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Solving a periodic single-track train timetabling problem by an efficient hybrid algorithm

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ABSTRACT

Train timetabling with minimum delays is the most important operating problem in any railway industry. This problem is considered to be one of the most interesting research topics in railway optimization problems. This paper deals with scheduling different types of trains in a single railway track. The primary focus of this paper is on the periodic aspects of produced timetables and the proposed modeling is based on the periodic event scheduling problem (PESP). To solve large-scale problems, a hybrid meta-heuristic algorithm based on simulated annealing (SA) and particle swarm optimization (PSO) is proposed and validated using some numerical examples and an Iranian case study that covers the railway line between two cities of Isfahan and Tehran.

1. Introduction

Rail transportation planning encompasses several steps: analyzing the passenger's demand, line planning, train schedule planning, rolling stock planning, and crew management (Ghoseiri et al., 2004). Train scheduling is considered as the most challenging problems in railway planning that affects the interests of customers and the cost saving utilization of existed infrastructures. A train timetable defines the planed arrival and departure times of trains to/from stations. The classical objective function is to minimize the delays of trains to their destinations. The idea can also be extended when other kinds of objectives, such as minimization of the deviation from the working hours of crews and the fuel consumptions, are considered. The main purpose of this paper is to present a mathematical model to solve periodic train scheduling and a hybrid meta-heuristic algorithm that helps us detect some near optimum solutions for large-scale problems in a reasonable amount of time. During the past decade, a train scheduling problem has become one of the most interesting research topics in railway optimization problems. Cordeau et al. surveyed a number of mathematical models for train routing and scheduling (Cordeau et al., 1998). Furthermore, Table 1 shows a brief summary of the recent published literature in this field. In this table, the railway type is divided into network, single track, and double track categories. It is worth noting that a railway network is defined as a number of tracks, which may cross each other, so that trains may have different routing options.

The signaling system is defined as a tool to make a safe condition for train movements on block segments. We categorize the system in three different levels: the moving block, the fixed block and the simple mode, in which the distance between two adjacent stations consists of only one block section. By the station capacity, it is meant that the limitation of the number of tracks inside the stations is considered in the problem. The periodic railway timetabling problem is the issue of scheduling arrival and departure events of trains to/from stations given a line-plan, such that each event is recurring with some interval T, and all necessary safety conditions hold.

Serfani and Ukovich introduced a new formulation for periodic scheduling, named the periodic event scheduling problem (PESP) (Serfani and Ukovich, 1989). Since then, there have been tremendous efforts to apply this formulation for train scheduling problems (Peeters, 2003; Liebchen and Peeters, 2002; Shafia et al., in press). The periodic robust railway scheduling was investigated by (Kroon et al., 2007; Odijk et al., 2006). Kroon et al. used a stochastic optimization model to modify the time supplements and the buffer times in the generated timetables to improve the robustness. To provide a periodic timetable, the PESP method is employed in this paper. It is worth nothing that the periodic scheduling considered in this paper differs from so-called cyclic scheduling (CS), in which some set of activities is to be repeated to an indefinite number of times and it is desired that the sequence to be repeated. The difference

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Table 1
Literature review.

Authors	Railway type	Signaling type	Station capacity	Solving method	Case study
(Sepehri and Pourseyed-Aghaee, 1999)	Single track	Simple	□	Modified B&B algorithm (4 methods to reach the optimum answer in less running time)	–
(Sahin, 1999)	Single track	Moving block	□	Heuristic algorithm	Istanbul–Ankara (Turkish Railway)
(Adenso-Diaz et al., 1999)	Network	Simple	□	Heuristic algorithm	Spanish Railway
(Ghoseiri et al., 2004)	Network	Simple	■	1-Finding the Pareto frontier 2-Using distance-based method	–
(Walker et al., (2005))	Network	Simple	□	Modified B&B algorithm	New Zealand
(Zhou and Zhong, 2005)	Double track	Moving block	□	Modified B&B algorithm + Heuristic algorithm	Beijing–Shanghai (Chinese railway)
(Caprara et al., 2006)	Double track	Moving block/ Simple	■	Heuristic algorithm (Lagrange relaxation)	Italian Railway
(Ghoseiri and Morshedsolouk, 2006)	Single track	Moving block	□	Metaheuristic alg. (Ant colony)	–
(D'Ariano et al., 2007)	Network	Tracking-Fixed block	■	Modified Branch & Bound (B&B) Algorithm	Schiphol Bottleneck (Germany)
(Tornquist and Persson, 2007)	Network	Fixed block	■	Four Heuristic algorithm	Swedish Railway
(Mazzarello and Ottaviani, 2007)	Network	Tracking-Fixed block	■	Heuristic algorithm	Schiphol Bottleneck (Germany)
(Tornquist, 2007)	Network	Fixed block	■	HOAT Heuristic algorithm	Swedish Railway
(Zhou and Zhong, 2007)	Single track	Moving block	□	Modified B&B alg. (3 methods to reduce the solution space)	Chinese Railway
(Abril et al., 2008)	Single track	Simple	■	Constraint programming techniques	Spanish Railway
(Jamili and Kianfar, 2009)	Single track	Simple	□	Metaheuristic alg. (Simulated Annealing)	Iranian Railway

