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Solving the block-to-train assignment problem using the heuristic approach based on the genetic algorithm and tabu search

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ABSTRACT

After the railroad blocking plan is generated, the block-to-train assignment problem determines which train services to be offered, how many trains of each service to be dispatched (service frequency) and which blocks to be carried by which train services. An integer programming optimization model is defined to solve the block-to-train assignment problem. The model aims to maximize the total cost savings of the whole railroad network compared to the single-block train service plan, where each block is allocated to a direct train service. The objective function includes the service design cost savings, the train operation cost savings, the car-hour consumption savings in the accumulation process, the car-hour consumption savings in the attachment and detachment operations and the waiting car-hour consumption savings. Furthermore, the model is improved to a path-based formulation, which has far fewer decision variables and is easier to solve for real-world problems. A heuristic approach based on the genetic algorithm and tabu search is developed to solve the path-based formulation. The model and approach are tested first in a small network to compare with the optimal solution obtained through the enumeration method and the solution obtained from commercial optimization software. Then the model and approach are applied to a real larger railroad sub-network in China.

1. Introduction

In 2016, around 2.3 trillion ton-km of goods were transported on the Chinese railroad network with only 124,000 km operating mileage. The goods transportation is combined with the passenger transportation on most of the lines and the passenger transportation always has a higher priority. The ever-increasing goods transportation demand, added to the limited investment and construction speed of new infrastructure, stimulates the motivation to optimize the current railroad operation. The train operating plan problem, which determines in which yards to provide which train services, how the individual cars are grouped into blocks, and how the blocks are routed through train services, aiming to deliver all cars to their destinations with the minimum total cost while satisfying the physical railroad network constraints and the customer requirements such as the yard classification capacity, the expected delivery date, etc., is the foundation of the railroad operation. The train operating plan problem includes many complex planning and execution decisions at different levels.

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Generally, it consists of the following sub problems: the blocking problem, the block-to-train assignment problem, the train scheduling and routing problem, the resource allocation problem and the empty car repositioning problem.

The blocking problem is the foremost sub problem of the train operating plan problem. In the railroad freight transportation system, a shipment consisting of cars with the same origin-destination (O-D) pair may pass through several yards. Since the classification process always causes some delay, to prevent shipments from being reclassified at each yard, several shipments may be grouped together to form a block. A block is associated with a specific O-D pair. After a shipment is placed in a block, it will not be reclassified until it reaches the destination of that block. Each shipment can be carried by either one direct block or a series of sequential blocks. The purpose of the blocking problem is to determine which blocks are to be built at each yard and how shipments are to be consolidated into blocks.

Once the blocking plan is determined, the next step is to consider which train services (defined by O-D pairs) are to be supplied at what frequency and the consolidation of blocks to train services, which is called block-to-train assignment. Each block can travel on several train services from origin to destination and each train service can carry different blocks on different segments of its journey. The operation to detach a block from a train service and then reattach it to another train service is called block-swapping. An extreme solution for the block-to-train assignment is where each block is allocated to a direct train service. Under this solution, since each train service only carries one block, we call it the single-block train service. The train service which carries more than one block during its journey is called the multi-block train service. Multi-block train services have a lot of advantages over single-block train services (Xiao and Lin, 2016). The purpose of block-to-train assignment optimization is to make use of the advantages of the multi-block train services to reduce the total operation cost of the railroad network.

The train routing problem determines which yards each train service will pass through during the journey from origin to destination. The train scheduling problem determines the timetable of each train, indicating the arrival time and departure time for each stop on the path. The resource allocation problem distributes the necessary resources to each train service to enable the appropriate service performance. Two major resources, locomotives and crew, are generally considered. The empty car repositioning problem indicates the distribution of empty cars to balance the car flow of the railroad network.

Generally, the core of the train operating plan problem is the two consolidation processes: the car-to-block assignment and the block-to-train assignment. On top of that, the train scheduling and routing problem (see, for example, Cordeau et al., 1998; Caprara et al., 2002; Rordriguez, 2007; Sun et al., 2014; Murali et al., 2016; Samà et al., 2016; Bešinović et al., 2016; Fang et al., 2017; Samà et al., 2017), the resource allocation problem (Gorman and Harrod, 2011; Suyabatmaz and Şahin, 2015; Janacek et al., 2017) and the empty car repositioning problem (Bektas et al., 2009; Upadhyay and Bolia, 2014) are considered.

There is rich literature in the research of the car-to-block problem. One of the first models was proposed by Bodin et al., (1980), who formulated the problem using an arc-based mixed integer programming model, including capacity constraints at each yard indicating the maximum number of blocks and the maximum car volume that can be handled. A recent trend is to consider the problem as a service network design problem, in which the nodes represent the yards and the arcs represent the blocks. Some recent typical research includes Barnhart et al., (2000), Ahuja et al., (2007), Yaghini et al., (2011), Yue et al., (2011), Lin et al., (2012) and Yaghini et al., (2015).

A few efforts in the literature seek exclusively to solve the block-to-train assignment problem. Thomet (1971) did early work in this area. He developed a cancellation procedure that gradually replaces the direct train services with a series of intermediate train service connections to minimize the operation and delay costs. Nozick and Morlok (1997) established an integer linear programming model to minimize the total cost through changing the assignment strategy of moving cars in a fixed train schedule, while satisfying the delivery due dates of the cars. A heuristic procedure was developed to solve the problem. Kwona et al., (1998) developed an algorithm to improve a given blocking plan and the block-to-train assignment. They formulated the problem as a linear multi-commodity flow problem and used the column generation technique as a solution approach. A recent typical research approach is by Jha et al., (2008). They formulated both arc-based and path-based time-space network models, which aim to obtain the assignment solution of a given blocking plan for a given train schedule with minimum global transportation cost. They also developed greedy and Lagrangian relaxation heuristic algorithms to solve the problem.

Since the above mentioned sub problems of the train operating plan problem are interrelated, some researchers consider several of the issues as an integrated optimization problem. Crainic et al., (1984) presented a comprehensive and adaptive model for the tactical operating process which considered the interactions between train routing, train make up, blocking strategy and classification operations at the yards. Haghani (1989) presented a formulation and solution of the combined train routing and makeup and empty car distribution model. Keaton (1989) formulated the combined train operating problem as a mixed integer programming model and presented a heuristic approach based on Lagrangian relaxation. Gorman (1998) developed a heuristic approach based on the genetic algorithm and tabu search to solve the freight railroad operating plan problem, integrating the train-scheduling and demand-flow problem. Recently, 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 relationships and time dimensions.

In this paper, we primarily address the train operating plan problem of the Chinese railroad freight. The Chinese railroad freight transportation has its own characteristics regarding the management system and the operation conditions. The Chinese railroad network operated by China Railway Corporation is geographically divided into 18 sub-regions, which are