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Branch-and-price approaches for the Multiperiod Technician Routing and Scheduling Problem

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ABSTRACT

This paper addresses a technician routing and scheduling problem motivated by the case of an external maintenance provider. Technicians are proficient in different skills and paired into teams to perform maintenance tasks. Tasks are skill constrained and have time windows that may span multiple days. The objective is to determine the daily assignment of technicians into teams, of teams to tasks, and of teams to daily routes such that the operation costs are minimized. We propose a mixed integer program and a branch-and-price algorithm to solve this problem. Exploiting the structure of the problem, alternative formulations are used for the column generation-phase of the algorithm. Using real-world data from an external maintenance provider, we conduct numerical studies to evaluate the performance of our proposed solution approaches.

1. Introduction

This paper addresses the Multiperiod Technician Routing and Scheduling Problem (MPTRSP) based on the case of an external maintenance provider (EMP) specialized in electric forklifts. Services offered by the considered EMP include preventive and corrective maintenance, failure diagnoses, and the delivery of spare parts and supplements to different geographically distributed customers. As these services are offered at the customers' locations, they require the visit of a team of technicians based on customers' service requests. Such requests may be either known in advance (*e.g.,*in the case of preventive maintenance based on yearly contracts and scheduled repairs), or requested on demand (*e.g.,*emergency repairs when breakdowns occur). In this research we consider programmed maintenance tasks, *i.e.,*maintenance demand is deterministic and known in advance, because the current problem constitutes one part of a hierarchical planning process for the EMP.

These maintenance tasks have the following features:

- First, based on maintenance contracts, a time frame for the provision of each task has been agreed upon with the respective customer. In this way, customers can specify the allowed time(s) (and day(s)) on which a task can be performed, *i.e.,* time windows are defined. These time windows can span several hours and possibly several days depending on the type of service requested. For example, a task can be allowed between Monday at 9:00 a.m. and Friday at 1:00 p.m., a corrective maintenance task between Tuesday at 4:00 p.m. and Wednesday at 12:00 p.m., or a delivery between Thursday at 9:00 a.m. and 4:00 p.m. Due to the EMP's working day duration limit, these time windows can be formulated as multiple alternative time windows on consecutive days. Maintenance contracts incur a penalty fee if a customer is visited after the latest starting time. The contracts also define the maximum waiting time per customer.
- Second, a single customer can request more than one service; therefore, multiple tasks might need to be performed at the same location. Due to safety requirements, however, tasks are not allowed to be left unfinished or split, *i.e.,*tasks are non-preemptive, and at most one team per task is allowed. Third, tasks' service time and travel time are known, as well as the minimum skill proficiency required for each task.

As for the workforce, first, each day, technicians are paired into teams and then dispatched to visit customers. Team compositions remain fixed for the duration day (*i.e.,* a technician is assigned to at most one team per day), although different team compositions on different days is not forbidden. The number of teams and size of a team are defined based on the company's safety policies, *e.g.,* since some maintenance tasks for forklifts require lifting heavy equipment. Each technician is qualified in certain skill domains (*e.g.,*hydraulics, mechanic, electric, *etc.*) and has a proficiency level in each domain (*e.g.,* basic proficiency, medium proficiency, or expert). Thus, team qualifications depend on the combined qualifications of the team members. Second, on any given day, teams

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are dispatched from the EMP's location and need to return to it before closing time. If a team returns after this time, overtime is incurred at a cost. Other workforce scheduling decisions, such as shift scheduling, days-off scheduling, and meal-breaks placement are outside of the scope of this paper.

The planning problem faced by this EMP consists of obtaining weekly schedules comprised by: (i) daily pairing of technicians into teams, (ii) assignment of teams to tasks, and (iii) dispatching teams into routes to perform their respective tasks. The goal is to obtain weekly schedules such that the operational costs are minimized. That is, the said schedules should minimize travel costs, customer waiting time and technician overtime. To the best of our knowledge, this problem with all its features has not been previously addressed in literature.

The contribution of this paper is three-fold:

- The Multiperiod Technician Routing and Scheduling Problem is defined and its relation to existing research is presented.
- Branch-and-price algorithms to solve this problem to optimality are proposed.
- Numerical experiments using real-world data are conducted to test the performance of the proposed solution approaches.

The remainder of this paper is organized as follows. In Section 2, an overview of the related literature is shown, and in Section 3, a problem description and a model formulation are provided. A description of the proposed solution approaches and details on their implementation are shown in Section 4. The numerical studies conducted in Section 5 compare the performance of the different solution approaches using real-world data. Concluding remarks and directions for future research are presented in Section 6.

