Real-time Crew Assignment in Double-ended Districts with Primary-Secondary Queues
(Extended Abstract)

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1. INTRODUCTION

For railroad operators, crew costs account for a large proportion of operating expenses. For instance, the three largest U.S. freight railway companies spent an average of 490 million dollars each on crew wages alone, accounting for 12% of their train operating costs in 2011 (Surface Transportation Board, 2011). Therefore, effective utilization and deployment of crews is a very important concern for these companies. Unlike the airline industry, the freight railroad industry has not widely adopted or implemented optimization-based decision support systems for crew assignment and scheduling. Crew assignment is largely done manually by experienced planners. The models and methods developed for airline crew scheduling do not apply to freight railroads because of the many differences in the structure and operational rules for crew deployment in these two settings. For instance, the schedule for freight trains can vary from day to day, and the assignment of crews to trains must satisfy various complicated operational rules and regulations. Moreover, crew planners in freight railroads have wider choices in terms of crew pools and deadheading options. Manual planning is not only time consuming but can also lead to suboptimal decisions with higher deadheading and crew layover costs. This paper describes the development and application of a large-scale mixed-integer programming model to support short-term crew assignment decisions for U.S. freight railways.

Crew scheduling has been studied intensively in a number of transportation industries, particularly in airlines. Barnhart et al. (2003) provide a detailed discussion of airline crew scheduling. In the railway context, the majority of research focuses on crew scheduling for passenger railways. Caprara et al. (2007) provide a recent survey of passenger railway crew scheduling in Europe, covering different modeling approaches and solution methods.

To the best of our knowledge, there are only two optimization-based papers that deal with U.S. freight railway crew scheduling. Gorman and Sarrafzadeh (2000) propose a dynamic programming based heuristic algorithm to solve the crew scheduling problem for single-ended districts, while Vaidyanathan et al. (2007) present a general multi-commodity network flow model for crew scheduling in North American railroads. Neither of these papers deals with the extra complexity of double-ended districts. Compared to single-ended districts, double-ended districts require additional crew dispatching rules to ensure equitable workload distribution between two home bases. Such rules are not trivial to formulate. Also, addition of these rules makes the crew assignment model more complicated and difficult to solve.

This research provides three broad contributions to effectively solve practical crew scheduling problems in U.S. freight railroads. First, we provide a formulation for crew assignment in primary-secondary-queue (PSQ) districts that have very complicated dispatching rules and have not been studied in existing literature. Second, we propose several model enhancements and solution techniques, including model strengthening, problem reduction, and a heuristic procedure to solve the problem effectively. Our heuristic provides optimal or near optimal solutions in one second, and the solution can be used to warm start CPLEX or as a final solution for crew dispatchers. On the application level, we validated our model and methods with 140 real-life problem instances provided by BNSF Railway, a leading U.S. freight railway carrier. The model provided optimal solution within one minute for most instances. The excellent computational performance of our model qualifies it to be incorporated into the company's real-time planning system.

2. PROBLEM STATEMENT

Given the schedule of trains traversing a specified crew district in a given planning horizon, the objective of the crew dispatcher is to select crews of required occupation type from multiple crew pools to staff each train, so that no train is delayed or canceled and the overall cost is minimized. While assigning crews, the selection of crew pool and crew member must follow crew dispatching rules. Each crew member is required to take a minimum amount of rest between two consecutive assignments. However, if a crew member is kept at her/his away-from-home station longer than a specified time limit, then the company must pay an hourly heldaway cost in addition to the lodging cost. Due to the imbalance of traffic volume in two directions, crews may be deadheaded from one station to another frequently in order to cover a crew shortage on a future train, or to reduce extensive layover at a crew member's away-from-home station. Deadheading can be done via company regular train, buses, passenger trains, and taxis. Different transportation modes vary in their cost, speed and availability. If deadheading cannot resolve a crew shortage, the crew dispatcher can temporarily call an extra crew to work. However, the usage of extra crews is least preferred, and should be avoided whenever possible.

To summarize, crew assignment is a complex decision process that involves the selection of crew members from different crew pools, the timing and selection of transportation mode for deadheading, and the usage of extra crews. The key cost components that are taken into account in this decision process include lodging and heldaway cost at a crew member's away-from-home station, deadheading cost, and extra crew cost.

