Applied Mathematical Modelling 38 (2014) 894–909

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Balanced train timetabling on a single-line railway with optimized velocity

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ARTICLE INFO

Article history:
Received 27 September 2012
Received in revised form 20 March 2013
Accepted 4 July 2013
Available online 23 July 2013

Keywords:
Train scheduling
Discrete event
Genetic algorithm
Travel advanced strategy

ABSTRACT

This paper aims to find an optimal balanced schedule with the least delay-ratio (i.e., the ratio of the total delay time and the total free-run time) by considering the impacts of the train velocity. A rigorous optimization model is proposed under the consideration of feasible speed constraint for finding the optimal velocity for each train on the railway line. To obtain an approximately optimal scheduling strategy, a combination of the improved TAS (ITAS) method and the genetic algorithm (GA), called GA-ITAS method, is in particular proposed to effectively solve the proposed model. The results of numerical experiments demonstrate the efficiency and effectiveness of the proposed approaches.

1. Introduction

Train scheduling, which focuses on specifying the departure and arrival times at each station, is required to satisfy a set of operational constraints, including the platform capacity constraints, headway constraints, velocity constraints, etc. Due to the complexity of these constraints, train scheduling problem then becomes a challenging and difficult problem for the real-world applications, especially for real-time scheduling. In general, two types of approaches can often be adopted to generate a feasible train timetable in the real-world applications, i.e., the manual method and computer-based method. In comparison, computer-based method has attracted more attentions in recent decades from the researchers and engineers with the development of computer techniques, and two scheduling techniques, namely mathematical optimization and simulation methods, have been proposed for generating a feasible or near-optimal schedule.

The majority of the researches in literature focus the scheduling and rescheduling methods on the mathematical optimization method, which was firstly applied to train scheduling problem by Amit and Goldfarb [1] in 1971. Three types of rail traffic environments, i.e., the single-line railway [2–6], multiline railway and railway network [7–10] have been often taken into account. For scheduling trains, for instance, on the single-line railway, Szpigel [4] firstly formulated the train scheduling problem as a mixed-integer program and applied a branch-and-bound algorithm to solve the problem. Zhou and Zhong [6] developed a branch-and-bound solution procedure to obtain feasible schedules with guaranteed optimality considering the constraints of the railway resource. Higgins et al. [2] presented a two-objective optimization model which minimizes the delay time and fuel consumption cost. And the model was developed as a decision support tool for dispatchers to optimize train schedules on a single line in real-time. Besides, an expected value programming model proposed by Yang et al. [5] to minimize the train delay time and the total passenger-time, in which the number of passengers getting on/off the train at each station is assumed to be a fuzzy variable. In recent years, some researchers turn to a more complex situation with

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0307-904X/$ - see front matter
http://dx.doi.org/10.1016/j.apm.2013.07.023

the development of computer techniques, namely, scheduling on the railway network. For this topic, Carey [7], Carey [11] and Carey and Lockwood [8] developed an iterative decomposition approach for solving the train timetable and path problem on the rail lines. In this approach, some solution heuristics and strategies, with which dispatchers can plan large-scale complex rail systems in an acceptable time, were proposed. Brannlund et al. [12] presented a heuristic optimization approach for the timetabling problem where Lagrangian relaxation solution approach was designed. Moreover, Ghoseiri et al. [9] developed a train scheduling model for minimizing the fuel consumption cost and the total passenger-time. Likewise, considering the global information of the railway network, Yang et al. [10] proposed an efficient mathematical model to find the optimal train movements strategy, which aims to minimize both energy consumption and travel time simultaneously.

