



A microscopic model for optimal train short-turnings during complete blockages



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ABSTRACT

Currently railway traffic controllers use predefined solutions (contingency plans) to deal with a disruption. These plans are manually designed by expert traffic controllers and are specific to a certain location and timetable. With a slight change in the timetable or infrastructure, these plans might not be feasible and have to be updated. Instead traffic controllers can benefit from algorithms that can quickly compute an optimal solution given a disruption specification. This paper presents a Mixed Integer Linear Programming model to compute a disruption timetable when there is a complete blockage and no train can use part of the track for several hours. The model computes the optimal short-turning stations, routes and platform tracks. In this approach short-turning as a common practice in case of complete blockages is modelled at a microscopic level of operational and infrastructural detail to guarantee feasibility of the solution. To demonstrate the functionality and applicability of the model two case studies are performed on two Dutch railway corridors. In the first case, four experiments are presented to show how different priorities can change the optimal solution including the order of services and the choice of short-turning station. In the second case the performance of the model on a big station is investigated. It is shown that the model can compute the optimal solution in a short time.

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1. Introduction

Railway operations are prone to unplanned events such as infrastructure failure or incidents. A timetable is designed to recover from small delays. However, in case of events that can lead to the blockage of a track section for several hours, the resources need to be rescheduled. Trains approaching the blockage cannot proceed with their original plans and have to short-turn at a station close to the disruption. Simultaneously, trains from the opposite direction are not able to pass the blockage and provide services further.

A common practice in case of complete blockages in railway operation is to short-turn trains. Short-turning is a measure that uses the arriving trains at a station before a disruption area to perform services in the opposite direction for which the trains could not reach the station from the other side of the disruption. The short-turning measure prevents the congestion of trains in the stations close to the disrupted area by maintaining the rolling stock circulation in the network. Providing services in the opposite direction can isolate the disrupted area by reducing delay propagation to the neighbouring stations.

To provide support for the traffic controllers, predefined solutions are generally used. These solutions which are called contingency plans are common practice in many countries such as the Netherlands, Germany, Switzerland, Denmark and

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Japan as pointed out by [Chu and Oetting \(2013\)](#). The solution provided by a contingency plan consists of cancelled, rerouted or short-turned services including the arrival and departure times and platform tracks. Obviously each contingency plan is designed for a specific location and a specific timetable.

The contingency plans are designed manually, therefore the suggested solution might not be optimal. For example the suggested solution does not always consider the operational constraints such as minimum short-turning time which eventually would result in an infeasible solution. Moreover they are not sufficiently detailed on the infrastructure allocation and they cannot cover all possible disruption scenarios throughout the entire network. Changes in the timetable or the infrastructure require an updated contingency plan. In case there is no relevant contingency plan, the traffic controllers have to deal with the disruption without any support. Therefore there is a need to develop an algorithm that is able to compute an optimal rescheduling solution in real-time.

There are several macroscopic rescheduling approaches proposed by [Louwerse and Huisman \(2014\)](#), [Zhan et al. \(2015\)](#) and [Veelenturf et al. \(2016\)](#). However providing a feasible solution requires a microscopic representation of the infrastructure and operation. [Ghaemi et al. \(2017\)](#) show the importance of employing microscopic models for rescheduling in case of disruptions. As [Cacchiani et al. \(2014\)](#) and [Ghaemi et al. \(2017\)](#) conclude, there are very few references that model disruptions at the microscopic level. The existing microscopic models can also be classified based on the covered level of detail. By doing so it is observed that none of the existing models such as [Hirai et al. \(2009\)](#) and [Corman et al. \(2011\)](#) provide a comprehensive solution with a sufficient level of detail for the entire disruption period. [Pellegrini et al. \(2014\)](#) developed a microscopic optimization model that provides rescheduling and rerouting solutions for railway disturbance management. The model computes the optimal route choice for each service by calculating the track section occupation based on the blocking time model ([Hansen and Pachl, 2008](#)). The advantage of this model is that the simultaneous occupation of each track section is avoided by defining an order variable. Unlike other microscopic rescheduling models such as [Caimi et al. \(2011\)](#) and [Lusby et al. \(2011\)](#) there is no need for pre-processing the track occupation for detecting any conflict.

To deal with disruptions of a complete blockage [Ghaemi et al. \(2016\)](#) propose a short-turning optimization model in which the arriving trains at the final station (before disruption) are assigned to the scheduled departures in the opposite direction. The final station before disruption is referred to as the primary short-turning station. The model allows the possibility for short-turning not only at the primary short-turning station, but also at a preceding station which represents the secondary short-turning station. Two main limitations of this model are that it excludes the possibility of reordering services and the infrastructure and operation are not considered at the microscopic level of detail. Fixed order can impose unnecessary restriction on the solution. For example by fixing the operation order of two train services from local and intercity lines might result in a situation where the intercity train is delayed because the preceding local train is delayed. While this can be avoided by considering a flexible order. The model proposed by [Ghaemi et al. \(2016\)](#) does not include the infrastructure and operation details and only computes the arrivals and departures. Thus based on these arrivals and departures the position of the trains along the routes can be roughly estimated. However in order to detect possible conflicts, it is necessary to know the precise running of the trains on track section level. Formulating the infrastructure and operation with a fine level of detail is essential to understand the real capacity. To give an example, in case of short-turnings, knowing the number of platform tracks in the station is not sufficient to compute a feasible solution. Although each platform track can be assigned to one short-turning at a time, but there might be conflicts with other trains in the inbound and outbound routes to and from the station. A conflict can be resolved by either rerouting or rescheduling the operation. Thus it is important to carefully take into account the movements of the trains specially in the short-turning stations.

The contribution of this study is a rescheduling model that selects the optimal short-turning stations, in/out bound routes and platform sections for all the services including the short-turning trains. In this paper we adopt the microscopic rescheduling model by [Pellegrini et al. \(2014\)](#) and extend it with the short-turning possibility introduced by [Ghaemi et al. \(2016\)](#) for the case of a complete blockage. In this way the limitations of the model by [Ghaemi et al. \(2016\)](#) are removed as the microscopic model takes into account the reordering possibility and represents the infrastructure and operation with fine level of detail. The extended MILP model computes optimal rerouting and rescheduling solutions for cases of complete blockages where all the approaching trains towards the blockage need to short-turn. Moreover some services might need to be cancelled. A key assumption of this extension is that a reliable disruption length estimate is available. There are different approaches to estimate the disruption length such as the one developed by [Zilko et al. \(2016\)](#) using Copula Bayesian Network. Within the disruption period, the arriving trains should be short-turned and assigned to the departing schedules in the opposite direction. The extended part includes the choice of short-turning taking into account the operational constraints such as minimum short-turning time. In other words, the model determines which scheduled departing service in the opposite direction is being performed by each approaching train. Since all the approaching trains to the disrupted area need to short-turn, there might not be enough capacity in the primary short-turning station. For this reason the possibility of short-turning at a secondary station is included. Although an early short-turning implies more service cancellations, it can result in less total delay.

The remaining of the paper is structured as follow: in [Section 2](#), first the macro short-turning model and the micro rescheduling model are described briefly and then the formulation of the integrated model is presented. [Section 3](#) shows the application of the model on two Dutch railway corridors and finally [Section 4](#) discusses the conclusions.

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