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Scheduling technicians for planned maintenance of geographically distributed equipment

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Abstract

A real-world planned maintenance scheduling problem that exists at several business units within United Technologies Corporation (UTC) is addressed in this paper. The scheduling problem is formulated as a multiple tour maximum collection problem with time-dependent rewards and an adaptive memory tabu search heuristic is developed to solve it. The effectiveness of the proposed solution approach is examined using real-world problem instances supplied by UTC. Relevant upper bounds are derived for the application. Results of numerical experiments indicate that the proposed tabu search heuristic is able to obtain near optimal solutions for large-size (i.e., actual) problem instances in reasonable computation time.

Keywords: Multiple tour maximum collection problem; Time dependent; Selective traveling salesman problem; Tabu search; Maintenance scheduling

1. Introduction

This paper addresses a planned-maintenance scheduling problem that exists at Otis, Carrier, Chubb and other business units within United Technologies Corporation (UTC). UTC manufactures, installs and services building equipment, including, for example: heating, ventilation and air conditioning (HVAC) systems; distributed power equipment; escalators; elevators; moving sidewalks; security system equipment; and fire detection and suppression equipment. Such pieces of equipment require regular maintenance and are located in buildings that are geographically dispersed. A technician should complete each maintenance procedure as close as possible to pre-specified recommended intervals of time that depend on the type of procedure, the last time that procedure was completed, the type of equipment that is involved, the equipment's condition, and the

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equipment's expected future usage. Each procedure that is to be performed in the future on a particular piece of equipment is referred to as a task. The scheduling problem is to determine, for each technician and each day in the scheduling horizon (typically, 1 or 2 weeks), the tasks to perform and the sequence in which to perform them. This selection of tasks to perform and the choice of sequence are determined, as best as possible, such that tasks are performed close to their recommended maintenance dates while simultaneously considering the key complicating constraint on workday duration limitations. The tasks to consider in the schedule include all tasks due several weeks prior to or beyond the schedule horizon such that opportunities for minimizing visits to the same pieces of equipment are exploited. Each technician handles multiple types of equipment in an assigned geographic territory. Since each procedure requires only one technician, we can consider each scheduling problem of each technician independently.

There is no limit on the number of tasks that each service technician can complete in a day, but the total travel time between equipment locations plus total service time must not exceed the duration of a workday (typically, 8 h). Each task requires between 10 and 960 min to complete. Tasks with service times that exceed the workday duration are handled separately.

Determination of an optimal or nearly optimal set of schedules by service technicians or managers is extremely difficult, as such determination requires the simultaneous consideration of a very large number of tasks and pieces of equipment, the travel time matrix, and target maintenance dates for each procedure. Thus, an optimization technique that can automate this process could provide significant improvement over the existing manual scheduling process.

In this paper, the planned maintenance scheduling problem is modeled as a Multiple Tour Maximum Collection Problem with Time-Dependent rewards (MTMCPTD). The Maximum Tour Maximum Collection Problem (MTMCP) with time-invariant rewards has been addressed previously in the literature. The authors are not aware of any work in the literature that addresses the MTMCP with time-dependent rewards. The objective of the MTMCPTD is to determine a set of tours, each corresponding to a technician's schedule on a particular day, such that the total reward collected during the scheduling horizon is maximized. Tours are simultaneously scheduled for multiple days. The associated reward for completing a task on a given day is a function of the day to which it is assigned, i.e., the rewards are time-dependent. Greater reward is assigned to tasks that are more past their due date, in order that these tasks will be selected. The reward is based on the "urgency" of the task. Note that the rewards are not actual monetary rewards or profit received for completing service; rather, they are values that are used internally to the algorithm that are set to try to force tasks that are most urgent to be scheduled earliest.

By employing time-dependent rewards, the proposed framework can explicitly model details of the real-world scheduling problem. In addition to its utility in modeling task urgency, one can model the relative desirability associated with performing a specific task on a given day. The desirability depends on the level of inconvenience that will be incurred in taking the piece of equipment out of service. The cost in terms of convenience and, thus, customer satisfaction can change dramatically from one day to the next. For instance, taking an elevator out of service to complete maintenance is more costly on a day when a major convention is being held in the building as compared with the cost on the day prior to the convention. The proposed framework with time-dependent rewards can also support condition-based maintenance, where the equipment condition is detected or estimated. Probability failure curves for each piece of equipment are known and can be used to estimate the urgency associated with completing a maintenance task on a given day.

The scheduling horizon may be either short-term (on the order of days or weeks) or long-term (on the order of months). In the particular application studied here, like in many related applications, procedures need not be repeated on a given piece of equipment in a short-term horizon, because the suggested interval before repeating a procedure on a given piece of equipment might range between several months and several years. On the contrary, if the horizon is long-term, such an assumption might not be reasonable.

As the MTMCPTD is shown to be NP-hard, a tabu search heuristic is proposed in this paper for the short-term planned maintenance scheduling problem. Tight upper bounds are derived for the scheduling application. Results of numerical experiments using problem instances supplied by UTC indicate that the heuristic is able to obtain near-optimal solutions in reasonable computing time. The MTMCPTD and its application to this short-term scheduling problem are described next. The long-term scheduling problem is considered in Section 5.