# A macroscopic railway timetable rescheduling approach for handling large scale disruptions

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## 1 Introduction

The occurrence of unexpected large disruptions, such as the unavailability of railway track segments due to broken overhead lines or rolling stock breakdowns, causes passenger train delays and passenger train cancellations with a consequent reduction of the quality of service to the passengers. Therefore, it is crucial to recover from such situations as quickly as possible in order to reduce passenger dissatisfaction and to restore the service of the railway system.

Due to its complexity, the recovery problem is usually decomposed into phases that are solved in sequence. The main phases consist of timetable rescheduling, rolling stock rescheduling and crew rescheduling. Timetable rescheduling calls for determining a feasible timetable by applying reordering, retiming, or rerouting of trains, or even cancelling of trains. The derived timetable is input to the second phase, in which it may be necessary to determine a new rolling stock allocation, due to the changes applied in the previous phase. Similarly, the new timetable and rolling stock allocation are input to the last phase that aims at obtaining a feasible crew schedule. Obviously, a feedback loop is sometimes necessary if no feasible rolling stock or crew plan can be obtained, possibly requiring to cancel additional trains. Solving the three phases separately leads to sub-optimal solutions. However, solving them all in an integrated way would lead to unacceptably long computing times for real-time problems.

In this paper, we focus on the timetable rescheduling phase. Thereby we also take into account constraints from the rolling stock rescheduling phase in order to increase the probability of obtaining a feasible rolling stock schedule during the second phase. Constraints of the crew rescheduling phase are more difficult to be taken into account, since these include more complicated rules about (meal) breaks and durations of shifts. Therefore they are not considered in our model.

We study timetable rescheduling at a macroscopic level, i.e. with high level constraints disregarding detailed information on signals and routes inside stations or junctions. The reason is that we want to deal with a complex real-world railway network and, at the same time, to solve the timetable rescheduling problems in very short computing times. On a macroscopic level it has to be determined first which trains can still be operated with the remaining infrastructure capacity. Thereafter, small conflicts at the detailed level should be detected and solved by slightly delaying some trains.

We consider large disruptions related to blockages of one or more railway tracks between stations for a certain period of time (e.g. two hours). This kind of disruptions are very hard to manage by railway operators and infrastructure managers as they cause many changes in the system and decisions need to be taken very quickly. In addition, they are not uncommon events. Therefore the support of automated tools for handling this kind of disruptions is highly desirable.

The main contribution of this paper consists of proposing an Integer Linear Programming (ILP) formulation for solving the timetable rescheduling problem to deal with large disruptions on a real-world railway network, which takes into account constraints that allow to partially integrate it with the rolling stock rescheduling phase.

A useful feature of the presented model is that it takes into account the possibility of rerouting trains along alternative paths in the network in order to reduce the number of train cancellations.

The proposed model is solved to optimality by a general purpose solver on a set of real-world instance of Netherlands Railways in short computing times.

# 2 Problem description

We consider a real-time timetable rescheduling approach for railway networks on a macroscopic level. In case of a major disruption (i.e. blocked tracks) this approach is able to determine, by taking into account the available infrastructure capacity, which trains (or parts thereof) should be cancelled and which should be delayed such that as many trains as possible can still be operated. The use of the available capacity in this approach is maintained from a macroscopic point of view. By maintaining the rolling stock capacity, there is a very high probability that the new timetable has a feasible rolling stock schedule as well.

## 2.1 Resource restrictions

We distinguish between three types of resources which a train may occupy at any given moment, namely tracks in a station, tracks at open track sections, and rolling stock compositions.

The capacity of a station is characterised by the number of tracks it has, and a track may only be occupied by one train at any given time. Furthermore, after a train has used a track in a station a certain headway time needs to pass before another train can use the same track.

The capacity of an open track section between two stations is also characterised by the number of tracks it has. It is assumed that a train cannot switch tracks on an open track section, and a track can only be used by multiple trains at the same time if they run in the same direction. A certain headway time should be taken into account between two trains using the same track at the same time, and, after a train has arrived from a track, a certain headway time should also be considered before another train can use the track in the opposite direction.

At each station with a shunting yard, a limited number of rolling stock compositions is available at the start of the day. A train uses a rolling stock composition for the entire duration of its service, after which the rolling stock composition is moved to a shunting yard or is used by another train. Hence rolling stock compositions may only end their duties at stations with shunting yards. Furthermore, two trains may share rolling stock only if they are of the same type, e.g. intercity trains or regional trains. After a train has ended its service, a minimum turnaround time is required before the rolling stock composition of the train may be used by another train.

Finally, a minimum running time between two stations and a minimum dwell time inside a station should be respected by all trains. Furthermore, the arrival or departure of a train at a station may be delayed by not more than a certain amount of time, and trains may only end their service at their final destination or at their last stop before the disrupted tracks.

### 2.2 Assumptions

In addition to the restrictions, a certain number of assumptions are made. First of all, it is assumed that a train entering a station from an open section is able to reach every track in the station, regardless of the open section track it is entering from. Furthermore, all tracks in the station are assumed to have a platform next to it. It is also assumed that shunting yards have an infinite capacity, and that rolling stock compositions do not change during the day. Finally it is assumed that a track in an open section can be used in either direction.

