Balanced Train Crew Assignment in Double-ended Districts

(Extended abstract)

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1. Introduction

Freight railway companies have been improving their crew scheduling performance in order to reduce operating costs and improve the quality of crew life. Crew scheduling in railways minimizes costs following each railroad company's operational policies, which may vary in different districts. In this paper, we discuss railway crew assignment in double-ended districts with workload balance requirements arising from a major North American railway company's operational rules.

In railway crew scheduling, crew planners need to assign required number of crews in each occupation (engineer, conductor and possibly brakeman) to every scheduled train in a planning horizon. A freight railroad network is geographically segmented into districts and crew planners only manage crew assignment within each district. Each district usually consists of two terminals, of which one or both can be crews' home terminals. In this paper, we study *double-ended* districts in which both ending terminals have home crew pools, that is, every station has a home crew pool and an away-to-home (away) crew pool for each occupation. When a crew leaves his/her home station and arrives at the away station, he/she enters the away crew pool at the arriving station. Each station also has an extra home crew pool which supplies extra crew members when no regular crew in the district is available for a scheduled trip. Every new extra crew member charges a penalty which is much greater than other costs and will leave the district after returning to his/her home station. In short, crew planners need to assign crews from either home crew pool or away crew pool to every trip. After choosing a crew pool, crew planners need to activate (or call on duty) crews from the chosen crew pool in the order which is determined by the crew activation rule (named as *Rotation Key* rule). We study two Rotation Key (RK) rules in this paper, including First-in-First-out (FIFO) and

First-out-First-out (FOFO). First-in-First-out (FIFO) rule requires crews to be called on duty in the order they arrived at their current crew pool. On the other hand, First-out-First-out (FOFO) rule ensures that crews should be activated in the order they were activated in the last assignment. Also, crew planners need to decide whether and when to *deadhead* crew members from one station to the other. Deadheading crews can relieve crew shortages, reduce waiting time and cost (layover cost) at away-to-home stations and balance workload across crew pools. However, deadheading will incur additional costs.

We focus on crew assignment in double-ended districts with workload balance requirements consisting of two detailed constraints. Firstly, *Maximum Calling Ratio* constraint enforces that workload at a terminal is evenly allocated to home crew pool and away crew pool. Secondly, *Workload Imbalance Control* constraint requires that the total workload is assigned to crews who are homed at two terminals according to a pre-specified ratio. Our objective of solving the railway crew scheduling problem is to minimize the total cost, which includes layover cost, deadheading fixed cost and trip cost. We allow violation of workload balance constraints while charge penalties for each unit violation, so the total cost also contains additional violation penalties. It is challenging to formulate an appropriate optimization model for this railway crew scheduling problem and to solve it optimally (or with performance guarantees) and quickly.

The main contributions in this study are summarized as follows: First, we provide an optimization model for the railway crew scheduling problem in double-ended district with workload balance constraints. Second, we improve the base model to reduce the model size and propose several solution techniques including problem reduction, constraint-violation repair method and warm-start method. Last but not least, we apply our algorithms to the real-life data coming from a major North American railway company. Our approach generates high-quality heuristic solutions in seconds and optimally solves most problem instances within minutes.

2. Literature review

In the last 40 years, crew-related scheduling problems have been extensively studied in and out of the transportation literature. In general, mathematical models for crew scheduling problem can be categorized into: set covering/partitioning formulations and network flow formulations. In this paper, we follow the network flow approach and formulate the problem as a mixed integer programming problem. We choose network flow approach rather than set covering/partition approach for the following two reasons. First, solving sub-problems generated by column-generation or branch-and-bound techniques quickly is essential for finding an integer feasible solution. However, the FIFO/FOFO rule and workload balance requirements spoil the special structure of sub-problems and make the problem intractable. Second, if we would use specific algorithms developed for set covering/partition approach, it would not be possible to take advantage of the recent improvements in standard optimization software products such as ILOG CPLEX.

Few researchers solve an optimization model for crew scheduling with the RK rules to optimality at the operational level. Vaidyanathan et al. (2007) propose a time-space network flow model which formulates the RK rules in railway crew scheduling, but their optimization model is computationally intractable for large-scale instances because of the substantial number of rotation key constraints required. Balakrishnan et al. (2013) discuss railway crew scheduling in primary-secondary-queue district in which not only rotation key rule but also the state of primary queue and secondary queue determine the crew activation order.

3. Model formulation and enhancement

As both Maximum Calling Ratio constraint and Workload Imbalance Control constraint are soft constraints in real time crew scheduling, constraint violations with large penalties are allowed in solutions. The total cost consists of connection cost, crew trip cost, taxi deadhead fixed cost, new extra crew penalty and workload balance constraints violation penalties. Besides workload balance requirements, the constraints need to enforce 1) crew flow conservation; 2) required amount of crews in each occupation are assigned to each scheduled train; 3) the capacity of taxi deadhead and train deadhead is not exceeded, 4) the order of activating crew members follows RK rules.

