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A hybrid solution method for fuzzy train formation planning

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ABSTRACT

The train formation plan (TFP) determines the routing and frequency of trains, and assigns the demands to trains. In this paper, in order to consider the real-life condition of railways, a mathematical model with fuzzy costs is proposed for train formation planning in Iranian railway. In this fuzzy model, the costs are considered in three scenarios, namely optimistic, normal and pessimistic. The model is formulated based on the fixed-charge capacitated multicommodity network design problem. Since the TFP problem is NP-hard, an efficient hybrid algorithm combining local branching and relaxation induced neighborhood search methods is presented. A three-step method is applied for parameter tuning using design of experiments approach. To evaluate the efficiency and effectiveness of the proposed algorithm, the results are compared with those of the state-of-the-art optimization software.

1. Introduction

The train formation plan (TFP) is one of the most important research areas in rail transportation planning. Among different transportation modes, railway has comparative advantages over others in the area of safety and transportation capacity for the long-distance or large-scale freight transportation. In railway network, it is desirable that the transportation plan adjusts to the changing economic and regulatory conditions, and offers reliable, high quality and low cost services to their customers, thus making an optimal transportation plan becoming an important issue for railway networks [1].

The large-scale planning problem is classified into two separate operating approaches: scheduled railway versus demand-driven railway. Iranian railway is a demand-driven railway. Fig. 1 presents the train formation planning in demand-driven railways. In demand-driven railways, trains only run when the freight is ready and there is no fixed train schedule. Arrival and departure times would be determined at the operational level. Assad divided planning activities into strategic (long-term), tactical (medium-term) and operational (short-term) levels. The formation of trains is classified as a tactical level problem [2].

In this paper, a new mathematical formulation and a hybrid solution method for the TFP problem in Iranian railway are presented. In order to consider the real-life condition of railways, the costs in the proposed model are considered in fuzzy forms, and three different scenarios are defined and applied. This fuzzy TFP model is formulated as a network design problem. The network design models are easy to describe but the medium and large-scale ones are difficult to solve [3,4]. The complexity of a train formation problem dependents on several factors such as number of yards, number of demands, number of potential trains, the network topology, and the dominances of variable or fixed costs.

A hybrid solution method combining local branching and relaxation induced neighborhood search is proposed to solve the suggested model. In order to increase the efficiency and effectiveness of the proposed algorithm, design of experiments approach is used for tuning the parameters. To evaluate the proposed model and the solution method, they are implemented for Iranian railway and the results are compared with those of CPLEX optimization software.

The main contributions of this paper are as follows. First, a new mathematical formulation is presented for the fuzzy TFP problem. Second, to solve the model, a hybrid local branching algorithm and relaxation induced neighborhood search is proposed. Third, the proposed model and solution method are applied to generate the fuzzy TFP in Iranian railway network.

The remainder of this paper is organized as follows. In Section 2, the literature review is conducted. Sections 3 and 4 present the proposed fuzzy mathematical formulation and the hybrid algorithm.

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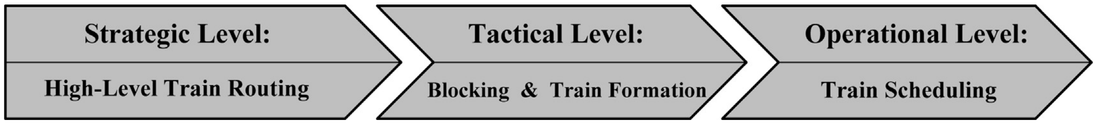

Fig. 1. Train formation planning in the demand-driven railways.

In Sections 5 and 6, parameter tuning by using design of experiments and experimental results are described. In Section 7, the fuzzy TFP model in Iranian railway is solved and the results are reported. Conclusions are presented in Section 8.

2. Literature review

The train formation plan (TFP) is a subclass of network routing problem, which is sometimes called the routing, and makeup problem [5]. One of the first efforts to integrate various components of the freight routing problem was proposed by Assad. He suggested a multicommodity network flow model that incorporates interactions between routing and yard activities [2,6]. Furthermore, the blocking policy may either be determined endogenously or be given as an input [7].

