Transportation Research Part C 86 (2018) 124–146

Contents lists available at ScienceDirect

Transportation Research Part C

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

Solving the train formation plan network problem of the single-block train and two-block train using a hybrid algorithm of genetic algorithm and tabu search

Jie Xiao, Boliang Lin*, Jiaxi Wang

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China

ARTICLE INFO

Keywords:
Two-block train
Train formation plan
Single-block train
Car-hour consumption
Genetic algorithm
Tabu search

ABSTRACT

This paper presents a formulation and solution of the railway freight Train Formation Plan (TFP) network problem in China using both the single-block trains and the two-block trains. Firstly, the single-block TFP model is established under given shipment demands, classification capacity and track quantity at the yards. Then the benefits which can be achieved by replacing single-block trains with two-block trains are systematically analyzed and summarized. The comprehensive optimization model of the train formulation plan using both the single-block trains and two-block trains is established aiming at the minimization of the total car-hour consumption at all yards. A hybrid algorithm of genetic algorithm and tabu search is developed to solve the single-block TFP model and then a greedy algorithm is proposed to replace single-block trains with two-block trains. Finally, the model and the solution approach are tested in an actual 19-yard railway sub-network in China.

1. Introduction

In 2015, the Chinese railway operating mileage is less than the half of the length of the United States railway operating mileage. However, the goods transported in the Chinese railway network (in ton-kilometer) is almost 80% of goods transported in the United States railway network (World bank open data, 2017). In 2017, with the deepening of the Chinese economic reform, the railway freight transportation demand increases significantly, which makes the network extremely stretched. This, added to the limited construction speed of the new infrastructures, stimulates the interest for improving the transportation efficiency through optimization of the current railway operation using the emerging technologies.

In the railway freight transportation system, one commodity also called a shipment which includes one or more cars with the same origin and destination (OD) may pass several yards. Since the classification process always causes some delay, to prevent the shipments from being reclassified at each yard, several shipments are grouped together to form a block. The block is defined with a determined OD pair. When a shipment is assigned into a block, it will not be reclassified until it reaches the destination of that block.

A shipment may be assigned to a direct block or a sequence of blocks along its journey. Theses blocks are moved by trains, where each train can carry one or more blocks. If a train is only assigned with a single block, it is called a single-block train. The single-block train has the same origin and destination with the block it carries. If a train carries two or more blocks, it is called a multi-block train, in which the long-distance block which is destined for the destination of the train is called a basic block while the short-distance block which is originated from or destined for an intermediate yard is called a complementary block.

* Corresponding author.
E-mail address: bllin@bjtu.edu.cn (B. Lin).

https://doi.org/10.1016/j.trc.2017.10.006
Received 22 April 2016; Received in revised form 28 September 2017; Accepted 4 October 2017
0968-090X/

Compared to the single-block train, the multi-block train has the following advantages (Chen, 2012): (1) To reduce the accumulation delay by replacing several single-block trains with a multi-block train; (2) To simplify the classification operation at the intermediate yards since only block-swap operations needs to be done instead of the classification of the whole train; (3) To speed up the train service by extending the train travel distance and avoiding classification of the long-distance shipments at the intermediate yards. However, the multi-block train has more stringent requirements on the traffic organization works.

In China, due to historical reasons and the constraints of the organizational efficiency, most of the trains among the major yards are single-block trains. As an advanced train organization form, the multi-block train has huge application potential in the Chinese railway freight network.

2. Literature review

The train formation plan (TFP), which determines which pairs of yards to provide train services and how the individual cars are routed through the train services, aiming at delivering all commodities to their destinations with the minimum total cost while satisfying the railway network constraints, is the foundation of the operation in the railway network. The TFP network problem consists of the below sub-class problems: the blocking problem, the train make up problem and the train scheduling and routing problem. Since the manual approaches are still widely used in the actual railway operation, which are time consuming and highly rely on the experience of the design managers, computer-based systems are now emerging that use the modern optimization models and algorithms to provide quick and high-quality solutions.

