COMBINE: A decision support system for real time traffic control

D. de Vries
Holland Railconsult, The Netherlands

Abstract

This paper addresses the need for and benefits of advanced real-time traffic management in railway operations. Specifically, the results of the COMBINE project, which was co-funded by the European Commission, are reported. In this project an advanced real-time traffic management system (TMS) was developed and tested on a simulation level, showing valuable advantages in terms of better punctuality and energy saving when compared with common dispatching rules. The architecture of this TMS, the conflicts detected, the means to control and the optimisation criterion are discussed. A simple example of a traffic situation controlled by the TMS is presented in order to clarify its operation and benefits.

Given the success of this project, a pilot is currently being set-up in the Netherlands to test benefits in real-life practice. Also, COMBINE II was recently accepted by the European Commission for co-funding and will extend the project scope to different safety systems and larger networks.

1 Introduction

This paper reports on the results of a project co-funded by the European Commission under the Telematics Application Programme, called COMBINE (enhanced COntrll centre for a Moving Block slGnalling systEm). The project consortium consisted of Adtranz, Cosmos, OnAir, Railned, Holland Railconsult, the University of Genova, the Third University of Rome and the European Rail Research Institute (at the start only). Sponsoring participant was Valtion Rautatiet (Finnish Railways). The duration of the project was two years (1999-2000).
COMBINE addressed train traffic regulation when using the moving block safety system (ETCS level 3). The objective was to develop and verify, by means of a demonstrator, a Traffic Management System (TMS) capable of locally determining the optimum traffic flow. That is, to increase punctuality and reduce energy consumption of trains through the effective exploitation of the capabilities offered by a moving block signalling system.

In order to achieve this the following steps were taken:

- list the generic functional and performance requirements to be posed on such a rail traffic conflict detection and resolution support system,
- identify a suitable system architecture as well as interfaces and relations among the different levels of a layered architecture for a train traffic control system,
- develop, test and tune effective algorithms for conflict detection and resolution task,
- evaluate possible performance gains.

A demonstrator was developed consisting of the TMS and a Field Simulator representing the real world as depicted in Figure 1. A Field Simulator is needed since behaviour of the TMS only can be studied in closed loop with its environment, from which it receives data and which reacts to its instructions. SimRail, a train traffic simulator developed by Holland Railconsult, has been used as Field Simulator.

A wide set of tests were formulated in order to assess the correctness of the demonstrator developed and to verified the ability of the demonstrator to optimise the traffic in a wide set of different cases. After successful completion of these tests, performance gains were studied on the Breda triangle in the Dutch part of the high-speed line Paris-Brussels-Amsterdam, under a set of realistic traffic and disturbance scenario's. This showed that the optimisation algorithms applied in the COMBINE TMS generate valuable advantages in terms of better punctuality and energy saving when compared with common dispatching rules. The evaluation of performance gains is discussed in detail in [1]. Algorithms used can be found in [2].
Additionally, the impact of operational parameters on TMS performance within a moving block signalling system was addressed. It turned out that the total delay time in the control loop is the decisive parameter when considering performance levels. Parameter values required for an effective traffic regulation have been indicated. It turned out that the TMS can cope with large total delay times (up to 1 minute) with only minor degradation of the overall system performance.

This paper will:
- discuss the need for advanced real-time traffic management in general,
- address the COMBINE TMS in some detail; functionality, optimisation criterion used, conflicts detected, possible control actions, system architecture, optimisation algorithm used and the steps in the optimisation process,
- provide a simple example illustrating the functioning of the COMBINE TMS.

2 The need for advanced real-time traffic management

Rail traffic regulation problems can be classified into categories according to the planning horizon considered. In this paper we deal with the daily tasks that are performed by taking into account the fine details belonging to the operational level. In particular, we will focus on the real-time control of the trains.

Railroads commonly operate with a master schedule strategy or plan. However, when executing these plans, disturbances usually occur, generating a need to actively attenuate the effects of such disturbances in real time, or in other words, to control and manage the traffic.

However, the complexity of the railway system has increased significantly over the last decades (more trains, larger networks, more interdependencies between processes, wish for more flexibility and different types of services). As a result, it has become more and more difficult for human operators to manage it in real time, leading to significant and sometimes even major losses of performance. This situation can be improved in a number of ways:
- simplify the process,
- reduce disturbances in order to be able to adhere strictly to the plan,
- provide advanced real-time management support tools to the operators.

These methods should not be seen as mutually exclusive. Disturbances will occur in any case. Also a more flexible system is desired in many instances which opposes rigorous planning. Furthermore, different services are required by the public (long distance trains, commuter trains, freight trains, etc.) which poses a limit on the level of simplification possible. We strongly believe that each method has its own merits and that they all should be used simultaneously. In this way a major performance increase can be achieved.

In this paper we will specifically address the third method. In our opinion real-time control of the speed of trains, local platform changes, routing through a station and the real-time scheduling of those routes while simultaneously reasoning out consequences for the wider network while giving due consideration
to all interdependencies and at the same time operating under severe time limitations due to the real-time nature of the process is not humanly possible and will at least lead to suboptimal control and sometimes unnecessary drastic actions like cancelling trains in order to keep the situation manageable by simplifying it. Automated control of routine tasks, automated conflict detection and solution for the common simple conflicts combined with supervisory control and decision support tools is needed to enable the operators to achieve a consistent high performance and allows them to concentrate on the real issues. This opinion is supported by considering the high level of automation in industrial systems with comparable complexity.

