Available online at www.sciencedirect.com
ScienceDirect
European Journal of Operational Research 189 (2008) 746–761
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
www.elsevier.com/locate/ejor

Real time management of a metro rail terminus

Marta Flamini *, Dario Pacciarelli

Dipartimento di Informatica e Automazione, Università Roma Tre, Via della Vasca Navale 79, 00146 Roma, Italy

Received 19 December 2005; accepted 29 September 2006
Available online 18 January 2007

Abstract

This paper addresses a scheduling problem arising in the real time management of a metro rail terminus. It mainly consists in routing incoming trains through the station and scheduling their departures with the objective of optimizing punctuality and regularity of train service. The purpose of this work is to develop an automated train traffic control system, able to directly implement most traffic control actions, without the authorization of the local area manager. The scheduling problem is modeled as a bicriteria job shop scheduling problem with additional constraints. The two objective functions, in lexicographical order, are the minimization of tardiness/earliness and the headway optimization. The problem is solved in two steps. At first a heuristic builds a feasible solution by considering the first objective function. Then the regularity is optimized without deteriorating the first objective function. Computational results show that the system is able to manage the terminus very efficiently.

Keywords: Scheduling; Train; Real time; Job shop scheduling; Blocking

1. Introduction

Railway traffic optimization is experiencing an increasing interest both among researchers and practitioners. Solving problems of practical interest in this field requires using detailed models, able to represent real and different railway traffic situations, and developing efficient algorithms to be used as decision support system in traffic control operation. Railway scheduling problems have been studied by using different techniques, including linear programming, integer or non-linear programming, graph theory and dynamic programming. Among the published results, we cite the papers by Carey (1994), Carey and Lockwood (1995), Higgins et al. (1997), Cai et al. (1998), Adenso-Díaz et al. (1999), Şahin (1999), Dorfman and Medanic (2004) and the survey paper of Cordeau et al. (1998). Most of published results focus on scheduling trains at off-line planning level and deal with simplified models, in which stations have often unlimited capacity. As observed by Carey and Carville (2003), busy stations may be the most complex part of the network to schedule. This is the case in

* Corresponding author. Tel.: +39 0655173225; fax: +39 065573030.
E-mail addresses: flamini@dia.uniroma3.it (M. Flamini), pacciarelli@dia.uniroma3.it (D. Pacciarelli).

0377-2217/$ - see front matter
doi:10.1016/j.ejor.2006.09.098

particular when dealing with metropolitan rail networks, in which scheduling decisions along the lines are typically simple, whereas traffic control at terminal stations is made more difficult because of the smaller area available and heavy traffic conditions.

This paper deals with the real time management of a metro rail terminus. The management and control of rail operations is usually based on off-line generated timetables for every train, and consists in operating in real time with strict adherence to these timetables. For a metro rail terminus, it mainly consists in routing incoming trains through the station and scheduling their departures according to the off-line timetable. However, when incoming trains are heavily delayed it is necessary to reschedule their departure times in order to provide service continuity and punctuality as much as possible. To a large extent, this task is carried out by human operators all over the world. A local area manager is in charge of setting routes and scheduling train departures with the objective of pursuing punctuality and regularity of the train service as much as possible. Computer support, when available, consists in most cases of a control panel describing the current situation of the network. On the other hand, there are several attempts to develop computerized decision support systems allowing a more efficient and easier management process.

There is a limited amount of published works on routing and scheduling trains at busy stations. Carey (1994) proposes a mixed integer programming (MIP) formulation for the problem, Carey and Carville (2003) provide heuristic algorithms that sequentially considers one train at a time and defines for it an arrival time, a departure time and a platform. If there is a conflict in the schedule, arrival or departure times for some train are increased until there is no longer a conflict. Carey and Crawford (2007) extend the single-station scheduling algorithms to find and resolve conflicts on lines between stations, and carry out an extensive computational study for a corridor with several stations.

Zwaneveld et al. (2001) consider the routing of trains through railway stations, given the detailed layout of the stations and a tentative timetable. They formulate the problem as a node-packing problem, and develop a branch and cut algorithm to determine a feasible path for as many trains as possible. Two additional objectives are considered in lexicographical order, namely the minimization of the number of shunting movements, and the maximization of train preferences for certain platforms or routes. Kroon et al. (1997) study the computational complexity of several variants of this routing problem.

In this paper we report on the implementation of scheduling algorithms for a real time Train Management System (TMS), able to route and schedule train movements through a metro line terminus. We report in particular on the results of a research project on the management of rail traffic at an underground metro rail terminus, in Italy. The scheduling algorithm developed within the project produces a plan of movements for all trains circulating in the terminus, with the objective of optimizing punctuality and regularity of the train service. According to railway practitioners preferences, punctuality is considered more important than regularity. In fact, respecting the off-line timetable would imply automatically respecting the regularity of train service, while the converse is not true. For this reason, in this paper the two objective functions are considered in lexicographical order.

One aim of the project is to move a step further in the direction of automating the train traffic control process, by enabling the TMS to implement most traffic control actions, without the authorization of the local area manager. To this aim, detailed optimization models are necessary, in order to guarantee that a solution, which is feasible for the optimization model, is always also physically feasible. Our optimization model incorporates a detailed description of the network topology, including railway signal aspects and safety rules. Differing from other authors, we explicitly include blocking constraints in the optimization model, which requires that a train, having reached the end of a track segment, cannot enter the subsequent segment if the latter is occupied by another train, thus preventing other trains from entering the former segment. In fact, omitting such constraints might cause deadlock situations in the terminus. To achieve this, we model the problem by using the alternative graph formulation of Mascis and Pacciarelli (2002), which allows modeling job shop scheduling problems with blocking constraints, and we adapt it to deal with specific constraints arising in the rail terminus.

The solution procedure described in this paper, consists in developing a plan of movements by first considering the punctuality function only. In a second step, the plan is improved by optimizing the regularity of train service, without affecting the punctuality objective function. More precisely, the overall decision problem is approached by dividing it into a routing/sequencing problem and a scheduling problem.