## 3 Mathematical formulation

The macroscopic timetable rescheduling approach is based on an *event-activity network* represented by a directed graph $N = (E, A)$, which is associated with a set of trains $T$ and an original timetable for these trains. The set $E$ of events consists of a set $E_{\text{train}}$ of arrival and departure events of the trains in $T$ and a set $E_{\text{inv}}$ of inventory events representing the resource inventories at the start of the day.

Each event $e \in E$ is associated with a number of resources (rolling stock units, open section tracks and station tracks) which it occupies at the moment the event takes place, and an activity $a = (e, f) \in A$ directed from event $e \in E$ to event $f \in E$ denotes the fact that event $f$ consecutively uses one of the resources occupied by $e$. Between two events there can be multiple activities, but for every resource type there can be only one activity between each pair of events. A minimum duration $L_a$ is associated with an activity $a = (e, f) \in A$, which is necessary for the specific resource unit used by $e$ to become available for $f$. Summarizing, the activities determine the order in which the events use the resource units.

# 4 Computational experiments

To test our approach we perform computational experiments on part of the Dutch railway network. Only trains of Netherlands Railways, which is the major railway operator of the Netherlands, are considered. The mathematical model is solved to optimality (with a gap of 0.01%) by CPLEX 12.5.

## 4.1 Case description

For our computational tests we consider a heavily used part of the Dutch railway network. We take into account 26 stations/junctions where trains can switch tracks. Furthermore, our network consists of 27 open track sections between the considered stations. Of these sections, 3 are single tracked, 21 are double tracked, 1 has three parallel tracks and 2 have four parallel tracks. In total 16 train series run (mostly twice per hour) on this network, and in total 61 rolling stock compositions are available to run the trains of the complete day.

## 4.2 Disruption scenarios

To test the approach, a large set of disruption scenarios is created. For all of the 27 open track sections we constructed 30 scenarios of full blockages where all tracks of that section are blocked. In addition, for the 24 open track sections with more than one track, an additional 30 scenarios are constructed where only one track is blocked. The first scenario is a 2 hour disruption of that open track section starting at 9:00. Then we increment every time the start time of the the 2 hour disruption by one minute. Since the timetable of Netherlands Railways in this region is a half an hour cyclic timetable, a disruption starting at 9:30 should be similar to a disruption starting at 9:00. In total this leads to 810 scenarios of full blockages and 720 scenarios where only one track is blocked.

We take a buffer time of 1 hour into account before everything should be able to run as planned again. This means that with a 2 hour blockage all trains in a 3 hour period are taken into consideration in the timetable rescheduling.

## 4.3 Rerouting of trains

In our network, trains can be rerouted via Tilburg if there is a disruption between ’s Hertogenbosch and Eindhoven. For this case, 30 scenarios where one of the two tracks is blocked are constructed in a similar way as described in Section 4.2. In these scenarios only intercity trains are allowed to be rerouted.

### 4.4 Results

First of all, the experiments show that the computation time is not an issue if rerouting is not allowed. Furthermore, in case of a complete blockage, on average 6.5 hours of train running time are cancelled if no delays are allowed for trains which are not running at the start of the disruption. Allowing 5 minutes of delay for these trains reduces the amount of cancelled train running time by less than 10%.

If only one track is blocked, the effect of allowing 5 minutes of delay for trains that are not running at the start of the disruption is much higher. Also in some parts of the network it is still possible to run all trains if one track is out of service. The price of forcing the new schedule to be a regular one, in which the number of trains run in each direction is balanced, is less than 10%.

Results on the 30 scenarios in which there is a rerouting option for intercity trains show that the rerouting option reduces the amount of cancelled train running time a lot, especially if small delays are allowed. In the case that reroutings are allowed, the price of balancing the number of trains in both directions is high, but if reroutings are allowed, then adding balancing constraints to the model does not really affect the amount of cancelled train running time. However, the rerouting options increase the computation time significantly, in particular in combination with balancing constraints.

It turned out that 102 of the 1530 scenarios were infeasible in our model. Most of the time these infeasibilities were caused by the constraints that already running trains are not allowed to be cancelled anymore. Hence, if there is no capacity for those trains within the maximum allowed delay of 30 minutes, there does not exist a solution matching the restrictions.

## 5 Conclusions

In this paper we introduced an Integer Linear Program (ILP) to solve the railway timetable rescheduling problem. The railway timetable rescheduling problem considered in this paper has a macroscopic view on the infrastructure network, which consists of stations and open track sections, each one with a certain number of tracks. Furthermore, constraints on the available rolling stock are also considered in order to have a high probability that there is a feasible rolling stock schedule for the new timetable.

The ILP is modeled as an event activity network in which an activity refers to passing on a resource unit from one event to another event, thereby describing the order in which the events are carried out.

Computational tests are performed on part of the Dutch railway network. Solutions are provided within computation times which are suitable for use in practice, possibly except for the case where we allow trains to be rerouted, together with the constraint that the number of trains running in each direction should be balanced.

The results also show that, especially in case only one track is blocked, less trains need to be cancelled if it is allowed to slightly delay some trains.