Rolling Stock Rescheduling in Case of Delays

Rowan Hoogervorst · Twan Dollevoet · Dennis Huisman · Gábor Maróti

Abstract In this paper, we introduce the Passenger Delay Reduction Problem. Here, we focus on rescheduling the rolling stock assignment in order to minimize the passenger delays that follow from an initial delay, while at the same time taking into account traditional cost objectives on passenger comfort and operational performance. We introduce two models to solve this problem, which are based on two models that are commonly used to solve the traditional rolling stock rescheduling problem. The first is based on a multi-commodity flow representation of the problem with side constraints, while the second is a Branch-and-Price approach that assigns sequences of trips to the individual train units. We test the effectiveness of these two models on real-life instances of Netherlands Railways (NS). The results show that the rescheduling of rolling stock can significantly decrease the passenger delays in the system, where especially the rescheduling of transitions at terminal stations turns out to be effective in reducing delays.

Keywords Rolling Stock Rescheduling, Disruption Management, Column Generation

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1 Introduction

When asked for factors that negatively affect their traveling experience, many railway passengers will name delays as a primary element of inconvenience. In this paper, we focus on reducing such delays by means of rescheduling the rolling stock circulation, i.e., the assignment of rolling stock to the trips. Such a rolling stock circulation links trips that are operated by the same rolling stock unit. When a trip becomes delayed, these links will then cause delay to propagate to other trips. When rescheduling the operated rolling stock on a trip, one also changes these rolling stock links between trips and hence the propagation of delay. Our aim in this paper is to find rolling stock circulations that minimize the total passenger delay that follows from some initial delay, while still taking into account other factors such as passenger capacity and operational efficiency. We will refer to this problem as the Passenger Delay Reduction Problem (PDRP).

In this paper we will propose two new models to solve the PDRP, which are based on two dominant streams in the literature for solving the existing rolling stock rescheduling problem. The first of these models is based on a multi-commodity flow representation of the problem with side constraints, while the second is a path-based approach that is solved by means of Branch-and-Price. Moreover, we will test these methods on real-life instances of Netherlands Railways (NS) to investigate the extent to which these methods are able to reduce the passenger delays.

2 The Passenger Delay Reduction Problem

Rolling stock scheduling deals with assigning train units to the trips that are operated in the timetable. Essential regarding rolling stock scheduling at Netherlands Railways (NS) is that one is able to combine compatible train units into compositions. Such a composition is a sequence of the train unit types that comprise a train, where each train unit type differs in the passenger capacity it offers. An example of a composition is presented in Figure 1. To offer more flexibility, one is often able to change the composition of a train at transitions, which define the moments that a train is parked along the platform between trips. The shunting operations that are executed at a transition, i.e., the coupling of additional train units to a composition and the uncoupling of train units from a composition, are jointly referred to as a composition change.

![Fig. 1 Example of a composition: train unit with 4 carriages in front, train unit with 3 carriages in the back.](image)

A rolling stock circulation is now an assignment of compositions to the trips in the timetable such that feasible composition changes exist to facilitate
this assignment. Generally, one tries to find a rolling stock circulation that minimizes a cost function consisting of a large number of cost components, including factors such as offering enough capacity and being efficient from an operator perspective. In case that an existing rolling stock circulation exists and when we try to update it when a disruption occurs, we refer to this problem as rolling stock rescheduling. The main goal in rolling stock rescheduling is generally to minimize the deviation from the existing rolling stock circulation.

In this paper we consider rolling stock rescheduling for a specific type of disruption: a delay that has occurred for one or more trips. Essential for the PDRP is that different rolling stock rescheduling actions can change the propagation of these initial delays in the system. For example, by changing the composition change at a transition, we may prevent that a trip has to wait for delayed train units which are coming from a delayed trip. Another measure in our problem setting that may lead to delay reduction is that of changing the transitions between incoming and outgoing trips at a terminal station. Here, we allow that an incoming trip at a terminal station is linked to a different outgoing trip than was originally planned, a situation that is referred to as flexible turning (Nielsen, 2011).

While possibly helping to reduce delays, rescheduling actions can also be costly themselves. No longer coupling delayed train units at a transition may, for example, lead to a shortage of seats on the trips that follow this transition. Similarly, the use of flexible turning may require changes to the shunting plans at stations and to the operated crew schedules. Hence, the aim of the PDRP is to find a rolling stock circulation in which passenger delays are minimized, but in which also the originally considered cost objectives are still taken into account. In this paper we will consider a limited form of delay propagation when determining these delays, where we do consider the delay propagation that follows due to delayed rolling stock but where we do not consider the delay propagation as a result of headway times between trains. Moreover, we assume that part of the delay may be absorbed during the day of operation by buffers in the timetable.

3 Methodology

In this paper, we introduce two new models for the PDRP: the Delay Composition Model and the Delay Path Model. These models are respectively based on the Composition Model as proposed by Fioole et al (2006) and the Path Based Model as proposed by Lusby et al (2017), which are frequently used to solve the traditional rolling stock rescheduling problem. The former is based on a multi-commodity flow representation of the problem with side constraints and the latter uses a path based approach which considers an explicit assignment of tasks (i.e., trips) to each of the available train units.

Modeling the PDRP requires two main changes to these existing models. The first is the modeling of delay propagation as an effect of rolling stock rescheduling actions. For this, we essentially model two forms of delay propa-
gation: delay propagation from a predecessor to a successor trip at a transition and delay propagation as a result of coupling a delayed train unit to a composition at a transition. Note that in both cases the incurred delay is caused by the late arrival of train units.

