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Railway crew capacity planning problem with connectivity of schedules

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ABSTRACT

We study a tactical level crew capacity planning problem in railways which determines the minimum required crew size in a region while both feasibility and connectivity of schedules are maintained. We present alternative mathematical formulations which depend on network representations of the problem. A path-based formulation in the form of a set-covering problem along with a column-and-row generation algorithm is proposed. An arc-based formulation of the problem is solved with a commercial linear programming solver. The computational study illustrates the effect of schedule connectivity on crew capacity decisions and shows that arc-based formulation is a viable approach.

1. Introduction

Crew is one of the most crucial resources in railways. In most systems, crew-related costs outweigh even the dominating energy expenditures. For instance, they constitute more than one third of general expenditures of the Turkish State Railways (Turkish State Railways, 2004, 2008, 2010). Dutch Railways report a share of more than 30% of their total operational expenses due to wages in both 2011 and 2012 (Dutch Railways, 2012). In 2012, Association of American Railroads has reported that 21.3% of the total operational expenses was spent for wages which was second in the ranking right after fuel expenses (Association of American Railroads, 2012). Hence, effective crew management is one of the critical planning issues.

For effective planning and management, railway systems are districted into multiple crew regions; home/base station of a region is responsible for its own crew while a centralized authority is responsible for the coordination and synchronization of regions. The operational level regional planning problems have attracted the utmost attention from both practice and academia; they consider assignment of crew to train duties which includes the tasks for a train service specified with a starting time and location and an ending time and location. This planning level is usually prescribed as crew scheduling. A common understanding considers a two-phase approach for this level: crew pairing and crew rostering. The pairing phase constructs sequences of train duties (by sequentially pairing duties with each other) spanning a finite planning horizon; if the pairings are feasible with respect to rest periods, total work time, total rest time, etc., they constitute feasible crew schedules. Rostering phase is concerned with the assignment of individual crew members to crew schedules.

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At the strategic level, system/company-wide decisions that would vastly affect the level and allocation of crew resources over all regions are made. Some of these issues are related to establishment of new crew regions or new crew exchange stations as well as high level adjustment of company practice such as re-distribution of inter-regional workload (assignment of duties to regions). At the tactical level, effective individual capacities of crew regions are the main planning issues; given the train timetable under the responsibility of a particular crew region, the minimum number of crew members required to operate these train services need to be determined. Based on the crew capacities of the regions, crew scheduling (crew pairing and crew rostering) is done at the operational level.

In hierarchical planning frameworks where a top-to-bottom approach is used, adjustments at the lower level plans are common and usual. Reflecting more concerns related with lower level plans into higher level plans is desirable as it keeps the level of such adjustments reasonable. In this respect, tactical planning decisions that take into account the operational level considerations as much as possible are considered more effective. In this study, we consider the tactical level crew capacity planning problem that involves finding the minimum number of crews in a region required to operate a predetermined set of train duties and take into account a particular set of new planning issues which mostly affects the pairing phase.

In most systems, train service schedules are periodic (e.g. weekly, bi-weekly, monthly); however, the recurrence of crew schedules and rosters over the periodic train service schedules are overlooked at the pairing phase. When the recurrences are considered, the last duty on every feasible schedule in a period would be connected to the first duty of one of the feasible schedules in the next period. This phenomenon shall be considered as schedule connectivity. In this respect, connectivity between two duties is governed by the same restrictions of a feasible pairing between two duties in the same schedule, i.e. there should be sufficient rest time after the end of the earlier duty and before the beginning of the later.

We may easily exemplify shortcomings of not considering the connectivity between schedules even on a small example with two crew members only: let us assume that the end of the period is Sunday midnight and one crew member returns back to the base at 11 pm on Sunday while the other member returns back at 11:30 pm conducting their last duties at the end of the week. In the case that the minimum home rest requirement is 16 h, none of these crew will be allowed to work before 3 pm on Monday. However, the earliest duty at the beginning of the week may start much earlier, for instance at 8 am on Monday. In essence, there should be at least 3 crew members (or 3 pairings) at this base station so that the pairings can feasibly be connected from one period to the next. This small example shows that the pairings may fail to honor some of the regulations in the second week of operations although we have feasible pairings for the planning period of one week only.

In practice, infeasibilities regarding the connectivity of the schedules are tackled at the operational level; either the managers resort to patching or the schedules are manually modified to guarantee connectivity so that the same schedules can be repeated from one period to the next. Thus, maintaining periodically connected schedules is a challenging task; the availability of crew should be guaranteed with respect to the periodic recurrence of the planning horizon.

In this study, the feasibility of crew schedules and their connectivity are integrated within a tactical level planning problem to find a set of schedules that satisfy the operational rules and regulations. The problem minimizes the crew size (i.e. number of crew members) required in a region. Our contributions shall be summarized as follows:

- Based on a well-known network representation of the problem, we develop a path-based formulation in the form of a set covering problem.
- We present an enhanced version of the network representation which enables an arc-based formulation in the form of a minimum cost network flow problem.
- We compare the computational performance of the two formulations with data sets acquired from Turkish Railways.
- We show that the decisions on regional crew capacities ignoring connectivity of the schedules might significantly differ from those where connectivity of schedules are integrated into the planning process.

Following a review of the literature on crew-related railway problems in Section 2, we propose two alternative formulation approaches and develop solution methods in Section 3. Section 4 presents the results of a computational study that compares the two solution approaches. In Section 5, we wrap up our findings and suggest further research issues.

2. Literature review

Crew planning problems at railways have been studied for various environments considering particular railway companies, and nation-wide or region-wide systems. For instance, Caprara et al. (1997, 1999, 2001) focus on the Italian case; Freling et al. (2001), Morgado and Martins (1998), Kroon and Fischetti (2001) and Abbink et al. (2005) focus on Dutch railways; Vaidyanathan et al. (2007) focus on the North American railways; Jutte et al. (2011) study the largest European railways DB Schenker; and Şahin and Yüceoğlu (2011) focus on Turkish railways. Although the problem environment is different from one system to the other, several features including universally accepted rules as well as company and legislative regulations are common. In this respect, the literature is compact as this line of research has improved steadily mostly by adding and integrating new and more challenging issues to the problem environment at different planning stages.

With respect to the problem domain, our study is closest to Ernst et al. (2001) and Şahin and Yüceoğlu (2011); they both consider minimizing the crew size required to operate the trains under the responsibility of a region. Ernst et al. (2001) consider the problem in two phases; the number of crew members is determined at the planning phase and the connectivity