

# Rail Crew Re-Scheduling: from Planning towards Operations

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## 1 Introduction

In the Dutch railway network, there are a few times per week modifications in the timetable necessary due to unexpected maintenance projects or planned maintenance project that finish later than expected. Moreover, there are about 20 disruptions per day on average. These disruptions can be caused by the infrastructure (e.g. broken switches, no power supply), the weather (e.g. longer braking times due to wet leaves on the track), third parties (e.g. suicides, accidents with other traffic), and the operator itself (e.g. broken rolling stock engines, sickness of crew). In the Dutch situation, the infrastructure manager ProRail is responsible for modifications in the timetable. However, the rolling stock circulation and the crew schedules are the responsibility of the operators. The main Dutch railway operator, NS, changes these schedules in its Operational Control Centers. Currently, there is no decision support at all in these centers. In this research, we develop some algorithms for crew re-scheduling to support their work.

Crew scheduling is one of the most successful OR applications in the railway industry (see e.g. Abbink *et al.* (2005); Fores *et al.* (2001); Kohl (2003); Kroon & Fischetti (2001) for applications at several railway companies). However, only limited research has been done on crew re-scheduling. In earlier work, Huisman (2005), we developed an approach for the Crew Re-Scheduling Problem (CRSP) in case of planned maintenance work. As far as we know, this is the only paper that deals with crew re-scheduling in the railway world. In this paper, we will apply this approach for re-scheduling

problems due to unexpected events. These events could be either unplanned maintenance, which is normally known a few hours up to a few days ahead, or disruptions, which happen during the operations itself. In that case, a quick reaction is required. In general, there is about 15 minutes to come up with a new schedule and communicate it to the drivers and conductors.

In Sections 2 and 3, we repeat the model and algorithm to solve the CRSP proposed by Huisman (2005). Afterwards, we discuss in Section 4, some extensions such that the algorithm can be applied in the context of unplanned maintenance and disruptions as well.

## 2 Mathematical formulation

The mathematical formulation for the CRSP proposed by Huisman (2005) is equivalent to a set covering formulation.

Let  $N$  be the set of tasks, which need to be scheduled. Furthermore, let  $\Delta$  be the set of original duties that are considered for re-scheduling. In the case of planned maintenance, this is often the complete set of original duties, but in case of unplanned events on for instance a single line, this can be just a subset. Moreover, define  $K^\delta$  as the set of all feasible duties which could replace original duty  $\delta \in \Delta$ . The costs of a duty  $k$  replacing original duty  $\delta$  is denoted by  $c_k^\delta$ . The parameter  $a_{ik}^\delta$  is 1 if task  $i$  is part of this duty, and 0 otherwise. Finally, decision variables  $x_k^\delta$  indicate whether a duty  $k$  replacing original duty  $\delta$  is selected in the solution or not. The CRSP is then formulated as follows.

(CRSP):

$$\min \sum_{\delta \in \Delta} \sum_{k \in K^\delta} c_k^\delta x_k^\delta \quad (1)$$

$$\sum_{\delta \in \Delta} \sum_{k \in K^\delta} a_{ik}^\delta x_k^\delta \geq 1 \quad \forall i \in N, \quad (2)$$

$$\sum_{k \in K^\delta} x_k^\delta \geq 1 \quad \forall \delta \in \Delta, \quad (3)$$

$$x_k^\delta \in \{0, 1\} \quad \forall \delta \in \Delta, \forall k \in K^\delta. \quad (4)$$

The objective (1) is to minimize the total costs of the duties. The first set of constraints (2) guarantee that every task is covered by at least one duty. The constraints (3) require that each original duty is replaced by at least one new one. We have “ $\geq$ ” instead of an equality sign, since it is sometimes possible that, due to the changes in the timetable, more duties are necessary than in the original schedule. By introducing high fixed costs for each duty, the number of extra duties will be minimized. In particular, there will be

no extra duties if they are unnecessary. Moreover, we assume here that an original duty can always be replaced by a new one. We can guarantee this by allowing that an original duty is replaced by an empty one, which practically means that the driver assigned to this duty will get an extra day off or he can act as a standby driver.

### 3 Algorithm

In this section we repeat the column generation based algorithm to solve the CRSP as presented in Huisman (2005). An outline of the algorithm is given in Figure 1.

