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Considering a dynamic impact zone for real-time railway traffic management

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ABSTRACT

In a railway system, a conflict occurs when two trains require the same part of the infrastructure at the same time. Currently, such conflicts are typically resolved manually by experienced dispatchers. However, it is impossible for them to fully anticipate the impact of their actions on the entire network. This paper proposes a conflict prevention strategy which focuses only on the relevant part of the network and traffic and, consequently, proposes a solution for that part only. The proposed strategy first looks for possible rerouting options by using an optimization model. If no solution is found, a solution based on delaying one of the trains is required. This retiming/reordering heuristic uses information from an offline calculation, for determining related conflicts that frequently occur. In this way, a so-called *dynamic impact zone* is created online for each conflict. When deciding which train to delay, the potential conflicts and the incurred delays of all trains in this dynamic impact zone are taken into account.

The performance of this new Conflict Prevention Strategy is compared to a common dispatching strategy, other heuristics, and an exact method. Extensive experiments on a large part of the Belgian railway network show that by considering this dynamic impact zone the total delay can be decreased by at least 67% compared to the basic First Come, First Served decision rule. Moreover, the dynamic impact zone has a reasonable size and scales well to large networks as only the relevant conflicts and their expected consequences are considered. This makes our Dynamic Impact Zone heuristic very fast. The computation time for returning a resolution to a conflict with the proposed conflict prevention strategy is, for 95% of the conflicts, less than two seconds, and at most 26 s, including the creation of the dynamic impact zone of the conflict.

1. Introduction

In the past few decades, the interest in public transport has been growing steadily due to the increasing need for sustainable transport. Railway companies want to attract more passengers by providing a high quality train service, including a robust timetable with as few delays as possible. A timetable normally ensures that two trains do not ‘interfere’ (conflict) with each other, such that delays are avoided in real-time. However, during daily operations, trains can suffer delays caused by e.g. mechanical failures, a broken part of the infrastructure, or bad weather conditions. If some trains are no

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longer driving according to their schedule, conflicts might occur. This means that trains now require the same part of the infrastructure at the same time. In real-time, conflict detection is required to check whether a timetable is still conflict-free or contains potential conflicts in the near future. If such a conflict is detected, it has to be decided which train can use the common part of the infrastructure first or whether some trains can be rerouted to resolve the conflict. This decision involves only two trains in the vast majority of the cases and is typically made by the dispatchers (traffic controllers) based on their experience. Dispatchers are increasingly seeking a Decision Support System (DSS) that includes conflict detection and prevention. If a near-future conflict is detected, it can still be prevented from happening by deciding to reroute or re-time one of the conflicting trains in real-time. These prevention measures are examined in a *conflict prevention module*. In this paper, our conflict prevention strategy, implemented in the conflict prevention module, will aim at minimizing the total secondary delay of all trains in the network. Optimizing conflict prevention strategies is still a challenging problem, both in practice and in practically oriented research. For the rerouting phase, we developed an exact optimization procedure. For the retiming/reordering phase, we created a heuristic, which we will refer to as the Dynamic Impact Zone (DIZ) heuristic.

In the literature, train movement prediction, conflict detection, and conflict prevention are sometimes solved together by using sophisticated optimization models. However, these approaches are typically limited in the size of the network that can be considered in reasonable computation times. This is due to the fundamental complexity of the problem and the fact that all trains on the network are considered, which can reach into the hundreds in a national network. In this paper, we present the DIZ heuristic which is able to focus only on those trains that are actually relevant. This focus is a necessity given that the computation time required for solving the complete optimization problem grows exponentially as the size of the network increases.

Summarizing, in this paper, we tackle the real-time railway traffic management problem. When a conflict is predicted, we want to prevent it in such a way that the total secondary delay of trains in the network is minimized. The line planning, timetable, available infrastructure, vehicles, and crews are considered fixed. The routing, order, and timing of the trains are allowed to be modified. We assume a fixed-speed model, i.e. we do not take braking and acceleration explicitly into account when facing restrictive signal aspects. For the network considered in this paper, in order to be of use in practice, the algorithm needs to be able to determine a solution in a few seconds.

The main contribution of this paper is that a very fast Conflict Prevention Strategy (CPS, in short) is presented, which is close to practice and suitable for large and complex networks. Furthermore, we show the benefits of using both the results of a set of calculations performed offline beforehand and a 'dynamic impact zone', created online for each conflict. This zone determines which other potential conflicts and trains are the most relevant to be considered by the conflict prevention strategy when determining the solution that minimizes the incurred delays on all trains. This approach delivers solutions that clearly outperform solutions generated by the First Come First Served (FCFS) decision rule and other heuristics. Moreover, since our module starts from timetable data and microscopic infrastructure data from a Traffic Management System (TMS), it can be integrated directly in such a TMS, for instance at the Belgian railway infrastructure manager Infrabel.

Section 2 starts with some important definitions required for the remainder of the paper. A literature review is included in Section 3. Section 4 describes how the real-time situation, including a TMS and a conflict prevention module, is modeled in a closed loop simulation and how these different components communicate. Next, the first part of our CPS, the rerouting optimization, is explained in Section 5. The second part of our CPS, the DIZ heuristic, is explained in Section 6. The performance of the CPS is extensively evaluated using a large and complex case study in Section 7. This paper is concluded in Section 8.

2. Definitions

A rail network can be represented by including every detail of the infrastructure, which is called *microscopic*. Alternatively, the network can be represented by considering no details, only stations and links, which is called *macroscopic*. In this paper, a microscopic model of the infrastructure is used. Rail infrastructure is composed of sequences of *block sections*, i.e. the part of a track between two consecutive signals. The railway infrastructure manager uses these signals as a means of communication to inform train drivers about the where-abouts of other trains. In Belgium, a signal can be either green, double yellow, or red. Green indicates that the next two block sections are free, double yellow indicates that the next block section is free but the one after that is occupied, and red indicates that the next block section is occupied. A sequence of different adjacent block sections is called a *route*.

In the initial timetable, trains are planned in such a way that they can always enter the next block section without slowing down. Stated otherwise, they are planned such that they always have a green signal, implying the next two block sections are free. This is a rule of thumb often applied in practice to minimize trains slowing down (at double yellow) or even stopping (at a red light) and losing time in re-accelerating.

The rail infrastructure can be divided into *station areas* and non-station areas. In station areas there are *platforms* where passengers can embark or disembark if the train has a *stop* in that particular station. Before and after the station platforms, there is an area in which many switches are present enabling trains to easily switch to a different platform in the station, also called a *switch area* (also known as interlocking area). In this paper, it is assumed that a station area includes the platforms and also the switch areas before and after these platforms.

The movement of a train through a block section is called an *operation*. The time required to travel through a block section is called the *occupation time*, and depends on the type of train, infrastructure, and rolling stock. The occupation time