between the CS and PESP is that for the CS, one intends to minimize the periodic length; however, the PESP deals with a scheduling problem in which the periodic length is fixed and the main objective is to minimize the total weighted delays.

The paper is organized as follows. First, we give a brief explanation of the PESP in Section 2. The problem statement of the periodic single-track train scheduling is presented in Section 3. Section 4 presents the proposed simulated annealing (SA) and particle swarm optimization (PSO) algorithms as well as the hybridization of these algorithms. Thereafter in Section 5, the computational results are shown and the effectiveness of the proposed algorithm is investigated. Furthermore, we present the Tehran–Isfahan railway line as a case study of our proposed algorithm. Finally, the conclusion remarks are given at the end to summarize the contribution of this paper.

2. Periodic event scheduling problem (PESP)

Serafini and Ukovich introduced the periodic event scheduling problem (PESP), which is defined as the problem of scheduling a number of recurring events, such that each pair of events fulfills certain constraints. Given a time period of T, a set of V events and a set of constraints A, every constraint $a=(i, j)$ defines a lower bound l_a and an upper one u_a for a pair of events (i, j). The set of periodic interval constraints imposed on the schedule can be encoded in an event-activity graph $D=(V, A)$ with node set V and arc set A which represent events and activities, respectively, see Fig. 1.

A solution of a PESP instance is the one that satisfies following inequality:

$$(\pi_j - \pi_i - l_a) \bmod T \le u_a - l_a, \quad \forall a=(i,j) \in A, \tag{1}$$

where π_i is the occurrence time of event i. To apply integer programming techniques, the following reformulation of Eq. (1)

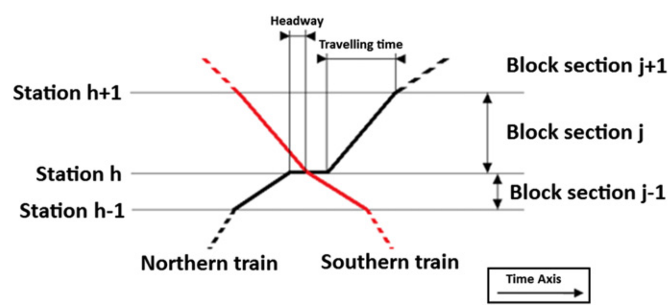

Fig. 1. Sample part of a graph for a single-track rail line.

can also be utilized.

$$l_a \le \pi_j - \pi_i - T \times z_a \le u_a \tag{2}$$

where $z_a \in Z$.

The reader is referred to a comprehensive study given by Kinder for more details (Kinder, 2008). There are some studies showing that the PESP is NP-complete for fixed $T \ge 3$ (Liebchen and Peeters, 2002; Nachtigall, 1996; Serafini and Ukovich, 1989).

In a single-track periodic train scheduling (SPTS) problem, events are defined as arrivals and departures. Therefore to reach the formulation of the SPTS problem, the constraints involved with the scheduling of arrivals and departures need to be modified based on the PESP approach. The SPTS formulation is presented in the next section.

3. SPTS model

The single-track periodic train scheduling (SPTS) problem is defined as follows. Consider a railway line consists of n stations connected by $n-1$ block sections. There are m trains passing the stations and block sections one after another. In general, in contrast with double track railway lines, the signaling system in