Real-Time Energy Consumption Optimization in Railway Networks

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1 Introduction

The *real-time Energy Consumption Minimization Problem* (rtECMP), as introduced by [1], has the objective of minimizing both train energy consumption and total delay by deciding speed profiles in a given control area and time horizon. It takes as input the decisions on train routing and precedences coming from a solver for the real-time Rail Traffic Management Problem (rtRTMP) [3]. In addition, to define energy-efficient speed profiles for multiple interacting trains, it takes into accounts infrastructure characteristics, operational constants and train dynamics. The rtECMP ouputs include arrival, departure, passing through and dwelling times along with speed profiles. We extend the research of [1] by proposing a graph-based rtECMP model that we solve with an Ant Colony Optimization (ACO) algorithm, to which we refer as ACO-rtECMP. An experimental analysis is conducted on a real life railway infrastructure (the Pierrefitte-Gonesse junction, located in France) subject to various traffic perturbations.

2 Solution Approach

We consider a so-called control area, which is a section of rail network supervised by a dispatcher. The infrastructure in the control area is composed of *track-circuits*. These are track elements fitted with an electric device capable of sensing the presence of a train. Track-circuits are grouped into *block sections*, which are track stretches that can be traversed by only one train at a time to maintain safe distancing. Every train is assigned a route, which is a sequence of block sections linking an origin-destination pair in the given infrastructure. To ensure the coherence of route formation, control areas are equipped with an *interlocking system*. To indicate whether a block section can be accessed or not, the interlocking system employs a signaling system : every block sections is delimited by two signals placed at its entrance and exit location (see, e.g., [2]). In the simplest case, a signal is capable of displaying three different aspects : green, yellow and red. A red aspect forbids the access to the following block section. A signal displaying yellow allows the access and demands a slow down so that a full train stop is possible before the following signal. Green grants the access to a block section and implies that a driver can safely enter the following one at full speed, if suitable. Given a block section b, we refer to all block sections sharing at least one track-circuit with b as *incompatible*. We consider a *route-lock route-release* interlocking system, i.e., block section b is available only if all its incompatible block sections are completely free.

We propose a graph model for the rtECMP with the following assumptions : (A1) the signal visibility distance is zero ; (A2) we represent a speed profile as a concatenation of pre-computed partial speed profiles, one for each block section in a train's route ; (A3) given a train that has stopped in a block section, the train restarts as soon as the following block in its route becomes available. Precisely, we define a speed-profile graph G such that each node represents a possible choice of speed profile for a block section in a train's route. A solution is represented by a path h in G that satisfies a set of constraints imposing continuous speed profile curves and their compliance with the interlocking system and with the signaling system. A feasible path h entirely describes each train's speed profile as well as the dwelling time in the blocks where stops occur (see assumption A3).

To account for the two objectives of the rtECMP, i.e., energy efficiency and delay reduction, we minimize the weighted sum of two terms accounting for the normalized total energy consumption and delay. The corresponding weights are parameters of the algorithm.

To tackle the graph model, we use an ACO algorithm. Precisely, we adopt a $\mathcal{MAX}$–$\mathcal{MIN}$ *ant system* ($\mathcal{MM}$AS) algorithm [5], to which we refer as *ACO-rtECMP*. Graph G is used as the construction graph in ACO-rtECMP.

3 Experimental analysis

We test the ACO-rtECMP on the French Pierrefitte-Gonesse control area. It consists of an infrastructure with 89 track-circuits grouped into 79 block sections. The possible train routes are 39 and the control area does not contain stations. The traffic is dense : 336 trains are scheduled to traverse the control area in a classic week-day timetable. Three kinds of trains are used here, each of which having different rolling-stock features.

We derive 100 rtECMP instances by employing an rtRTMP solver, with which we address 100 random perturbations of the peak-hour nominal traffic in the aforementioned control area. The instances correspond to the best (possibly proven optimal) set of routes and schedules to minimize total delays found in the available computational time. Precisely, each instance involves either 15 or 16 trains that traverse the control area between 06 :00AM and 07 :00AM.

In this study, we analyze the results achieved by ACO-rtECMP after 30 seconds of computation. Indeed, three minutes are often allocated for solving the rtRTMP in the literature [4]. Here, we consider that 150 of these 180 seconds are allocated to the rtRTMP solver before starting ACO-rtECMP.

Références

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