An adaptive procedure for railway periodic timetabling and tracks assignment

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1 INTRODUCTION

One of the tasks of SNCF Réseau, the French Railway Infrastructure Manager, is to produce yearly timetables. Each train is characterised by an origin station, a destination station, and is composed by several operations : a train can *run* on line sections and *pass through* or *dwell* at train stations. We name *slot* the spatio-temporal capacity reservation on the infrastructure that is necessary to allow a train to perform its operations. A slot is said to be scheduled when a precise time is decided for each of its operations. In this study, we focus on a specific phase of the production of yearly timetables. This phase occurs about two years before the execution of the timetables, and is called *capacity structuring* phase (SNCF_Réseau, 2021).

To tackle this planning phase, a Service Intention (SI) (Wüst *et al.* , 2018) is built by several stakeholders and describes a set of slots to be scheduled within a given cyclic period of time. For each slot, we know the origin and the destination points, the line sections and stations of its itinerary, the stations where a stop is required and those where it is not, and the nominal duration of each operation of running in line sections and dwelling at train stations. Moreover, we have a railway infrastructure description, and timetabling rules that locally describe the way to schedule one slot according to another in order to avoid the use of a same track at close times.

The challenge for SNCF Réseau is to assign a starting time for each operation of each slot of the SI, such that no conflict exists between the scheduled slots. This work aims to support the timetable planners in this task, providing them suggestions of sets of scheduled slots covering the SI. This decision aid can be particularly useful when important modifications in the infrastructure (*e.g.* maintenance and construction) and in the SI appear with respect to the previous situations. In addition to scheduling times for the slots, we provide solutions on which tracks are scheduled as well for its operations. Those decisions are important since they fully determine the itinerary of trains and allow a clear view of the resource usage on busy sections of the infrastructure.

2 PROBLEM DESCRIPTION

We aim at solving a combination between a *Train Timetabling Problem* and a *Train Platforming Problem* (Petering *et al.* , 2015, Sels, 2016) with periodic time horizon and mesoscopic infrastructure scale. This scale is more detailed than the macroscopic one because we represent tracks inside line sections and train stations. It is less detailed than the microscopic scale because we consider a decomposition of the infrastructure in homogeneous sections that are composed by parallel tracks with the same speed limit. If several microscopic routes exist between tracks of adjacent sections, we will consider only one corresponding route at the mesoscopic scale. A compatibility matrix informs about the possibility for two trains to run simultaneously on mesoscopic routes. We model this problem by a *Track-Choice Periodic Event Scheduling Problem (TC-PESP)* (Wüst *et al.* , 2018), an extension from the *PESP* (Serafini & Ukovich, 1989), and we propose a method in section 3 to solve it heuristically.

Let $I = \{1, 2, \dots, N\}$ be the set of slots of the SI and $J_i = \{o_{i1}, o_{i2}, \dots, o_{in_i}\}$ the set of operations of slot i. S is the set of sections, that can either be line sections or train stations. Each section contains one or more parallel tracks that are travelable in one or both directions. For each operation o_{ij} planned on a particular section $s \in S$, the problem is to choose a track where the operation will be assigned on s, and a value for the starting time t_{ij} of operation o_{ij}, with $t_{ij} \in [0..T[$, where T stands for the periodic time horizon, also named *period*, in minutes. The track assignment for every operation of a slot defines its precise itinerary on the infrastructure. Let p_{ij} be the processing time of the operation o_{ij}, *i.e.* the nominal duration of the operation o_{ij} including a mandatory robustness margin in order to allow some flexibility in the driving behaviour and to absorb small delays that may occur. We look for a solution such that the total duration of each slot is equal to $\sum_{j \in J_i} p_{ij}$. We can enforce this property by adding no-wait conjunctive constraints modulo T over the operations of each slot : each operation of a slot has to begin immediately after the completion of the precedent one, if they exist. Each operation has to be assigned to a unique track among the tracks of the section where the operation takes place. For any two consecutive operations of a slot, the track assignments have to be such that it exists a corresponding mesoscopic route in the infrastructure.

Three types of safety constraints guarantee that no two slots use the same tracks simultaneously or too close in time. *Spacing* constraints separate the beginning time of use of a line section track by slots planned in the same direction. *Reuse* constraints ensure that the use of a track is possible only if it has been released for a certain amount of time. *Reuse* constraints work on station tracks, and also on line section tracks in the case of slots planned in the opposite direction. *Crossing* constraints prevent slots to be assigned on tracks that generate incompatible routes whenever those slots are scheduled too close in time. Commercial requirements such as passenger connections between slots at stations, slots splitting or merging, predefined temporal spacing or predefined starting times for some operations are also to be taken into account.

3 METHODOLOGY

We modelled this problem by an ILP, implemented and solved using an off-the-shelf solver. The infrastructure considered is a real case study around Chambéry area. The solving time increases when we increase the number of slots in the SI. Thus we propose a heuristic in order to keep this problem tractable for larger instances. Recent research tackled a similar problem by a column-generation framework (Reisch *et al.* , 2021) based on a train path assignment heuristic (Dahms *et al.* , 2019). Our procedure is illustrated in Figure 1. The model is now decomposed into a timetabling module in charge of deciding the starting times of the slots, and a tracks assignment module responsible for the tracks decisions. The procedure is described in details below.