It is worth pointing out that the train scheduling problem is essentially an integer programming problem known to be NP hard (see Cai and Goh [13]). Then, the above-mentioned mathematical programming models for train scheduling problem are usually solved by some special heuristics or modified algorithms. According to the statement by Dorfman and Medanic [14], two drawbacks mainly exist in the mathematical programming methods: (1) despite the tremendous speed of today's supercomputers, an integer programming problem with constraints for every train and siding in a railway network still cannot be resolved in an acceptable time; (2) once such a solution is implemented, whenever a single train is unable to keep the schedule, the entire problem must be rescheduled from the current state of the network. Due to these drawbacks, Medanic and Dorfman [15] proposed an effective simulation approach to schedule trains by considering the combination of local, state-dependent, travel-advance strategy (TAS) and discrete-event model, which can produce sub-optimal time-efficient and energy-saving schedules rapidly. In their recent works, they also extended the aforementioned approach to solve the large-scale real-world train scheduling problem. To further improve the quality of the generated schedule, Li et al. [16] proposed a modified TAS method by introducing some modified rules which aim to characterize train's micro operation based on global conflicts information. Also, they incorporated the simulation of train's acceleration and deceleration into their work after analyzing the train's micro movement features. To search for a good train schedule, Pudney and Wardrop [17] proposed a probabilistic search technique, called problem space search, with which hundreds of different train schedules can be quickly generated. As for the other simulation techniques, interested readers may refer to Frank [18], Peat et al. [19], Rudd and Storry [20], Petersen et al. [21], Sahin [3], Sauder and Westerman [22] and Jovanovic and Harker [23].

In literature, few researches allowed different train speeds on different sections such as Mills et al. [24]. The majority of the researches on train scheduling problem usually assume that the velocity of the train on each railway link is a pre-specified constant (see [14,16,5,6]). In general, although this assumption is much easy to be handled in the scheduling process, the generated timetable may probably correspond to some non-balance characteristics, e.g., causing more waiting time at stations or more delays on the railway line. For instance, according to the original timetable, a train is scheduled to arrive at an intermediate station and then wait a long time for another train's meeting and crossing. For this case, it is generally expected to further reduce this train's actual waiting time as much as possible if its velocity is allowed to be reduced, and what's more, this modification essentially produces two advantages, i.e., (1) decreasing the delay time at the stations and (2) saving the energy consumption according to Davis Equation because of the reduction of the velocity (see [9]). On the other hand, this non-balance feature (waiting time) can also be canceled by enhancing velocity of the opposite train at the cost of more energy consumption. Practically, this type of non-balance feature essentially can be attributed to the coupling effects of the non-optimal velocities of trains. With this concern, we are particularly interested in generating a balanced schedule through optimizing train's velocity with the least delay-ratio. To the best of our knowledge, this is a new idea in literature.

The remainder of this paper is organized as follows. For the completeness of this research, the discrete-event model proposed by Dorfman and Medanic [14] and Medanic and Dorfman [15], is firstly reviewed in Section 2. In Section 3, train scheduling problem with speed constraints is described in detail. To solve the model, a new scheduling algorithm, which is combined by our improved TAS and genetic algorithm and denoted by GA-ITAS, is proposed to find an approximate optimal schedule. The efficiency and the effectiveness of the proposed approaches are demonstrated in Section 4. Finally, a conclusion is made in Section 5.

2. Reviews of the discrete-event model

As we aim to propose a genetic algorithm based on our improved TAS to generate train schedules, a brief review of TAS will be given in this section for the completeness of this research.

Based on the concept of travel advanced strategy (TAS), an efficient train scheduling generation approach was proposed by Dorfman and Medanic[14] and Medanic and Dorfman [15]. In this approach, the involved trains on the railway network are firstly classified into two categories, i.e., trains on sections and trains at stations. A discrete event is defined through the arrival of a train at a station. That is, a discrete event occurs once a train arrives at a station. At the time that an event occurs, a capacity checking algorithm will then be employed to detect the state of the traffic system to avoid the possible future deadlock (A segment is said to be in a state of deadlock if no train on a segment of railway line can advance without causing a collision). In the capacity checking algorithm, for each train at a station, local and non-local information will be used to determine the capacity of the rest rail line of the focus train's trip. In the case of enough capacity, the focus train can be scheduled to continue its journey; otherwise, it is required to stop at its current station until the next discrete event occurs.