Abstract

We present a generic mathematical modeling approach for solving rolling stock scheduling problems. Our approach is based on a time-space network and a multi-commodity flow model; in order to deal with the various types of rolling stock scheduling problems faced by SNCF planners, it integrates numerous modeling settings and features including maintenance routing requirements which are treated by a heuristic post processing procedure.

Introduction

The production of railway circulations requires scarce and heterogeneous resources: railway infrastructure, rolling stocks, drivers, cars... More specifically, as far as rolling stock management is concerned, mid/short-term scheduling aims at (i) guaranteeing that the company production capacity is suitable for a given workload and (ii) increasing the productivity by anticipating technical operations that are necessary but do not provide any income (e.g. rolling stock maintenance and light traveling of resources).

Our work is motivated by the fact that several slightly different versions of that scheduling problem can be considered at SNCF:
- mid-term periodic schedules are built over a given planning time horizon and propose cyclic allocation patterns where resource types are allocated to “regular” (i.e. periodic) transportation tasks;
- short-term schedules are built for a given workload over a specific time horizon and provide precise information on rolling stock nominative assignment to tasks.

Besides, scheduling problems can be characterized, on the one hand, by the nature of the considered resource fleet and workload:
- the rolling stock fleet may be homogeneous or heterogeneous with regard to the technical types; resources may therefore be identified by their type and/or their name;
- the workload may contain fixed-type pulling tasks, for which a rolling stock type has already been chosen, or free-type pulling tasks, for which a rolling stock type has yet to be chosen among a given set of technically legal types.

On the other hand, several other functional features have to be considered:
- rolling stock grouping into homogeneous or heterogeneous consists; possible technical incompatibilities between given types of rolling stock are to be respected as well;
- resource repositioning on the network:
  - light travels which consist in moving rolling stocks across the network without pulling a train;
  - deadheadings which consist in integrating rolling stocks into a consist; deadheaded rolling stocks are called passive, while pulling ones are active;
- rolling stock maintenance requirements:
  - in a mid-term (tactical) scheduling context, these requirements consist in ensuring periodic visits (based on the traveled distance or on the number of operation days) of each resource operating the schedule, to particular depots;
  - in a short-term (operational), nominative scheduling context, maintenance operation appointments have already been scheduled over the planning time horizon and are to be covered by each appointed resource.
Tactical maintenance routing requirements

As mentioned, tactical maintenance routing requirements consist in ensuring that each operated rolling stock unit is routed to maintenance depots before it has reached its maintenance limit. Such maintenance limits are expressed in number of operating days or in traveled kilometers; for example, toilets in public transportation units are to be cleaned every two days at particular depots, and locomotives fuel tanks are to be filled every 2,000 kilometers.

Besides these limits, each maintenance operation requires a specific amount of time to be performed at depots. Actually, what has to be taken into account is not really the maintenance duration – that could vary from one or two hours to several days – but the time needed to swap the unit to be operated with another unit that is already available at the depot. Such unit swaps can generally be performed in about two hours.

Mathematical modeling approach

The proposed generic modeling approach for dealing with the various scheduling problems first relies on a space-time network representing problem data and settings. This network is automatically exploited to formalize a minimum cost multi-commodity flow problem as a mixed integer programming model which aims at maximizing workload production while minimizing the overall rolling stock costs [3].

This mathematical formulation of our problem is computed with CPLEX to obtain numerical values for each flow variable in the model; it is therefore needed to apply a flow separation procedure to this numerical solution in order to recompose resource paths on the network and thus to build rolling stock schedules.

Our recent research focus on integrating maintenance routing requirements in the above described mathematical approach for scheduling rolling stock. Literature review shows that such requirements can easily be modeled in a path formulation model but are quite difficult to consider exactly in a multi-commodity flow model where commodities correspond to resource fleets [1,2,4]: our approach clearly fall into the latter case when considering mid-term scheduling. We therefore choose to deal with that problem in a heuristic manner, adding a second-stage solution procedure to our modeling approach. This second-stage procedure first detects maintenance requirements violation by analyzing schedules computed by the first-stage model (former solution approach). It then introduces sets of possible break points in resource paths (sequences of trains assigned to a resource) where periodic maintenance requirements are not respected. Figure 1 illustrates a schedule with three lines – thus needing three rolling stock units – and three break points sets.

The space-time graph used in first-stage is consequently completed with routing arcs connecting stations and depots, according to every detected break points set. We then formalize a new integer program, slightly different from first-stage program: it mainly aims at finding a new rolling stock allocation pattern where trains coverage is preserved (with respect to first-stage coverage), and one break points set is chosen so that resources are constrained to visit depots (using the new station-to-depot arcs corresponding to that particular break points set in the graph) in order to respect maintenance requirements.
be necessary to involve more resources than in first-stage; our second-stage model actually allows additional flow units and its main objective is to minimize them.

As mentioned for first-stage solution, we are looking for rolling stock paths on the network, not for numerical flow values. A new flow separation procedure has then to be applied to solutions provided by CPLEX computations. This new procedure differs from the previous one in the way that it needs to consider first-stage paths and, more generally, first-stage schedule structure that was used to take assumptions on possible break points.

Figures 2 and 3 illustrates how schedule lines are “broken” on chosen break points – assuming 1st set was selected - and then what a new schedule should look like after recombining unit swaps and broken lines.

Our overall computation scheme is summarized below (see also figures 4 and 5).

- First-stage:
  - space-time graph and integer program are automatically built according to problem data and settings;
  - problem is solved by CPLEX;
  - rolling stock schedule (set of paths) is obtained by a flow separation procedure;

- Second-stage:
  - maintenance requirements violation are detected and break points in rolling stock paths are considered;
  - new space-time graph and integer program are derived from previous ones;
  - new problem is solved by CPLEX again;
  - new paths are computed by the new flow separation procedure and constitute new rolling stock schedule.
Conclusion

This two-stage solution approach for rolling stock scheduling problems at SNCF is currently being implemented into a C++ software prototype. Numerical tests are being carried on real-size instances to assess more precisely our approach and enhance its performances, in terms of solution quality and computation time. Future work perspectives include many refinements of the second-stage solution procedure, for example in order to allow recombining procedure to consider possible “line crossings” that could prevent from using additional rolling stock units, with regard to first-stage schedules.

References