Crew scheduling and benefits from integration of the planning process at a freight railway operator

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1 Introduction

In this paper we investigate to what degree we can integrate a Train Timetabling/Routing Problem and the Crew Scheduling Problem (CSP) as described by Caprara et al. (2007), based on a case at a freight railway operator, DB Schenker Rail Scandinavia (DBSRS).

The planning process at railway operators are described at different levels of detail by, among others, Caprara et al. (2007) and Lusby et al. (2011). In general, the planning process can be described in five levels as follows; Line Planning, Timetabling, Train Routing/Rolling Stock Circulation, Crew Scheduling and Crew Rostering.

In the Timetabling Problem we design a timetable for the desired lines - from the Line Planning Problem - and fix the departure and arrival times. Also, we allocate time-slots in the network to secure a feasible timetable. Before we assign engines and rolling stock in the Train Routing Problem to the lines in accordance with the timetable. We ensure that this allocation produce a feasible plan. Often the objective would be to minimize cost. In this paper we solve an integrated version of these two problems faced by a freight railway operator. We then integrate these two phases with the crew scheduling; the overall goal is to compare whether it is favorable to consider the crew scheduling at these earlier stages. Thus, we will solve the CSP based on a sequential approach and compare this to the CSP solved based on an integration with the Timetabling and Train Routing Problem.

2 Crew Scheduling

The purpose of the Crew Scheduling Problem is to design duties based on trips given by the Train Routing, subject to a set of work regulations.

In this paper we apply the CSP to the case from DBSRS. A particular difference is that we consider crew employed in different countries, and thus with different working
regulations. The crew considered work in Sweden, Denmark, or Germany. The main working regulations are similar though we have some differences that has to be addressed. Papers considering train working regulations related to these countries include; Rezanova and Ryan (2010) for a Danish, and Jütte et al. (2011) for a German setting.

3 Integration

The integration approach focuses on adjusting the cost of a job in the engine related part of the problem. An engine job performed at a specific time is described as $\tilde{d}$, whereas a crew task is described by $\tilde{p}$. A $\tilde{d}$ will thus usually correspond to more than one crew task $\tilde{p}$. We adjust the cost of performing a job at a specific time $\tilde{d}$, this adjustment in the cost stem from the cost of the corresponding $\tilde{p}$’s and will be the link between the two problems. Hence, the adjustment should somehow reflect the attractiveness or the cost implications a $\tilde{d}$ has on the crew plan. This could be that certain $\tilde{d}$ implies crew tasks, $\tilde{p}$, in the CSP that are unfavorable due to:

- A $\tilde{d}$ is prone to cause an additional night shift.
- Overlap with other trips, causing the need for extra crew.
- Lack of or to short time to connect to the next departure when servicing a destination that has infrequent connections.

Everything included here requires that we are able to calculate the cost implication before designing the timetable and adjust the costs.

4 Methodology

Both the combined Timetabling and Train Routing Problem, and the Crew Scheduling Problem are solved using exact methods, namely using a delayed column generation approach.

4.1 Engines

The engine problem is formulated as a Set Partitioning Problem, with $R$ being the set of engine routes, $r$, under consideration, $D$ as a set of all demands, $d$, $N$ is the set of all stations, indexed by $n$, $S$ a set of all time-slots, $s$, and $E$ the set of engine types, $e$. $w_e$ is the engine availability for engine type $e$, and is given as a parameter. The parameters determined in the sub-problem are $c_r$ which is the cost of routing $r$. $\alpha_r^d$ if demand $d$ is covered on route $r$. $\beta_r^n$ if station $n$ is used on route $r$, as origin station $= 1$, as destination
= -1, as both or neither = 0. \( \gamma^s_r \) if time-slot \( s \) is used by route \( r \). \( \delta^e_r \) if route \( r \) is driven by engine type \( e \).

\[
\text{minimize } Z = \sum_{r} c_r x_r \\
\text{s.t., } \sum_{r} \alpha^d_r x_r = 1, \forall d \in D \\
\sum_{r} \beta^n_r x_r = 0, \forall n \in N \\
\sum_{r} \gamma^s_r x_r \leq 1, \forall s \in S \\
\sum_{r} \delta^e_r x_r \leq w_e, \forall e \in E \\
x_r \in \{0; 1\}, \forall r \in R
\]

In equation (2) we make sure that all demands are serviced by the engines. To ensure that there is the necessary balance between the starting and ending stations of the engines we have the balance constraint, equation (3). In equation (4) we ensure that each time-slot is used at most once. Engine availability is ensured by equation (5). In the sub-problem we handle one weekly routing of an engine through the network. To get the routing we solve a Shortest Path Problem. As cost for the jobs we use the original costs adjusted with the duals from the master-problem. To ensure that we get elementary paths we solve an ESPPRC as in Feillet et al. (2004).

### 4.2 Crew Scheduling Problem

The CSP is formulated as a Set Covering Problem, for the coverage of duties, with extra constraints handling the maximum availability of crew at the different depots. As mentioned earlier the crew scheduling problem is solved by a delayed column generation approach, where we generate duties ad-hoc in our sub-problem.

\( R \) is the set of all duties (columns) under consideration, indexed by \( r \), \( P \) is the set of all trips, indexed by \( p \), \( Q \) is a set of all depots, indexed by \( q \). We have \( w_q \) as a predetermined maximum amount of work that can be allocated to a depot \( q \). The cost of a duty, \( r \), is given by \( c_r \), \( \alpha^p_r \) indicates if a trip \( p \) is covered by duty \( r \), and \( \beta^q_r \) how much work there is assigned to a depot \( d \) by duty \( r \).

\[
\text{minimize } Z = \sum_{r \in R} c_r y_r \\
\text{s.t., } \sum_{r \in R} \alpha^p_r y_r \geq 1, \forall p \in P \\
\sum_{r \in R} \beta^q_r y_r \leq w_q, \forall q \in Q \\
y_r \in \{0; 1\}, \forall r \in R
\]
Equation (8) ensures that all tasks are covered by a duty and equation (9) constrains the amount of work that can be assigned to a given depot. The duties are generated in a sub-problem by solving a Shortest Path Problem on a graph representing the tasks and adhering to the working regulations.

5 Conclusions

In addition a computational study will be conducted in order to assess whether the integration is beneficial to the freight railway operator. The study will be based on real data provided by DBSRS. The implementation is done in C++ using the IBM ILOG CPLEX 12.4 callable library.

References


