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An iterative bi-level hierarchical approach for train scheduling

Sudhir Kumar Sinha*, Shripad Salsingikar, Siddhartha SenGupta

Decision Sciences and Algorithms Lab, Tata Consultancy Services Ltd., Andheri (E), Mumbai, 400–093, India

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This paper presents an iterative bi-level hierarchical approach for train scheduling based on the concept of decentralized operational control in railway operations. The entire railway network is divided into a number of subnetworks connected at boundary stations, called interchange points. The planning of this decomposed network is done by two types of planners, namely, low and high level, handling subnetworks and interchange points respectively. The plan of the entire network is generated using an iterative approach, where at each step the low level planners generate feasible schedules for each subnetwork independently and share their version of the schedule of interchange point with the high level planners. The high level planners analyze individual schedules of the interchange point for possible conflicts, devise resolutions of the found conflicts and send back updated schedules to low level planners. On receipt, the low level planners adjust schedules to comply with boundary conditions subject to internal constraints. The iterative process continues until a global feasible solution is obtained. In current implementation, both planners use greedy heuristics to generate schedules of subnetworks and to resolve conflicts at interchange points respectively. We illustrate the concept of iterative bi-level hierarchical approach for train scheduling on a test network extracted from Indian Railways. This approach succeeds in generating feasible solutions for all tested instances in a finite number of iterations. Even though unified approach outperforms decomposed approach both in terms of schedule quality as well as response time, the use of suggested approach will become relevant where time taken by the algorithm to generate schedule of a railway network increases non-linearly with its size.

1. Introduction

Railways are a cost effective and energy efficient mode of transport. They play a significant role in the economic development of a geographical region. Modern railways are vast and complex, utilized by a variety of traffic, owned and operated in different manners and by multiple organizations with inter-dependent stakes. For example, Indian Railways is a multi-gauge railway network comprising 116,000 km of track over a route of 65,436 km and 7172 stations. Indian Railways runs 12,617 passenger trains and 7421 freight trains daily. In the US, there are seven 'Class I' railways spread over 153,000 km of standard

* Corresponding author.
E-mail addresses: sudhir.sinha@tcs.com (S.K. Sinha), shripad.salsingikar@tcs.com (S. Salsingikar), siddhartha.sengupta@tcs.com (S. SenGupta).

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gauge moving primarily freight. The operations planning and control of traffic on such a large railway network is a challenging task because of the size, configuration, traffic heterogeneity, and diversified safety rules and regulations.

In railway operations planning, train scheduling involves allocating network resources (e.g. tracks) to a set of trains while satisfying operational and safety requirements and optimizing objectives such as throughput, resource utilization and delay. The process results in a schedule which defines entry and exit times of the trains on the allocated track sections. Train scheduling at tactical level involves constructing a schedule from a clean slate (offline planning or timetabling) whereas, at operational level this involves modifying an existing schedule in response to disruptions (online planning or dispatching).

Over the years, researchers have studied different aspects of train scheduling problem. Cacchiani et al. (2014), Cordeau et al. (1998), Fang et al. (2015) and Törnquist (2005) provide a comprehensive overview of the research in railway optimization, (re)-scheduling and dispatching. The train scheduling problem has been addressed using (non)-linear (mixed) integer programming, network optimization and job shop scheduling models. Cai and Goh (1994) showed that scheduling trains on a single track railway line is a NP-hard problem. Thus, it is difficult to obtain an optimal solution of train scheduling problem for large-scale and complex instances. The heterogeneous traffic mix (trains with different halt patterns, preferences and speed characteristics) operating on the rail network (diverse topology and size) under strict safety rules and varying operational practices across geography makes the train scheduling problem interesting and challenging for managers as well as researchers. Often, an online train scheduling system aims to obtain good feasible schedule within an acceptable time limit. The solution techniques described in the literature include branch & bound, (meta-) heuristics, rule-based, Lagrangian relaxation, constraint programming, simulation, etc.

Recent studies on the train scheduling are based on a geographical decomposition of the physical railway network (Corman et al., 2010, 2012; Strotmann, 2003). The railway network is divided into local networks and local solutions are computed for each of the local networks. A high level coordinator checks global consistency of the local schedules and imposes a few restrictions on train movements in local networks, if required, to make the schedule globally feasible. These two steps of planning iterate until a global feasible schedule is obtained. This approach is based on operational control practices of railways. For example, the Dutch network is subdivided into a national center in Utrecht, four regional centers and more than sixty dispatching areas. The dispatching areas have dispatchers who regulate traffic in their respective area, whereas the regional control centers coordinate dispatchers' work in multiple areas to regulate traffic at the global level and avoid situations of global infeasibility (Corman et al., 2012). Another example of decentralized control regime is Indian Railways, which is section oriented. A control section normally covers about 150–200 km of a railway line and covers a set of stations. These control sections have controllers who regulate traffic in their section based on track capacity, availability of locomotives, crew and readiness of trains (Rangaraj and Vishnu, 2002).

Corman et al. (2010, 2012) and Strotmann (2003) decompose a physical railway network into local networks by identifying borders and border sections between adjacent local networks. A block section is a track segment between two main signals and a border section is a block section shared between neighboring areas. They use alternative graph based representations for low and high level planning problems. The alternative graph representation of high level planner is termed as a coordinator or border graph. In Strotmann (2003), the low level local solutions are computed using a greedy algorithm which successively fixes arcs of alternative pairs based on priority rules such as Avoid Maximum Current C_{max} (AMCC) and First Come First Serve (FCFS). The conflicts between solutions of the local areas result as positive cycles in the border graph. These are identified using longest-path-version of Floyd-Warshall algorithm. The high level planner introduces suitable constraining arcs in local area networks to impose trains' ordering at borders between areas. The tests are carried out on a hypothetical network with 3–4 local areas, 73 block sections and 16 trains. In Corman et al. (2010), the local solutions are computed using a truncated branch and bound algorithm while coordinator problem is solved using a heuristic procedure. The experiments are done on a densely occupied railway area of the Dutch network composed of two dispatching areas. They have also presented an extensive computational assessment of the centralized and distributed systems. Using the same framework, Corman et al. (2012) use a branch and bound algorithm to compute optimal solutions of the coordinator problem. The experiments are conducted on a portion of the Dutch railway network, spanning over ten dispatching areas with more than 1200 block sections and station platforms. The network is divided into different configurations of 1, 3, 5 and 7 areas. Their experimental results show that an optimal or near-optimal global solution can be found within the tight time windows required for real-time traffic control.

Prior studies on train scheduling based on geographical decomposition of a railway network rely on alternative graph representation. In this study, we present a decomposition framework based on the primitive representation of a railway network. This generality will help in the usage of existing algorithms of train scheduling for large size railway networks, which otherwise will remain unrealistic because of their long computation time. Here, the entire railway network is divided into a number of subnetworks connected with each other at stations called interchange points. The planning of this decomposed network is done by two types of planners, namely, low and high level, handling subnetworks and interchange points respectively. Both the planners work in conjunction to create a feasible schedule of the entire railway network. The plan of the entire network is generated using an iterative approach, where, at each step:

1. The low level planners generate feasible schedules for each subnetwork independently and share their version of the schedule of interchange point with the high level planners.

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