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Benefits of a combined micro-macro approach for managing rail systems in case of disruptions

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Abstract

Optimisation and simulation tools are vital for planning and managing rail systems, providing performance analysis and evaluation of interactions without any kind of disturbance to the service. We may distinguish between combinatorial optimisation and simulation models which can be also classified into macroscopic and microscopic models. The former models describe the network and the timetable in a simple way by means of a simplified graph. The latter models consist of the specification of all technical characteristics related to infrastructure, rolling stock and signalling system as well as timetable data.

Macroscopic models are useful during the planning process when the design of service frequencies and capacity to satisfy demand are carried out. The major benefit of this approach is the possibility to consider jointly several features of the rail system obtaining reliable results. By contrast, microscopic models reproduce the network as closely as possible to the 'real world'; they allow evaluating the interactions among trains and the performance of the network precisely.

The aim of this paper is to propose a new approach for planning and managing the rail system combining both approaches macroscopic and microscopic. In particular, an optimisation model, based on a macroscopic approach, represents the kernel of the procedure and it is used as a first step to study any kind of scenario. The microscopic simulation model, by contrast, generates detailed (and precise) data, such as headways or running times, to overcome the approximations of the macroscopic model. Above all, in case of disruptions, the combination of the two models provides reliable results taking advantage of the benefits of the two approaches. Numerical applications have been applied in a realistic case taken from a real metro network located in the south of Italy; the preliminary results show the effectiveness of the proposed approach.

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Keywords: Rail; macro-optimization approach; micro-simulation approach; disruption; public transport management.

1. Introduction

The management of the rail service in the case of disruptions is an important process for any Train Operating Company (TOC). Especially in the case of dense rail networks characterised by high frequencies and short headways, recovering promptly from any kind of disturbances can prevent the propagation of knock-on delays to

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other trains (Corman and D'Ariano, 2012). Solving these problems in metro rail contexts is even more complicated since the configuration of the line and the stations does not give so many alternatives to re-establish the ordinary conditions.

For this reason tools are necessary to provide performance analysis and evaluations of interactions in order to define plans and strategies to be adopted in real time. In the literature, both macroscopic and microscopic models have been adopted to solve the so-called rescheduling problem (see for instance Corman *et al.,* 2012b; Cadarso *et al.*, 2013; Quaglietta *et al.*, 2013). However, the macroscopic approach, which provides outputs in short computational times and allows the implementation of optimisation models, is not able to evaluate precisely the interactions between trains. The microscopic approach, by contrast, produces accurate results but needs a great number of input data and requires long computational time. For this reason our proposal is to combine the macroscopic and the microscopic approach to provide reliable dispatching solutions taking advantage of the benefits of the two methods (Eickmann *et al.*, 2003). Moreover, our methodology analyses the effect of these rescheduling strategies on passenger demand: TOCs are interested in increasing service quality for improving the attractiveness of their services. In fact, recovery strategies focus on just operational aspects (i.e., reliability of the service) considering erroneously that it is always the best solution to achieve (Quaglietta *et al.*, 2011). Indeed, since neglecting user satisfaction during the rescheduling process could provide strategies which increase the disutility perceived by customers (D'Acierno *et al.*, 2012), the aim of the paper is to present an innovative procedure for managing rail and metro networks giving more importance to passenger needs.

The rest of the paper is organised as follows. In section 2 the state of the art regarding rail system management is provided. Section 3 describes the problem in detail. In section 4 the proposed methodology is analysed providing the analytical formulation. Section 5 presents the preliminary application on a real network and finally, in section 6, conclusions and research prospects are summarised.

2. State of the art

Planning and management are key steps for any TOC so as to keep high service quality standards. Many authors have indeed focused on these topics proposing different kinds of methods which are based either on optimisation or rail simulation approaches.

Caprara *et al.* (2010) for instance, proposed a robust routing model to assign paths to trains through a station by means of an optimisation procedure. A macroscopic simulation framework was also presented to validate the outputs of the proposed approach.

Cadarso and Marín (2010, 2011 and 2014) presented sequential and integrated optimisation models to solve the routing and rolling stock circulation problems in rapid transit networks. The authors gave importance to minimise possible delays during the service which could propagate throughout the network in short time. In fact, due to the constant increase in capacity consumption, it is likely that conflicts between trains arise after single deviations from the planned timetable (Goverde 2010), and therefore robustness is an important factor to assure during the timetable planning process. To reach this aim, Goverde (2007) adopted a timetable linear description by means of max-plus algebra theory and time event graph, describing a real time procedure to provide sensitivity analysis to delays.

Schlechte *et al.* (2011) dealt with the timetable optimisation problem through the combination of macroscopic and microscopic approaches. In particular, the authors presented an algorithm to transform a microscopic network into a macroscopic representation so as to optimise a given timetable by means of an integer programming model. Then, a comeback to the microscopic level assures that a conflict free timetable is obtained.

However, unforeseen events may cause perturbations; therefore, rescheduling actions must be adopted to restore schedule feasibility. D'Ariano (2008) proposed a real-time procedure based on microscopic models to minimise delays, once some deviations from the original timetable occur. The same method was then extended to coordinate two dispatching areas (Corman *et al.*, 2010) or multiple areas (Corman *et al.*, 2012a) so as to reschedule jointly a wider traffic zone.

Kecman *et al.* (2013) presented four macroscopic models to deal with rescheduling actions in the case of wide networks such as, national rail networks. In particular, the authors focused on computational time in order to produce dispatching actions very quickly considering the whole rail traffic flow and not just a small part of it.