In the base model, we provide an intuitive connection-based rotation key formula which is similar with the formula in Vaidyanathan et al. (2007). However, the base model cannot solve medium or large-scale instances to optimality because of its large model size. We propose a model enhancement which removes more than 50 percent of connection variables and also provide a time-based rotation key formula in which the number of constraints is only 2% of that in the connection-based rotation key constraints.

4. Solution techniques

Since our goal is to support real-time crew scheduling decision, long runtime is not acceptable. Therefore, to provide optimal or near-optimal solutions quickly, we propose several solution techniques, including RK-violation repair method, restricting taxi candidates and warm-start CPLEX. As the rotation key constraint is the most complicated constraint in our model, we propose RK-violation-repair method that generates heuristic solutions in seconds. The RK-violation-repair method firstly solves the RK-relaxed model which drops RK constraints and then repairs RK violations in the solution. However, large heuristic gaps in the RK-violation repaired solutions motivate us to develop other optimization-based methods to improve solution qualities. The warm-start method solves the complete problem to optimality with an initial feasible solution produced by the RK-violation-repair method. While a great improvement of solution quality is achieved, long runtimes for some instances are still not acceptable in the real-life crew scheduling. Finally, we restrict taxi candidates to reduce problem size and model size to accelerate the runtime on top of warm-start method.

5. Computational results

We test our models and solution techniques with problem instances form 3 districts representing small, medium and high traffic volume districts. Instances from the medium traffic volume district only contain single occupation type, while the rest of instances consider engineers and conductors simultaneously. In all tests, the stopping criterion is reaching 0.1% opt. gap, and the maximum runtime is one hour.

The total number of trips in small instances is 76 on average. Since the base model solves all small instances optimally in seconds, we do not need to develop advanced model or solution methods for the small instances. While medium size instances contain about 450 trips, the base model requires 200 times constraints as many as that in small size instances. Therefore, most medium or large instances cannot be solved and model improvement becomes necessary. With the improved model, all instances with FIFO rule can be solved to optimality within a half of minute and medium size instances with FOFO rule can be solved to optimality in one hour. But, some large-scale instances with FOFO rule cannot obtain any integer feasible solution at termination.

It is clear that the RK-violation-repair method is a very effective approach which solves all instances with FOFO rule within 10 seconds. However, the biggest heuristic gap is 0.38% which means hundreds dollar difference between the heuristic solution and the optimal solution. Therefore, in order to reduce the gap, we warm start CPLEX based on the RK-violation repaired heuristic solution. Even though the warm-start method provides optimal solutions, the maximum runtime is still too long to be acceptable. To reduce runtimes in the warm-start method, we restrict taxi candidates on top of warm-start method. This combination of methods can solve all instances in FOFO rule with maximum runtime of 422 seconds. Moreover, the solution quality is guaranteed, since a half of instances are solved to optimality and the maximum heuristic gap is 0.06%.

6. Conclusion

In this paper, we study crew assignment in double-ended districts with workload balance requirements which request workload to be evenly assigned across crew pools at both ending terminals. Crew planners used to manually schedule crew assignments following the workload balance requirements. However, with an unbalanced traffic pattern, where much more trains travel in one direction than the reverse direction, keeping workload assignment in balance is a difficult task. To solve this problem, we provide an optimization model that satisfies the complicated Rotation Key rules. We also improve the model and reduce model size dramatically by providing a time-based Rotation Key formulation. Thus, large-scale instances are no longer computationally intractable. For the real-time crew scheduling environment, we develop effective solution techniques to provide optimal or near-optimal solutions quickly. We believe that our model and solution techniques can provide effective support to railway crew scheduling in real time.

Reference:

P. Cappanera and G. Gallo, "A Multicommodity Flow Approach to the Crew Rostering Problem," *Operations Research*, vol. 52, no. 4, pp. 583–596, Aug. 2004.

B. Vaidyanathan, K. C. Jha, and R. K. Ahuja, "Multicommodity network flow approach to the railroad crew-scheduling problem," *IBM Journal of Research and Development*, vol. 51, no. 3.4, pp. 325–344, May 2007.

A. Balakrishnan, A. Kuo, and X. Si, "Real-Time Decision Support for Crew Assignment in Double-Ended Districts for Freight Railways," pp. 1–37. Proceeding paper.

A. T. Ernst, H. Jiang, M. Krishnamoorthy, H. Nott, and D. Sier, "An Integrated Optimization Model for Train Crew," *Annals of Operations Research*, vol. 108, no. 1–4, pp. 211–224, 2001.