Traffic management in moving block railway systems: the results of the EU project COMBINE

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Abstract

In this paper the authors present the results of verification and evaluation activities carried out for the final assessment of the project called COMBINE, acronym of enhanced Control center for a Moving Block Signalling system. The project, concluded in mid 2001, was co-funded by the European Union (EU) within the Telematics Application Programme in the Fourth Framework Research and Development (R&D) Programme, and represents a successful pioneer research which provides the technical basis for the implementation of innovative optimisation tools in moving block Traffic Management Systems (TMS). Besides the valuable contribution to the current knowledge as far as TMS operation in moving block is concerned, the Demonstrator developed within the project provides a powerful tool for purposes ranging from feasibility studies to costs/benefit analysis, which is strategic when the adoption of and/or the migration to moving block signalling system for new or existing railway infrastructures is to be considered.

1 Introduction

The implementation of a moving block signalling system compliant with ERTMS/ETCS Level 3 specifications is expected to bring important improvements in railways operation: increased line capacity and reduced energy consumption are among the main benefits expected from the adoption of traffic regulation systems exploiting the features of a moving block signalling system. Of course, much of the actual improvements will depend on the effectiveness of a TMS able to operate in the moving block environment complying with the
relevant technical and operational requirements. As it is apparent that the implementation of such new generation of TMS will imply several changes in traffic operation (compared with TMS operating with fixed block signalling systems), the following questions have to be answered before industrialisation of such systems could take place:

- How can a TMS be developed in order to comply with both the new operating requirements and the present practice in train control?
- What are the technical and operational requirements affecting the feasibility and/or the performances of such TMS?
- How can moving block opportunities be best exploited by a TMS?

The COMBINE project addressed all such topics and more (Giuliari, Pellegrini & Savio [1]). Within the project, the complete system architecture for an advanced TMS operating in the moving block environment was designed, developed and integrated into a Demonstrator, allowing to overcome the lack of a suitable demonstration site in the railway context.

Once the complete functioning of the Demonstrator has been verified, it provided a powerful tool for the analysis of the most important technical and operational parameters for traffic regulation in moving block, as well as the instrument for the evaluation of the effectiveness of the advanced conflict detection and resolution system (CRS) constituting the core of the COMBINE TMS. This paper presents the results of the evaluation activities carried out within the project for its final assessment.

2 The COMBINE project

The COMBINE project started in January 1999 from a heterogeneous consortium composed by railway operators (Railned), railway systems providers (Adtranz, now Bombardier Transportation), IT-companies (CO.S.MO.S. and OnAir), consultants (Holland Railconsult) and research institutions (Università di Genova and Università di Roma Tre; the European Rail Research Institute was also present at the very beginning of the project).

The project was co-funded by EU DG XIII (Telematics Application Programme) in the IV Framework Programme, and reached its successful completion in the first half of 2001.

COMBINE addressed problems and opportunities of train traffic regulation when using the moving block signalling system: the objective of the project was to develop and to study, by means of a simulation environment, the technical feasibility and the performances of an advanced TMS exploiting the features of ETCS Level 3 for optimal train traffic regulation. In order to achieve such objectives, project activities started with the identification of users needs and the subsequent specification of a comprehensive set of functional requirements, which formed the basis for the definition of a suitable TMS architecture.

The positive experience from the project MARCO (Multilevel Advanced Rail Operation and COntr0l, EU DG XIII, IV Framework Programme) was
utilised in developing the automatic conflict detection and traffic optimisation algorithms for the COMBINE TMS (Savio [2], Copello & Mazzarello [3]).

Moreover, the required simulation environment was developed by integrating the COMBINE TMS and a Field Simulator (SimRail) into the so called Demonstrator, i.e. a powerful software environment in which only railway infrastructures, train characteristics, trains movements, drivers behaviour, communication delays and the signalling system are simulated.

The complete functionality of the Demonstrator was tested through an extensive verification campaign which addressed both the correctness of the COMBINE TMS implementation, the correctness of its integration with the Field Simulator, and the ability of the Demonstrator itself to provide the tools required for the analysis in the objectives of the project. Once the Demonstrator has been verified, it allowed to analyse the impact of the most important technical and operational parameters on TMS performances, as well as the benefits of the advanced conflicts detection and resolution algorithms the COMBINE TMS is based on. The latter activity, which was among the main objectives of evaluation, was performed taking into account the results of tests specifically designed to address the behaviour of the COMBINE TMS in a realistic demonstration site. A brief description of the demonstration site and the results of evaluation activities are reported in the next sections of this paper.

The project development phases are summarised in Table 1, where main tasks and results of each phase are also reported, whereas the overall architecture of the Demonstrator is depicted in Figure 1. Further details on the COMBINE TMS have been reported by De Vries [4].