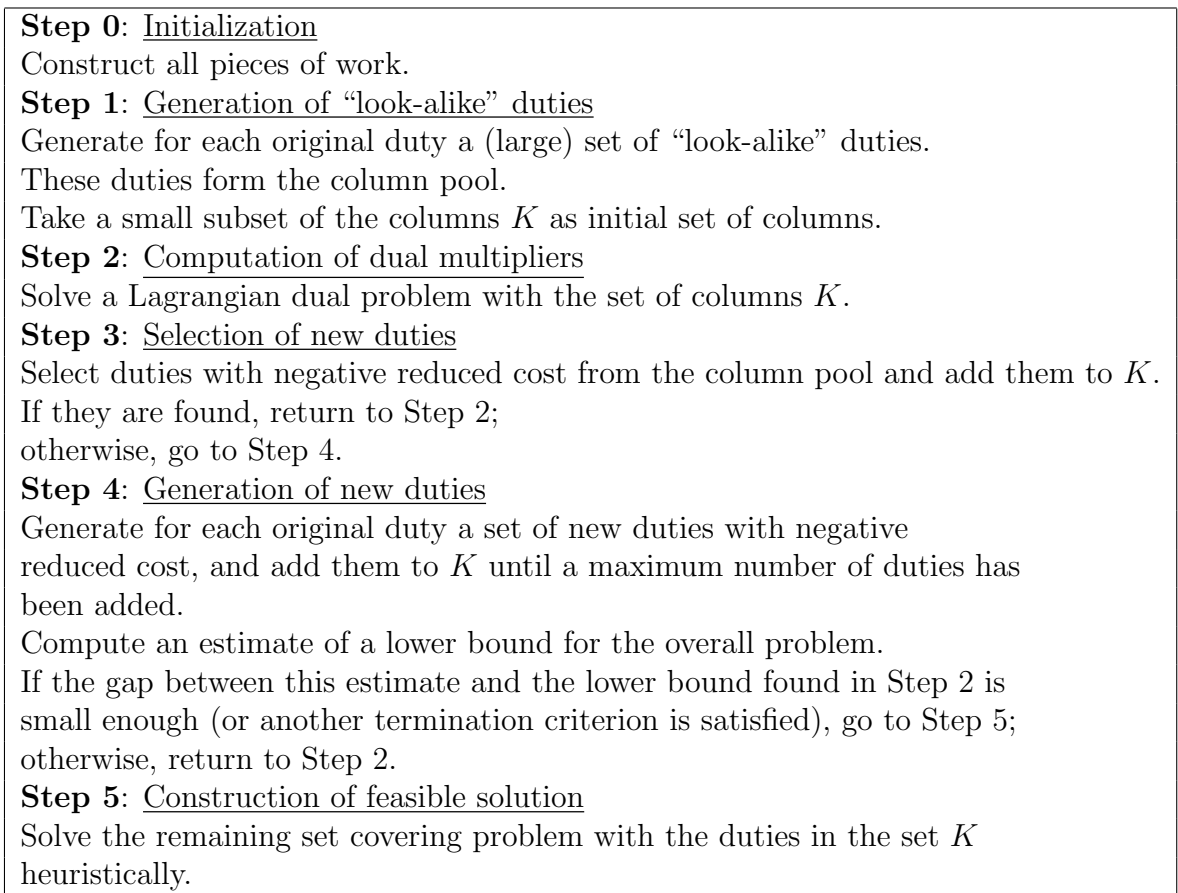


Figure 1: Algorithm to solve the CRSP

Below, we give a short description of the algorithm. For the details, we refer to Huisman (2005).

In Step 0, pieces of work are constructed. These are sequences of tasks on the same rolling stock. These pieces are used to generate the duties later on. In the first step, for each original duty where at least one of the original

tasks does not exist anymore, we generate some alternative duties. These duties should look like the original one. We use Lagrangian relaxation to obtain the dual multipliers (Step 2). With subgradient optimization (see e.g. Beasley (1995)) we solve the Lagrangian dual problem. With the multipliers obtained in Step 2, we can easily calculate the reduced costs of all duties in the column pool. The best duties with negative reduced costs are added to  $K$  (Step 3). It is very unlikely that a good solution can be found with only the “look-alike” duties. Therefore, other duties with negative reduced costs should be generated. This is done in Step 4 by solving a pricing problem for the original duties. Finally, in Step 5, a feasible integer solution is calculated. We use the very successful heuristic in the crew scheduling package *Turni* to solve the remaining set covering problem. This heuristic is based on the ideas of Caprara *et al.* (1999) with some local improvement heuristics.

## 4 Extensions of the algorithm

The algorithm described in Section 3 is developed for the CRSP in case of planned maintenance. In that case, the computation time is not very important. Huisman (2005) showed that real-world problems can be solved close to optimality, on the other hand the computation times can be up to 20 hours. In case of unplanned maintenance, a computation time of at most a few hours is acceptable, while in the case of disruptions only a few minutes is available. On the other hand, the problem instances are smaller, because in the case of planned maintenance several lines can be out of service, while in the case of disruptions it is mostly one line. Therefore, it is sufficient to consider only a subset of the original duties. However, it is not always clear which ones are necessary. This is an interesting research question on its own. Due to the smaller instances, and because a similar model and approach is used by Nissen & Haase (2006) for airline crew scheduling, we believe that the approach can be adjusted to give quick solutions as well.

We will discuss several ideas to speed-up the algorithm and we will show its results. These ideas are partial pricing, stabilization techniques, and fast heuristics to get feasible solutions of the set covering problems in Step 2. The latter one means that we do not have to first solve the relaxation, but that we can compute feasible solutions during the column generation process. If the dispatcher is satisfied by one of these solutions, he can decide to terminate the algorithm.

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