Tactical Crew Planning with Connectivity Considerations in Pairings

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1 Crew Pairings with Schedule Connectivity

Crew planning problems are conceived within a two-phase approach where the first phase is concerned with duty pairings that are feasible sequences of duties and the second phase is concerned with crew rostering that assigns duty pairings to individual crew members. While the rosters are usually concerned with cost-wise optimality of the operational plans, the pairing phase may be considered as a tactical level decision making process where the feasibility is main concern.

Within the general approach for the pairing phase, there are two particular deficient suppositions with respect to the constructed crew schedules: (i) available crew resource in the region is sufficient; (ii) schedules can be repeated over the periodic recurrence of the planning horizon. Particularly, the second assumption regarding the continuity of schedules over the recurrence of the schedule period may lead to crew schedules that are not implementable in practice. For most businesses where crew resource is critical and needs to be scheduled with respect to strict rules and regulations, this problem is commonly faced at the operational level. When companies face with such cases, they either resort to crew patchings (i.e. temporary workers that enable that operate only in limited number of days) or manually modify the schedules to guarantee continuity of the crew schedules so that the pairings can be repeated from one period to the next.

In this study, we deal with the tactical crew capacity planning problem where the aim is to determine the minimum required number of crew members. In our setting, the feasibility of crew schedules and the connectivity of rosters are integrated to find a repeatable set of schedules that satisfy the operational rules and regulations. With respect to the problem environment we consider, our study is closest to Ernst et al. [1] and Şahin and Yüceoğlu [3]. Both studies consider minimizing the crew size (i.e. number of crew members) required to operate the trains under the responsibility of the region. In [1], they consider the problem in two phases: the planning stage where the number of crew members is determined and the operational (rostering) stage where the connectivity of the crew schedules is maintained. They develop a two-stage solution methodology that fails to guarantee optimal solutions. Their heuristic two-stage approach minimizes the number of crew members in the first stage and tries to satisfy the connectivity of rosters in the second stage. In [3], they study the planning stage and represent the operational stage problem as the tactical level counterpart of the planning stage problem. They focus on optimally minimizing the number of crew members required in the region to cover the duties.

2 Solution Methods

The crew planning literature is rich with studies focusing on both network flow formulations and set covering-type formulations of the problems.

In [3], they model the tactical level crew capacity planning problem with a space-time network representation where different policies and practical considerations that also include the ones as applied in the Turkish State Railways (TCDD) are considered. On the space-time network, a source-sink (s-t) path corresponds to a schedule of a crew member which represents the sequence of events (i.e. duties) and activities (i.e. rest, deadhead, direct connection) the crew is engaged with. Since the space-time network is constructed according to the rules and regulations, the flow on an (s-t) path corresponds to a feasible crew schedule. In our study, we consider finding a set of feasible crew schedules that can be connected to other schedules from one period to the other. To formulate this version of the problem, the network formulation in [3] is enriched with an additional set of arcs that represent the connectivity relationship among the schedules. These particular arcs, designated as connectivity arcs, functionally replace source and sink arcs and eliminate source and sink nodes on the network representation. In a circular closed-loop fashion, a flow on a connectivity arc marks the end of a schedule and the beginning of a new schedule, thus they represent not only the end-points of individual schedules but also the connectivity relationship among the selected schedules. In this manner, the corresponding model aims to minimize the total flow on such arcs since the objective is to minimize number of schedules that cover duties in the planning horizon while the corresponding flow balance constraints (i.e. network structure) honor rules and regulations in order to operate the trains under responsibility of the region.

We also show that a traditional set partitioning problem is not sufficient to formulate the problem with connectivity constraints. Therefore, a column-and-row generation algorithm following the framework in [2] is developed as an alternative solution method.

3 Computational Results

We employ a commercial IP solver to solve the resulting integer network flow problem and a column-and-row generation algorithm to solve the set-partitioning problem. We present results for three representative TCDD crew regions. We solve the problem instances with a planning horizon of one week and two weeks considering various day-off requirements. From the decision maker's point of view, we show that the decisions on regional crew capacities without connectivity of the schedules might significantly differ from those where connectivity of schedules are integrated into the problem. We also demonstrate the computational challenges of the column-and-row generation algorithm.

References

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[2] Muter, İ., "Large-scale Linear Programs with Column-Dependent-Rows", PhD Thesis, Sabanci University, 2011.

[3] Şahin, G., and B. Yüceoğlu, "Tactical crew planning in railways", *Transportation Research Part E: Logistics and Transportation Review* 47(6), 1221-1243, 2011.