.

The working time of a nurse is limited by H. If it exceeds R, a break of r time units has to be scheduled. This break starts before or after any job and ends at the same location. Furthermore, it has to be scheduled at a time so that between start or end of the working day and the break, no continuous working time longer than R exists. Maximum detours L of nurses due to other stops on the vehicles' tours must be observed to limit ride times. Therefore, the time spent between pickup and delivery on a vehicle's tour $t_{ij}^{K''}$ is compared to a direct transport ($t_{ij}^{K''} \leq t_{ij}^K + L$). Nurses can also walk to their next job; however, only if t_{ij}^M is below a predefined threshold F. Walking to any other places is not enabled. The cumulative walking time and cumulative wait time of a nurse