2. Related literature

Personnel scheduling has been addressed frequently by many researchers due to its presence in many application areas (see Ernst, Jiang, and Krishnamoorthy, 2004b; Ernst, Jiang, and Krishnamoorthy, 2004a, and Van den Bergh, Beliën, De Bruecker, Demeulemeester, and De Boeck, 2013 for more thorough reviews). As it is a complex process, several sub-stages need to be carried on for its completion: (i) demand modeling, (ii) days-off scheduling, (iii) shift scheduling, (iv) line of work construction, (v) task assignment, and (vi) staff assignment (Ernst et al., 2004b). The present problem belongs to task assignment and staff assignment stage of this classification, although it also involves additional decisions that need to be considered, *e.g.*, the assignment of technicians into teams, the assignment of teams to tasks, the construction of routes, and the selection of the day on which a service is provided.

On the other hand, the Multiperiod Technician Routing and Scheduling Problem (MTRSP) can also be classified as a generalization of the Workforce Scheduling and Routing Problem (WSRP), as it combines aspects from personnel scheduling and vehicle routing problems (see Castillo-Salazar, Landa-Silva, and Qu, 2014 for a review on recent WSRP literature). However, it also incorporates additional features: tasks have multiple alternative time windows on multiple days (*i.e.*,multiple periods are considered), and teams of technicians need to be formed on a daily basis (*i.e.*,team building).

In the following, we review related literature that addresses similar problems. First, we analyze existing literature and classify it according to the extent to which they incorporate the special features from our problem. Second, we provide an overview of the proposed solution approaches used in these works.

2.1. Related problem formulations

This section reviews problem formulations similar to ours found in literature. This analysis focus on contrasting the features considered in these formulations, in comparison to the features of our proposed problem. Accordingly, the related works are then classified into the following categories: (i) a single period and no team building, (ii) multiple periods and no team building, and (iii) a single period with team building.

(i) Single period, no team building

Most literature on WSRP-related problems differs to our problem in the fact that they consider single-day routes and the tasks to be assigned involve single agents (*i.e.*, no team building decisions are made).

In Xu and Chiu (2001) a staff-scheduling problem for field technicians of a telecommunication company is considered. Skill levels for each technician are given as a percentage of proficiency on each task. In contrast to our model, tasks do not require proficiency levels but rather the objective function maximizes the assignment of technicians to tasks by weighting their proficiency level, so that highly skilled technicians are more likely to be assigned. Dohn, Kolind, and Clausen (2009) propose a manpower allocation problem in which teams of technicians are assigned into maintenance tasks constrained by time windows. Tasks have different skill requirements, which constrain their assignment to teams, and the collaboration of multiple teams in one task is allowed. Pillac, Guéret, and Medaglia (2012) consider the Technician Routing and Scheduling Problem (TRSP) where the technician-task compatibility includes spare parts and tools as well. All these models, however, differ from ours in that all tasks observe a single-day planning horizon and no team building decisions are considered. Lim, Rodrigues, and Song (2004) deal with a different version of a manpower allocation problem for service personnel at the port of Singapore. They formulate this problem as a multi-objective problem where, in contrast to our model, minimize the number of servicemen used as a primary objective and minimize the routing costs as a secondary objective.

Additional WRSP literature addresses the home health care problem. In this problem staff members from a health care provider are dispatched to visit geographically dispersed clients (Akjiratikarl, Yenradee, & Drake, 2007, Cheng & Rich, 1998). In other examples of home health care related literature the tasks or clients require the visit of multiple agents. In Bertels and Fahle (2006) and Eveborn, Flisberg, and Rönnqvist (2006) a staff planning problem for home care is addressed where some visits require the coordination of multiple staff due to, *e.g.*, safety regulations. However, in contrast to our problem, these groups of staff do not remain together for the entirety of the working day. Instead, the authors model additional constraints to force the synchronization on the arrival and departure of the agents.

(ii) Multiple periods, no team building

In Blakeley, Arguello, Cao, Hall, and Knolmajer (2003), technicians are assigned to customers and dispatched on routes in a multiperiod planning horizon. Technicians have different qualifications, and compatibility of customers and technicians is taken into consideration. Similar to the Periodic Vehicle Routing Problem (PVRP) (Francis, Smilowitz, & Tzur, 2006; 2008), technicians are assigned to routes according to predetermined visit frequencies, and customers are visited within their preferred visit days. In contrast to our model, the visit frequency is predetermined, the validity periods do not consider specific time windows, and no team building decisions are made.

Similarly, Tang, Millerhooks, and Tomastik (2007) consider the routing of technicians to maintenance tasks for geographically distributed customers on multiple days. The authors formulate this problem as a Multiple Tour Maximum Collection Problem with Time-Dependent rewards (MTMCPTD). In this model, single-day routes are obtained for technicians such that the reward obtained