The objective of the blocking problem is to determine the blocking policy at each yard and the shipment-to-block assignment. One of the first models is proposed by Bodin et al. (1980), who formulated the problem using an arc-based mixed integer programming including capacity constraints at each yard in terms of the maximum number of blocks and the maximum car volume that can be handled. Recent researches formulate the blocking problem as a service network design problem where the nodes represent the yards and the arcs represent the blocks. Mixed integer programming (MIP) models are established and different heuristic optimization algorithms are proposed to solve the problem, including Lagrangian relaxation heuristic algorithm (Barnhart et al., 2000), ant colony optimization algorithm (Yaghini et al., 2011; Yue et al., 2011), genetic algorithm (Gorman, 1998; Yaghini et al., 2015), simulated annealing algorithm (Yaghini et al., 2014) and very large-scale neighborhood (VLSN) search algorithm (Ahuja et al., 2007), etc.

The train make up problem is to determine the train services to be provided and the routing strategy of the cars to the trains in the forms of blocks. In some literature, the blocking policy can be given as an input and the train make up problem focuses on the block-to-train assignment process. Thomet (1971) did the early work in this area. He developed a cancellation procedure that gradually replaces direct trains with a series of intermediate train connections in order to minimize operation and delay costs. Jha et al. (2008) formulated both arc-based and path-based time-space network model which aim to obtain the assignment solution of a given blocking plan to a given train schedule with minimum global transportation cost. Alternatively, the blocking problem can be integrated with the train make up problem and the blocking policy is determined endogenously. Keaton (1989) formulated the combined problem as a mixed integer programming model and presented a heuristic approach based on Lagrangian relaxation. In addition, Keaton (1992) formulated the problem as a 0–1 linear programming problem using the service network design method and used a dual adjustment method for implementing the Lagrangian relaxation. Fügenschuh et al. (2015) presented a linear mixed-integer model for a strategic freight car-to-train routing problem that arises at Deutsche Bahn. The model aims at finding the car routes with the most economical cost, which considers train and car travel kilometers and the amount of used sorting tracks. For the railway network where only the single-block trains are used, the blocking problem and the train make up problem are naturally combined. The typical reference is Lin et al. (2012). They built a bi-level linear integer model to solve the train service network problem of the China railway system. A simulated annealing algorithm is applied to the real-life Chinese railway sub-network consisting of 127 yards and a significant improvement of the total operation cost is achieved.

The train scheduling problem is to specify the timetable of the planned train services. The train routing problem is to determine the final travel path of each train. Although the routing plans of the trains are already set up at the tactical level in the train make up process, alternations and adjustments to the train paths are not avoidable in the timetable make up process at the operation level. Without taking the train routing problem into consideration, it may be difficult to find a feasible timetable which can accommodates all the planned trains and satisfy the track and yard capacity constraints. As a result, the train scheduling and routing problems are usually combined. Cordeau et al. (1998) and Caprara et al. (2002) presented excellent surveys of the early researches on this topic. Recently, most of the literatures formulate the integrated train routing and scheduling problem as an integer programming model and use heuristic approaches to solve it (Sun et al., 2014; Murali et al., 2016; Samà et al., 2016; Fang et al., 2017). These models usually only consider the macroscopic infrastructures and ignore the microscopic details which are important for the accuracy of the timetable. In order to improve the feasibility of the obtained timetable in practice, hierarchical models integrating the macroscopic level with the microscopic level are presented in some literature (Bešinović et al., 2016; Samà et al., 2017).

The above mentioned three sub-class problems of the train formation plan network problem are interrelated. In order to obtain the global optimal solution, some researches also try to consider the whole process as an integrated network design problem. Crevier et al. (2012) proposed a bi-level mathematical formulation which encompasses pricing decisions and network planning policies such as car blocking and routing as well as train make-up and scheduling. Zhu et al. (2014) presented a model integrating service selection and scheduling, car classification and blocking, train makeup, and routing of time-dependent customer shipments based on a cyclic three-layer space-time network representation of the associated operations and decisions and their relations and time dimensions. He also presented a matheuristic methodology and a new intensification mechanism to solve the model. Xiao and Lin (2016) presented a comprehensive optimization model which integrates the routing problem, shipment-to-block assignment problem and the block-to-