Modeling the delay propagation from a predecessor trip to a successor trip at a transition can be done in a unified manner for both the Delay Composition Model and Delay Path Model. To model delay propagation as a result of coupling a delayed train unit, we make use of the characteristics of the Composition Model and Path Based Model. For the Delay Composition Model, we extend the existing concept of inventory that is used in the Composition Model, which tracks the number of train units present at a station at any moment in time. In particular, we record the delays with which train units enter and leave the inventory. We can then link the uncoupled and coupled train units, by requiring that the number of train units present in the inventory should be non-negative at any moment in time. For the Delay Path Model, we make use of the fact that we obtain explicitly the sequence of trips operated by a train unit in the Path Based Model. By recording at which trip a train unit is uncoupled before being coupled to another trip, we can then determine between which trips delay propagation occurs.

The second main change to the existing models concerns the modeling of flexible turning at terminal stations. For this, we use the modeling approach as introduced by Nielsen (2011), who models explicitly the number of compositions that are parked at the station between arriving at some incoming trip and departing in some outgoing trip. Moreover, we model the delay propagation that follows from the chosen assignment between incoming and outgoing trips. Here, we use similar ideas as have been used for the modeling of delay propagation due to the coupling of delayed train units. In particular, we keep track of the delay with which compositions arrive and depart the terminal stations in the Delay Composition Model, while we model in which trips a train unit arrives and departs from a terminal station for the Delay Path Model.

Finally, we penalize the presence of delays in the system. This is done by considering a weighted objective, which accounts for delays on top of the existing cost objectives that focus on passenger comfort and operational efficiency. Furthermore, by penalizing delays more heavily for those trips that have a higher passenger demand, we ensure that the impact of delays on passengers is taken into account.

4 Results

We benchmark the two proposed models on two different timetables operated by Netherlands Railways (NS), which are for respectively Intercity (long-distance) trains and Sprinter (short-distance) trains. Moreover, we consider three different moments of the day during which the initial delays occur: during the morning peak hours (Morning Peak), between the peak hours (Between Peak) and during the evening peak hours (Evening Peak). Random input de-
lays are then introduced into these timetables to obtain the different instances which are to be solved by the models. In this way, we create 25 instances for each of 6 different scenarios, which consider respectively the two different timetables and the 3 different moments of the day to introduce the disruptions.

Table 1 gives an overview of the effect that rescheduling, i.e., solving the PDRP by the proposed models, has on the delays that are faced in the problem instance. What we can observe is that in up to about 44% of the instances we are able to find optimal solutions in which the total delay is reduced. Moreover, the delay can be reduced by up to about 40% in the cases where rescheduling actions can be found. These results thus show that rolling stock rescheduling actions can significantly reduce the total delay in the system, even when balancing the effect of delays with other objectives. Furthermore, our computational experiments showed that optimal solutions can be obtained relatively quickly for these instances, where especially the Delay Composition Model is able to return high-quality solutions within a short timeframe. This allows the application of our work in the actual rescheduling of rolling stock, where the time available to make a decision is limited.

Table 1 Results displaying the effect on the delays for two different timetables (Intercity and Sprinter) and three moments of the day during which the initial delay occurs. The columns respectively indicate the percentage of instances where the delay is reduced (Reduced) and the average percentage of delay reduction for the instances where the delay can be reduced (Reduction).

<table>
<thead>
<tr>
<th></th>
<th>Intercity</th>
<th>Sprinter</th>
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<tbody>
<tr>
<td></td>
<td>Reduced</td>
<td>Reduction</td>
</tr>
<tr>
<td>Morning Peak</td>
<td>8%</td>
<td>40%</td>
</tr>
<tr>
<td>Between Peak</td>
<td>28%</td>
<td>29%</td>
</tr>
<tr>
<td>Evening Peak</td>
<td>8%</td>
<td>39%</td>
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Table 2 shows the impact that flexible turning has on the delay reduction. In particular, the table shows for how many of the instances in which rescheduling allows to reduce the passenger delays, flexible turning is used as well. What we can observe is that flexible turning is commonly used to reduce the passenger delays, where flexible turning is used in 50% to 100% of all the instances where delay reductions can be found. Moreover, further inspection of these results showed that flexible turning is often responsible for a significant part of the delay reduction that can be achieved for these instances. Combining these observations, the use of flexible turning turns out to be an important tool in reducing the passenger delays.

5 Conclusion

In this paper we have introduced the Passenger Delay Reduction Problem (PDRP), which focuses on minimizing the passenger delay that follows from
Table 2 Results displaying, for each scenario, the number of instances for which flexible turning occurs as a percentage of all the instances for which delay can be reduced.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Intercity</th>
<th>Sprinter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning Peak</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Between Peak</td>
<td>86%</td>
<td>89%</td>
</tr>
<tr>
<td>Evening Peak</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
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an initial delay in the railway system, while at the same time taking into account objectives on passenger comfort and operational efficiency. Moreover, we have introduced two new models to solve the PDRP and have shown how these models can be derived from two existing models that are commonly used to solve the rolling stock rescheduling problem. By means of testing these methods on real-life instances of Netherlands Railways (NS), we have shown that rolling stock rescheduling is able to significantly reduce the passenger delays that are encountered in the railway system. Moreover, we have shown that especially flexible turning plays a large role in reducing the passenger delays.

References