Crainic et al. proposed a mixed integer programming (MIP) model, which minimizes the operating and delay costs [8]. An MIP model and a heuristic method based on Lagrangian relaxation is presented by Keaton [9,10]. An implicit enumeration algorithm with ε-optimality to solve the TFP model is proposed by Lin [11]. Haghani pointed out there exist intense interactions between the routing of trains, their makeup and frequency, and the empty car distribution process [12]. However, the models that consider all these aspects often become extremely complex, if not simply intractable. Haghani proposed a formulation and a solution method for a combined train routing and makeup, and empty car distribution problem [13]. Marín and Salmerón proposed a local search heuristic for the tactical design of rail freight networks where the objective was to minimize the operating and time costs [14,15]. Gorman offered an application of genetic and tabu searches for the same problem [16]. Gorman designed a model to minimize the schedule-related costs of service within the rail-operating capabilities, which had been successfully used in Santa Fe Railway [17]. Godwin et al. presented a heuristic approach for this problem [18]. Shafia et al. proposed an MIP model for the TFP problem where the input data are subject to uncertainty [19]. Yaghini et al. presented a hybrid simplex-based simulated annealing for the TFP problem. The basic idea of their algorithm is to use a simulated annealing algorithm to explore the solution space, where the revised simplex method evaluates, selects and implements the moves [20].

The TFP problem is a special case of network design problem. In recent years, many researchers have investigated the network design problem, and presented many solution algorithms. The goal of network design problem is to plan services and operations to satisfy demand and ensure the profitability of the firm [21]. The branch- and-bound method can either be implemented as an exact or as an approximate method. The latter is achieved by fixing variables using the information given by the Lagrangian heuristic embedded in the branch- and-bound scheme [22]. Crainic et al. described a tabu search heuristic based on a path formulation of the problem [23]. Ghamlouche et al. presented a cycle-based neighborhood structure, which is obtained by moving flows around cycles [24]. This approach is later improved in Ghamlouche et al. by adding a path-relinking search [25]. Crainic et al. proposed a slope-scaling heuristic that combines a Lagrangian perturbation scheme with intensification and diversification mechanisms based on long-term memory [26]. Finally, Rodríguez-Martín and Salazar-González presented a local branching method for the capacitated fixed-charge network design problem [27].

The previous works dealt with the train formation problem under different planning horizons or in interaction with other elements of the operating plans. The real-life condition is considered in a few works. Shafia et al. scheduled different types of trains in a single railway track and focused on the periodic aspects of produced timetables. A fuzzy approach is used to reach a balance among the total train delays, the robustness of schedules, and the time interval between departures of trains from the same origins [28]. However, the previous researches do not present the fuzzy TFP model and solve the problems by considering crisp costs. The reasons for presenting a fuzzy model are as follows.

- The variable and fixed costs are dependent on many factors such as time, season and weather conditions.
- Inadequate knowledge of the effects of environmental conditions on the measurement, or imperfect measurement of environmental conditions.
- Inaccurate values of measurement standards.
- Inexact values of traffic constants, and other parameters obtained from external sources.
- Approximations and assumptions incorporated in the measurement method and procedure.

In the literature, considerable challenges are faced when solving realistically sized problem instances. These challenges are not only due to the large size of real applications but also due to a trade-off between variable and fixed costs. The exact algorithm guarantees the optimal solution but for large-scale problems, memory limitation and computing time are two fundamental obstacles making them unusable. The main goal of this paper is to present a fuzzy TFP model and a solution method to cover this gap in the literature.

In this paper, in order to consider the real-life condition of railways, a fuzzy mathematical formulation is proposed for Iranian railway network. Then, a new efficient and effective hybrid solution method is proposed to solve the suggested fuzzy TFP model.

3. Mathematical formulation

In this section, symbols used in the proposed model, the fuzzy numbers and the proposed fuzzy mathematical model for the TFP problem are presented.

3.1. Symbols

The different symbols used in the proposed mathematical model are defined in the Table 1.

3.2. Fuzzy numbers

A fuzzy number $\tilde{a}$ is a convex normalized fuzzy set of the real line $\mathbb{R}$ whose membership function is piecewise continuous [29–32]. Eq. (1) is the membership function and $\mu_{\tilde{a}}(\lambda x_1 + (1-\lambda)x_2) \geq \mu_{\tilde{a}}(x_1) \wedge \mu_{\tilde{a}}(x_2), \quad \lambda \in [0, 1]$.

$$\mu_{\tilde{a}}(x) : \mathbb{R} \to [0, 1] \quad (1)$$