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Procedia - Social and Behavioral Sciences 111 (2014) 528 – 537

Procedia
Social and Behavioral Sciences

EWGT2013 – 16th Meeting of the EURO Working Group on Transportation

Recovery of Disruptions in Rapid Transit Networks with Origin-Destination Demand

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Abstract

This paper focuses on disruption management of Rapid Transit Rail Networks. We propose an integrated model for timetable and rolling stock rescheduling in order to minimize the recovery time, the passenger inconvenience and the incurred system costs. We introduce Origin-Destination demand formulation to the recovery problem in order to account for rerouting possibilities for passengers through the network, considering the presence of different transport modes. The computations presented are based on realistic problem instances of the Spanish rail operator RENFE. The tests have been accomplished using data from Madrid's rapid transit network.

Keywords: disruption management; integrated re-scheduling; timetable; rolling stock; passenger demand.

1. Introduction

Disruption management is the process of determining whether an incident produces a disruption or not and designing plans to recover from a disrupted situation. Such incidents may include infrastructure blockage, failing rolling stock, crew shortage, etc. In case of incidents the railway operations are said to be disrupted. A disruption imposes some new constraints to the railway operation (i.e.: canceling or delaying some trains).

The disruption management process includes the following major tasks: adapt the timetable according to the restrictions imposed by the disruption; re-schedule the rolling stock to cover the disrupted timetable; re-schedule the crew to serve the adapted rolling stock schedule; and re-schedule passenger.

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1877-0428 © 2013 The Authors. Published by Elsevier Ltd.
Selection and/or peer-review under responsibility of Scientific Committee
doi:10.1016/j.sbspro.2014.01.086

Defining recovery plans is a complex task since the presented resources have to be re-planned in near real-time. A disruption is in most cases addressed by solving the problem in a sequential manner. However, this approach will provide suboptimal allocation of resources, where the solution of one of the problems may restrict the set of feasible solutions of the problems solved sequentially.

A complicating issue in a disrupted situation is the fact that the duration of the disruption is usually not known exactly and that the status of the railway system is changing at the same time. That impact is generally in the form of a change in the system settings, a change in resource availability, or both. The response to a change in resource availability is to replan the current operations to apply only the available resources which may include giving up some of the planned services. A disruption may also cause a change in the system settings. Closing a station (or part thereof) temporarily is an example of a change in the system settings that affects the system's ability to operate.

A further change in the system environment is a deviation in demand because the passengers are free to choose their own itinerary in the network. In case of a disruption, some itineraries will not be available anymore and others may become less attractive. Passengers react to disruptions in different ways: either they reroute (within the network or with other modes of transport), or they wait for a train in their original itinerary, or they do not travel at all.

1.1. State of art

Jespersen-Groth et al. (2009) describe the disruption management process and the roles of the different actors involved in it. They discuss the three main subproblems in railway disruption management: timetable adjustment, rolling stock and crew re-scheduling. De Almeida et al. (2003) propose an approach for dealing with large scale disruptions where track capacity is greatly reduced. They propose a heuristic approach to re-building passenger transportation plan in real time. Kroon and Huisman (2011) describe models and algorithms for real-time rolling stock rescheduling and real-time crew rescheduling. Budai et al. (2010) state that in order to prevent expensive deadheading trips, it is attractive to modify the rolling stock schedules such that the rolling stock is balanced before the night. Nielsen (2011) formalizes the rolling stock rescheduling problem as the problem of adapting a set of rolling stock duties to a modified situation. The reschedule of the rolling stock considers a balance between the rescheduling effort and the service level. Almodovar and García-Ródenas (2011) deal with a special case of the vehicle re-scheduling problem for passenger railways in case of emergencies.

Sequential scheduling and re-scheduling have been common in the railway industry (see Cadarso and Marín (2010) and (2011) for examples in sequential planning). Cadarso and Marín (2012) demonstrate the benefits of integrated planning in timetable and rolling stock planning: the integrated approach leads to clearly superior solutions with regard to their efficiency and their robustness, while the integrated model is still solvable in reasonable time for real-life cases.

Cadarso et al. (2013) propose a two-step re-scheduling solution approach. First, they anticipate the passenger demand pattern using a discrete choice model. Then, they use an integrated optimization model for timetable and rolling stock recovery to minimize the recovery time, the passenger inconvenience and the incurred system costs. They report their computational tests on realistic problem instances of the Spanish rail operator RENFE.

1.1. Contributions

We present a new approach to deal with disruptions in rapid transit networks, where resources and capacities are limited and frequency values are high. For an undisturbed scenario we have full information on the timetable, rolling stock assignment and passenger demand. Once the disruption has started, we know the infra-availability of the network (with estimated time duration). We compute the expected passenger demand decisions according to a logit model. Finally, we run an integrated timetable, rolling stock and passenger use optimization model to deal with disruptions. Historically, disruption management has been addressed in a sequential manner. However, this sequential approach may produce suboptimal or even infeasible schedules. Therefore, we develop an optimization