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Macroscopic multiple-station short-turning model in case of complete railway blockages

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A R T I C L E I N F O

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A B S T R A C T

In case of railway disruptions, traffic controllers are responsible for dealing with disrupted traffic and reduce the negative impact for the rest of the network. In case of a complete blockage when no train can use an entire track, a common practice is to short-turn trains. Trains approaching the blockage cannot proceed according to their original plans and have to short-turn at a station close to the disruption on both sides. This paper presents a Mixed Integer Linear Program that computes the optimal station and times for short-turning the affected train services during the three phases of a disruption. The proposed solution approach takes into account the interaction of the traffic between both sides of the blockage before and after the disruption. The model is applied to a busy corridor of the Dutch railway network. The computation time meets the real-time solution requirement. The case study gives insight into the importance of the disruption period in computing the optimal solution. It is concluded that different optimal short-turning solutions may exist depending on the start time of the disruption and the disruption length. For periodic timetables, the optimal short-turning choices repeat due to the periodicity of the timetable. In addition, it is observed that a minor extension of the disruption length may result in less delay propagation at the cost of more cancellations.

1. Introduction

In railway operation unplanned events such as infrastructure failures, rolling stock breakdown, and incidents are recurrent and unavoidable. As a result, a part of a railway track might be unavailable for several hours. In such cases, the traffic controllers have to deal with the disrupted traffic. Short-turning is a common practice to isolate the disrupted area. This measure suggests that those train services that are heading towards the disrupted area, short-turn in an earlier station and provide service in the opposite direction. In this way, some services can still be offered in the opposite direction and the trains do not queue up in the stations close to the disrupted area. Consequently, the disrupted area can be isolated from the rest of the network.

To improve the performance during the disruption, traffic controllers commonly use pre-defined solutions called contingency plans. Each contingency plan is manually designed for a specific disrupted area given a specific timetable. These plans resemble if-then scenarios: if a certain part of the infrastructure is out of service, then specific disruption measures should be pursued. The main input for designing contingency plans are the original timetable (basic hourly pattern) and the infrastructure layout around the disrupted location. The contingency plan then provides the disruption timetable structure that includes the cancelled services, operating services, and short-turned services. For each short-turned service, the arrival, departure, platform track and the train line numbers are indicated. The advantage of these contingency plans is that they provide some guidelines and consensus when there is a

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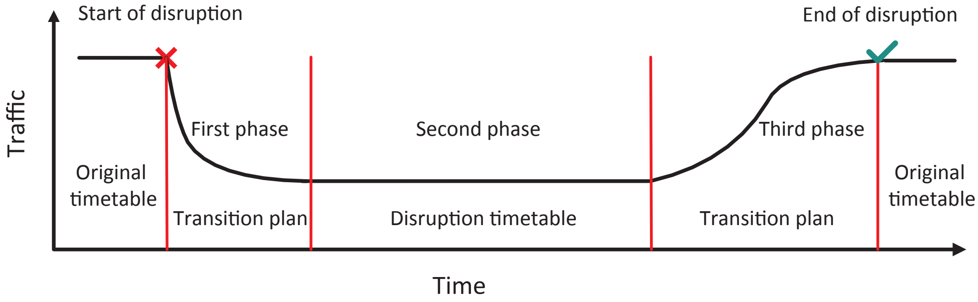

Fig. 1. The service level during disruptions (Ghaemi et al., 2017b).

need for a fast action to deal with the disruption Ghaemi et al. (2017b).

During disruptions the level of service decreases and remains so until the cause of disruption is solved and the original operation can be resumed. From this perspective the traffic level during a disruption resembles a bathtub as shown in Fig. 1. Corresponding to the bathtub, the disruption period is divided into three phases. The first and third phases are called transition phases as they represent the transition of operation from the original timetable to the disruption timetable in the second phase and vice versa. The first phase starts as soon as the blockage starts. Usually there are some irregularities (e.g. different short-turnings) before a stable and reduced timetable (disruption timetable) can be observed.