3 The COMBINE TMS

Aim of the TMS is to control the train traffic in order to realise the original plan as well as possible and to save energy, while considering the constraints given by the moving block safety system and operational procedures. The plan contains the timetable, stops, connections, meetings, passings and allowable routes. To control the trains the TMS can specify and set routes and specify speeds or targets for the trains. Also, the TMS receives information on the position and speeds of trains periodically and on the status of the routes and availability of the infrastructure (e.g. temporary speed restrictions, tracks that are out of service).

To be able to provide suitable advice the TMS performs the following tasks:

- Conflict detection.
  Given the current state (position and speed of trains, interlocked routes), the future evolution of the system is estimated. Conflicts are present when estimated arrival times and speeds deviate from the targets as specified in the plan, when routes are not available in time or when trains hinder each other.

- Conflict resolution.
  Suitable speeds and routes should be determined in time for the trains in order to realise the plan as well as possible and save energy, considering the train dynamics, infrastructure topology, safety system and operational procedures.

In order to efficiently perform these tasks the TMS has a hierarchical architecture consisting of the following three levels, as depicted in Figure 2:

- Automatic speed regulator (Speed Regulator).
  This subsystem calculates a suitable speed profile or target for a train and schedules the route setting, given the current state of the system, an optimisation criterion, the higher level targets and the routes. At this level the higher level targets and routes are fixed.

- Automatic conflict detection and resolution system level 1 (CRS1).
  This subsystem detects and solves conflicts arising locally within a given area. It determines local targets and routes for trains.
Automatic conflict detection and resolution system level 2 (CRS2). This level controls the whole area, setting high level targets and determining the order of trains and helping a Dispatcher monitoring it and taking decisions. The dispatcher can change the plan (i.e. timetable, stops, connections, meetings, passings, suitable routes) and specify the allowable routes and optimisation criterion to the two lower levels. The dispatcher is supported by a train graph and train describer depicting how the current plan is being executed and by a what-if simulator with which the dispatcher can construct his own solutions and which shows how these solutions will influence the performance. Also, the dispatcher can view and modify the timetable by means of a train scheduler.

This level also represents the higher management level that could synchronise more than one local area and could have interfaces to adjacent or again higher management levels. This higher management level is not the topic of the COMBINE study and is not elaborated, but the higher management level definitely has been taken into account in the COMBINE architecture and will be addressed in COMBINE II.

Figure 2: The COMBINE TMS and its connections to the rail traffic system.
The Conflict resolution system optimises punctuality and energy consumption. It is based on the alternative graph representation of the train movements, developed by Mascis and Pacciarelli [2]. The alternative graph is a powerful discrete optimisation tool, especially designed to deal with scheduling problems. It is able to include in the optimisation model a number of relevant features that are frequently neglected in most of the models from the literature on train scheduling. At the same time it allows to obtain effective solutions in a fast way. The speed regulator algorithm as been implemented as a fast algorithm, able to control the train speed.

The TMS detects the following conflicts:
- timetable (i.e. a train probably will arrive too late),
- headway,
- order of trains,
- local route,
- degraded track or track out of service.

The TMS can take the following measures:
- adapt the speeds or targets for trains,
- change the order of trains,
- change the local route to be used by a train.

4 Example

In this section a simple example, provided by Railned, is given to illustrate the behaviour of the COMBINE TMS.

The infrastructure layout is given in Figure 3. The Gx trains are freight trains, the IC is an inter-city train. The aim is to merge the train Gi smoothly in the flow of freight trains. To do this, first Gi has to cross the upper flow while simultaneously entering the second flow.

![Figure 3: Example infrastructure layout.](image-url)
When no disturbances are present, Gi can cross and enter using the larger gap in the upper and lower flow without problems. However, Gi is delayed (11 minutes) and Gk1 and Gz1 are also delayed (both 2 minutes). Figure 4 shows the resulting speed-time graph using common first-come-first-serve control rules, while Figure 5 shows the results when using the COMBINE TMS.

Figure 4: Speed-time graph in case of disturbances using common dispatching rules.

Figure 5: Speed-time graph in case of disturbances using the COMBINE TMS.
As can be seen, using the simple first-come-first-serve rule $G_i$ blocks the upper flow while at the same time it cannot yet enter the second flow, resulting in an order change and a large disruption of the process. Using the COMBINE TMS, the trains $G_kl$ and $G_zl$ are being slowed down a bit, even if they are delayed already, and speeds up $G_i$ to its maximum speed, enabling $G_i$ to cross the upper flow and enter the lower flow smoothly and without order change.

The above is a specific example, for a thorough evaluation of performance gains we refer to the paper by Giannettoni and Savio [1]

5 Conclusions

Optimisation algorithms and architecture applied in the COMBINE project give rise to valuable advantages in terms of better punctuality and energy saving when compared with common dispatching rules.

The demonstrator software developed can help railway authorities in deciding if and where to apply advanced traffic management systems by quantifying expected benefits. These simulation tools can also be used as a basis for suggesting standards and for elaborating solutions to manage railway networks.

Considering these results, a pilot currently is being set up in The Netherlands where the knowledge and software developed in COMBINE will be applied in practice to study the possible benefits of traffic control in real life. Also, COMBINE II was recently accepted by the European Commission for co-funding and will extend the project scope to different safety systems and larger networks. The latter by creating a network of a number of TMSs.

References