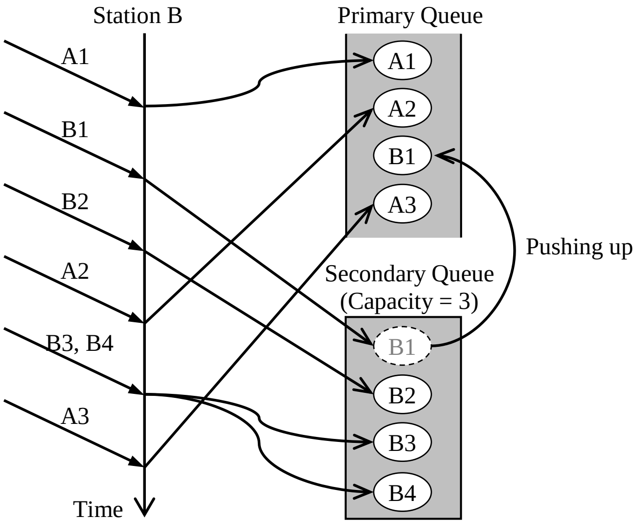

Figure 1 PSQ Illustration

Next we describe the crew dispatching rules in PSQ districts. The PSQ scheme consists of two crew queues: primary queue and secondary queue, at each home station. The first rested crew in the primary queue is called to work on the first available train. Crews in the secondary queue are called to work if and only if the primary queue has no rested crews. Figure 1 depicts how a crew member moves to either the primary queue or the secondary queue when she/he arrives at a station. A crew arriving at her/his home station goes to the secondary queue, whereas a crew arriving at her/his away-from-home station joins the primary queue. The primary queue is uncapacitated, while the secondary queue has a fixed capacity that is controlled by the crew dispatcher. Once the number of crews in the secondary queue exceeds its capacity, the first home crew in the secondary queue will be pushed up to the primary queue, thus blending the primary queue with both home and away-from-home crews.

3. MODEL FORMULATION AND SOLUTION METHODOLOGIES

The formulation uses three types of variables: connection variables *x*, taxi selection variables *y*, and assignment variables *v*. The connection variable x_{ij}^{kp} equals one if a crew member of occupation *k* from pool *p* is transferred from an inbound trip *i* to an outbound trip *j*, and zero otherwise. The binary variable y_i indicates whether or not a taxi trip *i* is selected in the solution. Trip assignment variables, v_i^{kp}, denote the number of crews of occupation *k* from pool *p* assigned to trip *i*. The objective is to minimize total crew assignment costs, including connection cost, trip cost, and taxi fixed cost. The constraints enforce that (1) all scheduled regular trains are staffed; (2) crew flow conservation on all trips; (3) the number of crews deadheaded on a taxi or train does not exceed its capacity; (4) assignments of crews to trains do not violate crew dispatching rules, namely the PSQ rules. The PSQ rules are not trivial to formulate and have not been studied in earlier literature. Their introduction to the crew assignment model makes the problem large-size and difficult to solve.

To solve the problem effectively, we propose two methods to enhance the model. The first method strengthens the crew dispatching constraints for unit-capacity trips. The second method follows the PSQ scheme to identify the latest outbound trip that each initial trip can connect to. Connections from the initial trip to trips later than its latest outbound trip are deleted. Both methods reduce the problem size significantly, and tighten the LP relaxation.

We develop a heuristic algorithm that can provide high quality solutions in one second. The algorithm runs in two stages. The first stage obtains an initial feasible solution by eliminating crew shortages on all trips, whereas the second stage applies several strategies to refine the initial solution based on certain characteristics of the initial solution. The heuristic solutions are used to warm-start CPLEX and accelerate the branch-and-bound procedure.

Table 1 Average Problem Size and Computational Result

District ID	# crews[a]	# trains	# connection variables	# rotation key constraints	# PSQ constraints	Heuristic gap[b] (%)	Avg. CPU time (sec)	Max CPU time (sec)
A	5	5	161	32	577	0	0.05	0.08
B	9	11	327	451	2,138	0	0.13	0.34
C	10	8	306	253	2,039	0	0.10	0.16
D	10	14	405	581	2,930	0	0.14	0.23
E	14	13	475	848	3,702	0.04	0.24	0.48
F	20	21	1,069	4,738	11,426	1.91	2.27	11.48
G[c]	22	40	1,779	7,450	0	0.18	2.29	6.85
H	25	19	1,423	4,017	14,716	0	0.85	1.37
I	25	36	1,720	15,660	24,438	0.01	11.37	87.20
J	27	39	2,501	27,671	36,278	0.06	10.08	31.93
K	33	34	2,157	15,625	27,303	0	3.67	7.24
L	38	56	3,606	57,583	58,950	0.07	30.42	115.55
M	47	52	3,593	33,372	51,931	0	8.72	29.50
N	52	61	3,306	63,068	64,843	0.01	28.48	124.54

[a] Number of crews averaged across two occupation types.

[b] Percentage gap of the heuristic solution value, compared to the optimal solution value.

[c] This district has zero-capacity secondary queues.

4. COMPUTATIONAL RESULT

We tested our model and methodologies with 140 problem instances from 14 different PSQ districts. Table 1 is a summary of the problem size, heuristic solution gap and total computational time of the optimization model. All statistics are averaged over 10 instances for each district.

5. CONCLUSION

Crew scheduling in U.S. freight railways is very different from that in airlines and passenger railways due to the differences in operational rules and configurations of these settings. This work focuses on crew assignment in PSQ districts that have not been studied in existing literature. We formulated the problem as a mixed-integer program, and proposed various model enhancements and solution methodologies to solve it effectively. By exploiting the crew dispatching rules, we significantly reduced the problem size with the latest connection method. Insights of the crew dispatching constraints lead to the idea of using CPLEX lazy constraint pool, which is very effective for large and difficult problem instances. In addition, we developed a heuristic algorithm based on the fact that the PSQ scheme fixes exact crew assignments for a given trip schedule. The heuristic algorithm provides high quality solutions that can be used alone. We also use the heuristic solutions to warm start CPLEX and accelerate the computation of the optimization model. We believe that our crew assignment model and solution methodology provide practical decision support capabilities that crew dispatchers can use in real-time to make more effective assignment decisions.

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