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Modeling strategies for effectively routing freight trains through complex networks

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ABSTRACT

An important factor in an efficient operation of freight railroad companies is their ability to obtain routes and schedules that improve rail network capacity utilization. In this paper we present a decision tool to aid train planners obtain quickly good quality routes and schedules for short time horizons (e.g., daily) to better manage the limited track capacity available for train movements. This decision tool is made up of an integer programming (IP)-based capacity management model and a genetic algorithm (GA)-based solution procedure. The capacity management model assigns trains to routes based on the statistical expectation of running times in order to balance the railroad traffic. The GA procedure determines the best initial routes and release times for trains to depart from origin stations and enter a network, given travel time estimates across aggregated sections of a network. We test our modeling technique by comparing the travel times obtained for a network in Los Angeles using these initial routes and release times, with those obtained from a simulation model, presented by Lu et al. (2004), which has been shown to be representative of the real-world travel times. Our experimental results show that our recommended solution procedure is capable of lowering travel times, as estimated by Lu et al. (2004), by up to 20%.

1. Introduction

According to a study conducted by Hillestad et al. (2009), railroads contribute to transporting approximately 40% of the freight traffic in the United States, by freight ton-miles. The American Association of Railroads (AAR) expects the freight rail volume to dramatically increase by 2035, resulting in 55% of the rail network being congested. To effectively manage the capacity of the rail network system it is important to consider the problem of routing and scheduling trains at the macro level taking into account multiple rail routes for a given origin and destination. For example, in Southern California there are three distinct rail lines from the Colton crossing area to the Downtown area (two served by Union Pacific and one by BNSF). The capability to balance the freight rail traffic along the three routes has the potential to significantly reduce train travel times in the area.

Our research falls in the broad area of routing and scheduling trains as part of the railway *planning* process. The focus of this paper is the development of an optimization-based approach that can aid train planners to quickly develop good quality routes and schedules over medium-scale networks, which are 30–50 miles long, to better manage the limited track capacity

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available for train movements. Given the daily traffic volume, train mix or heterogeneity, and sets of origins and destinations, the integrated routing and capacity management model can be solved to obtain the routes the trains should travel on and their order of departure from the origin stations. This problem is akin to a *no-wait job-shop scheduling problem with alternative routes*, where the trains are similar to jobs that need to be processed and the rail-tracks are resources such as machines, with each job J_i having a processing time p_{ik} on machine M_k. The primary difference is the scale of the problem. That is it is not computationally feasible to model each track segment as a single resource (e.g., machine). Therefore, we aggregate multiple track segments into a single resource. In a typical job-shop scheduling problem, the order of release of the jobs impacts the overall delay in processing all of them. Hence, determining the release times of our trains from their respective origins is vital to minimize travel-times. Similar to job-shop scheduling, trains are scheduled to depart from origin and intermediate stations such that the travel-times in the network are minimized. It could even be necessary to hold back a train ready to depart and instead allow another train to depart ahead, because doing so might reduce interferences between trains somewhere down in the network. However, once a train has been released into a network, a simple greedy scheduling algorithm that moves a train from one track segment to the next tends to work well in practice since holding a train reduces track capacity. Of course, there may be number of valid reasons to hold a train at intermediate track segments (e.g., to allow a higher priority passenger train pass), but these types of decisions are typically made in real-time and by dispatchers, and is outside the scope of this paper.

Fig. 1 is a section of a medium-scale network from the Los Angeles-area rail network. The network is between downtown Los Angeles and Colton crossing. There are three main routes in this section of the network – UP-Alhambra, UP-San Gabriel and BNSF. The first two are operated by Union Pacific (UP) and the third by Burlington Northern Santa Fe (BNSF), the two largest railroad companies in the United States. Each of the three routes is approximately 60 miles long. UP trains can run on the segment owned by BNSF due to an existing agreement between the two. We note that the network shown in Fig. 1 is an example network; a single railroad company can also own multiple lines. The *routing* decision determines the train track route that minimizes expected travel time given a set of possible routes going from an origin to a destination or a set of destinations. Delays occur when trains traveling in the train network interfere with each other, thus requiring one of the trains to stop or be pulled over for the other to cross or overtake it. The time taken to decelerate or stop, the duration for which the train is stationary, and the time taken to accelerate together constitute delay. We consider routing at a macro level, that is, it does not deal with which siding to travel on, which crossing should be used, which track segment of a double- or triple-track the train should travel on, etc. As an example, the routing problem for the network shown in Fig. 1 would involve determining the optimal route (Alhambra line, San Gabriel line or BNSF line) for each train departing from Colton and traveling to the Alameda Corridor. It is important to note that an underlying problem to be solved is balancing trains along the three routes depending on the expected travel times. This is very closely associated with determining the optimal release or departure times from the origin station, Colton. Releasing trains too close to each other would drastically increase travel times. To tackle this issue, we solve a joint routing-scheduling problem. As a whole, this research represents an effort in developing a quantitative model to tactically plan the movement of trains through a complex network, with decisions based on an accurate representation of the delays these trains cause on the railroad. Mu and Dessouky (2011) develop a model that determines the tracks the train travels on as well as the schedule. The authors refer to this as the pathing problem which is different from the routing problem considered in this work in terms of the scale considered. Although both problems relate to determining which track segment the train travels on, the pathing problem is concerned with the micro level and deals with, for example, which side of the track segment the train travels in a double-track segment or which train uses the siding at a meet or pass point. The routing problem is at a more macro level and determines which rail line the train travels when there are multiple lines serving the same origin/destination pair. This permits the consideration of larger scale train networks in the routing problem covering a larger area. We note, however, that in the literature the

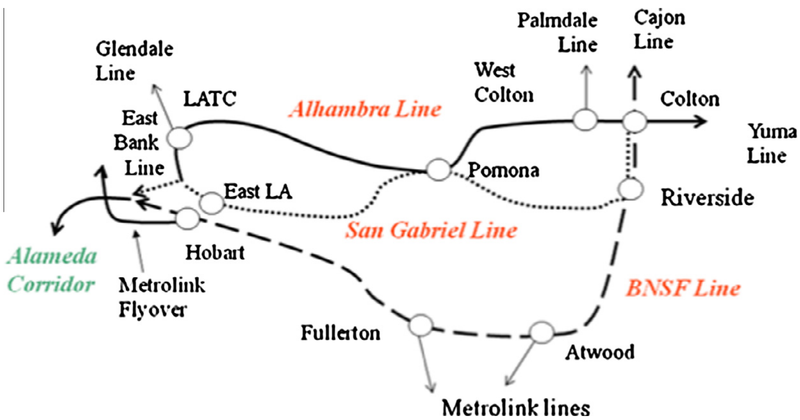

Fig. 1. Railway network between Downtown Los Angeles and Inland Empire trade corridor.

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