3.1 Timetabling module

The main feature of the timetabling module consists in the replacement of the safety constraints of the problem description by a *conflict evaluation function* that counts the number of inactivated safety constraints unsatisfied by the slots starting times. This allows to integrate the tracks assignment possible decisions without needing to fix them explicitly. Next subsections show how we build a solution and iteratively solve the conflicts that may occur.

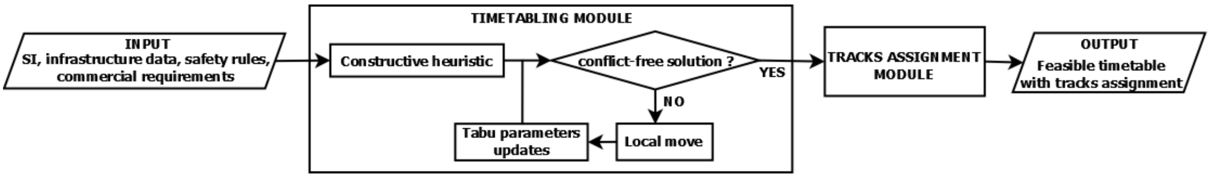

Figure 1 – *Periodic timetabling and tracks assignment adaptive procedure flowchart*

3.1.1 Constructive heuristic

This routine attributes a starting time for each slot of the SI, such that the aforementioned *conflict evaluation function* is minimized in a greedy way. More precisely, at each step of the heuristic, a slot is selected to be scheduled, and a starting time is chosen for the selected slot. Before each new step, we update for each remaining slot its number of possible starting times for which the slot would be compatible with all the previously scheduled slots. The slot to be scheduled in priority is the one with the minimum strictly positive number of possible starting times that does not generate conflicts. In case of a tie, we look at the *impact score* of those slots: this score corresponds to the sum of the number of other slots planned on each section of the operations of this slot. When a slot is selected to be scheduled, its starting time is chosen such that it should impact as little as possible the number of possible conflict-less starting times of the remaining slots to be scheduled. At some step of the heuristic, it is plausible that a list of slots cannot be scheduled in a conflict-free manner anymore. We prioritise those slots by the earliest heuristic step when they join the list, and we choose a starting time that deteriorates as little as possible the *conflict evaluation function*. Once all the slots have been scheduled, the constructive heuristic is completed. If the *conflict evaluation value* equals zero, then the tracks assignment module is run. Otherwise, we stay in the timetabling module and resolve the conflicts as explained below.

3.1.2 Local move

A solution of the timetabling module with a strictly positive *conflict evaluation value* is not conflict-free: infrastructure capacity is overused by some slots scheduled too close in time. Those slots are said to be *involved* in the conflict. When such a solution is found, a local move is performed from the current solution to a new one, attempting to reduce the *conflict evaluation value*. A local move consists in modifying the starting time of a small set of slots of the solution. A heuristic way to choose among the moves is to select the slots that are *involved* in the maximum number of conflicts. To escape from local optima that might prevent to reach a conflict-free solution, we embed the local search into a tabu framework detailed in the subsequent subsection.

3.1.3 Tabu parameters updates

A local move applied to a given set of slots is named *combination*. Each combination is associated with a *tabu countdown* initialized with value 0, along with a *tabu duration* initialized with value 1. A combination is applicable only when its *tabu countdown* equals 0. When applied, a combination becomes tabu for the next *tabu duration* iterations. Indeed, we assign to the *tabu countdown* of this combination the value of its *tabu duration*, and the *tabu countdowns* of every combination is decremented at each iteration if strictly positive. Another effect of the application of a combination is the increment of its *tabu duration*, for the next times it may be reselected. As a result, the more a combination is selected because of the concentration of the conflicts on some specific slots, the longer it will be temporarily unavailable in order to let other combinations attempt to unlock the situation.

3.2 Tracks assignment module

A *conflict evaluation value* of 0 ensures that a track assignment for each operation of each slot respecting all the safety constraints exists while keeping the starting times obtained from the timetabling module solution. This module is solved almost instantaneously on the instances we tested, the main difficulty is indeed resolved during the timetabling module which evaluates carefully the mesoscopic capacity necessary to perform the tracks assignment.

4 RESULTS

The SI contains 32 heterogeneous slots hourly scheduled on the Chambéry area infrastructure, including 8 crossing each other at stations of three unique tracks of the area, and 18 passing at Chambéry, of which 7 in each direction between Chambéry and Montmélian. We present 20 instances with the same SI, differentiated by the *randomly generated* initial solution considered before applying local moves on *sets of 1 slot*. Table 1 shows the number of moves applied on sets of 1 slot to resolve the conflicts.

Table 1 – *Number of moves on sets of 1 slot applied to resolve the initial conflicts of 20 instances*

Initial conflicts			Number of moves		
min	max	average	min	max	average
395	1368	553	17	117	40

The same instances are unable to be solved when we remove the tabu framework.

5 DISCUSSION

The timetabling methodology using a mesoscopic scale *conflict evaluation function* to take into account the tracks assignment decisions gave promising results. Ongoing work includes the implementation of the constructive heuristic as well as additional types of local moves to solve the conflicts more efficiently.

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