There are several processes during the first phase including receiving the disruption notification, announcing the disruption in the online system, identifying the exact disrupted location, selecting the relevant contingency plan and finally executing the plan. A study by Zon and Wink (2014) on 452 disruption cases of the Dutch railway network reports that the first phase can take on average around 40 min. In this study it is also shown that the longest process relates to selecting the relevant contingency plan and adjusting it which can take on average around 16 min. The third phase starts when it is known that the blockage is going to be resolved shortly and the train services can resume operating in the previously disrupted area. However it might take some time to recover from the disruption timetable to the original timetable as is shown in Fig. 1. For detailed processes during each phase see Ghaemi et al. (2017b).

Besides being static and inflexible, the main drawback of the contingency plans is that they do not provide any support for handling the transition phases. Having fast and smooth transition plans is essential for quickly resuming the disruption timetable in the second phase and recovering the original timetable in the third phase. The existing contingency plans are not able to provide any support for the execution of the transition phases, since they do not take into account the disruption period. After all, different causes of disruption can lead to different disruption lengths (Zilko et al., 2016). This leaves the traffic controllers without any support for making decisions in the transition phases. Besides the fact that the existing contingency plans do not suggest the optimal solution, with each update in the infrastructure or operation, the contingency plans need to be manually updated. Moreover, certain disruption may not have a corresponding contingency plan. A slight difference between the timetable in operation and the one used for designing the contingency plan may make the latter invalid.

The rescheduling domain in case of disruptions specially at the microscopic level is relatively unexplored, as Cacchiani et al. (2014) and Ghaemi et al. (2017b) conclude. Since disruptions of complete blockages can have a huge impact on the network it is necessary to consider bigger areas as opposed to the disturbances that perturb a timetable locally. The microscopic approaches, such as Pellegrini et al. (2014) or Caimi et al. (2012), can only include relatively small areas due to the magnitude of the modelled details. Despite techniques such as the one developed by Samá et al. (2017) to reduce the number of route choices, considering several stations at the microscopic level can lead to long computation times. Thus the focus of this literature is on the macroscopic rescheduling models that can handle disruptions. Zhan et al. (2016) apply a rolling horizon approach to take into account the uncertainty of disruption length for rescheduling in case of the partial blockage. Xu et al. (2017) developed a rescheduling model for disruptions caused by temporary speed restrictions. Since there is no blockages short-turning is not considered as a rescheduling measure. Coor (1997) investigates the impact of the short-turning strategy on the passenger waiting time on a high-frequency single transit line and concludes that in case of severe delays it is more beneficial than in case of small delays. In another study by Shen and Wilson (2001) different strategies such as short-turning, holding and stop skipping are examined. It is concluded that the combination of short-turning and holding strategies can reduce the mean passenger waiting time considerably. Ghaemi et al. (2016) model short-turning exclusively as a main measure to handle disruptions during the second phase. Only one side of the disruption is considered and the impact of the transitions are discarded. Its focus is on the trade-off between cancellation and delays by selecting different cancellation and delay penalties. Ghaemi et al. (2017a) extend the microscopic rescheduling model developed by Pellegrini et al. (2014) with the short-turning model presented in Ghaemi et al. (2016). Louwerse and Huisman (2014) develop a MILP model to compute the disruption timetable by maximizing the service level. Similarly Binder et al. (2017) develop an ILP model to compute a disruption timetable with three objectives of passenger satisfaction, operational costs and deviation from the original timetable. Veelenturf et al. (2017) developed a heuristic to adapt the timetable during disruption. To find the best adaptation, a list of alternative timetables are evaluated in terms of rolling stock and passenger flow and the one with the least consequences is selected. These references focus on the second phase of the disruption and neglect the transition phases. There are a few models that address the recovery from a disruption such as Jespersen-groth et al. (2009), Meng and Zhou (2011), Narayanaswami and Rangaraj (2013), Zhan et al. (2015). However, they do not provide any support for the second phase of the disruption. There are a few references such as