Table 1: Project development phases, tasks and results

<table>
<thead>
<tr>
<th>Project phase</th>
<th>Tasks</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Needs</td>
<td>State of the art reporting, user identification, functional analysis of user needs and constraints, system performance requirements analysis.</td>
<td>Users requirements specification for TMS operating in the ETCS Level 3 environment; functional requirements specification; performance requirements specification</td>
</tr>
<tr>
<td>System Architecture</td>
<td>System context definition, system architecture development, algorithms choice, COMBINE logic model.</td>
<td>Specification of a modular, multi-layered architecture for a TMS operating in the ETCS Level 3 environment; customisation and implementation of conflict detection and resolution algorithms; TMS Data Flow identification</td>
</tr>
<tr>
<td>Demonstrator</td>
<td>Demonstrator specification, traffic regulation modelling, development and integration of demonstrator.</td>
<td>Specification, development and integration of a Demonstrator including Field Simulator, Speed Regulator, advanced conflict resolution system (CRS1), GUI (Train Graph) and user friendly decision support system (What-If Simulator)</td>
</tr>
<tr>
<td>Verification</td>
<td>Data collection, definition of significant test cases and procedures, verification of demonstrator, analysis of operational parameters.</td>
<td>Specification of a comprehensive verification plan and definition of Demonstrator site; Demonstrator verification; COMBINE TMS functional verification; analysis of the impact of technical and operational parameters on TMS performances</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Evaluation planning, quality assurance, evaluation reporting.</td>
<td>Assessment of COMBINE added value (functioning of the system with respect to a reference case, users acceptance, impact analysis)</td>
</tr>
</tbody>
</table>
3 The Demonstration site

The site chosen for the evaluation analysis is the Breda triangle (Breda junction) in the Dutch part of the high-speed line Paris-Brussels-Amsterdam, since such site is planned to constitute a real world implementation of the ERTMS/ETCS level 3 system in the near future (2005). Figure 2 shows the layout of the site. Only minor changes have been made to the site description with respect to the actual design data in order to increase its suitability as a test site for the COMBINE project. The traffic over the Breda junction is composed by TGVs running on the main line from Amsterdam to Brussels, and Shuttle trains running from Rotterdam to Breda and from Brussels to Breda, where merging and exiting the main line is done via fly-overs.
3.1 Description of tests performed for evaluation purposes

In order to evaluate the performances of the system, two complementary set of tests were performed. Both tests sets addressed the comparison between the behaviour of the COMBINE TMS, although with reduced functionalities (this was found necessary in order to assure the comparison fairness), and a reference case implementing simple First – In – First – Serve rules for conflict resolution, instead of the optimisation algorithms characterising the COMBINE TMS. In the following, the COMBINE TMS is also referred to as the “TMS on” option, while the TMS utilised for the reference case is also referred to as the “TMS off” option, provided that also in the latter a TMS was working.

The first tests set, referred to as “scenarios tests”, addressed the behaviour of the TMS in traffic conditions derived from those planned for the operation of the Breda junction; in such tests, traffic scenarios were defined as a given scheduled traffic to which a given disturbance scenario was applied. Three different scheduled traffic (Normal, Heavy and Extreme) were defined, starting from the traffic planned for 2015. Trains were scheduled to enter the control area regularly spaced in time, with the time intervals listed in Table 2, and to travel throughout the control area at the maximum allowed speed (minimum travel time). It is worth noting that such choice, although representative of how the Breda junction will be operated, meant that no margins were left in the timetables for recovering entry delays.

Table 2: Time intervals for the scheduled traffic

<table>
<thead>
<tr>
<th>Train</th>
<th>Route</th>
<th>Normal</th>
<th>Heavy</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGV</td>
<td>Rotterdam – Belgium</td>
<td>30'</td>
<td>30'</td>
<td>30'</td>
</tr>
<tr>
<td></td>
<td>Belgium – Rotterdam</td>
<td>30'</td>
<td>30'</td>
<td>30'</td>
</tr>
<tr>
<td></td>
<td>Breda – Rotterdam</td>
<td>30'</td>
<td>15'</td>
<td>15'</td>
</tr>
<tr>
<td></td>
<td>Rotterdam – Breda</td>
<td>30'</td>
<td>15'</td>
<td>15'</td>
</tr>
<tr>
<td></td>
<td>Breda – Belgium</td>
<td>60'</td>
<td>30'</td>
<td>30'</td>
</tr>
<tr>
<td></td>
<td>Belgium – Breda</td>
<td>60'</td>
<td>30'</td>
<td>30'</td>
</tr>
<tr>
<td></td>
<td>Breda – Rotterdam on secondary line</td>
<td>-</td>
<td>-</td>
<td>15'</td>
</tr>
<tr>
<td></td>
<td>Rotterdam – Breda on secondary line</td>
<td>-</td>
<td>-</td>
<td>15'</td>
</tr>
</tbody>
</table>

Disturbances were represented by stochastic delays distributed among entering trains according to truncated exponential distributions with different distribution parameters (mean values of 0.75 and 2.5 minutes with truncation to 3 and 10 minutes respectively). Additionally, a disturbance scenario also addressed the effects of small stochastic delays combined with large deterministic delays originating cascades of conflicts.

In order to address the behaviour of the system also in conditions where significant delay recovery margins were available, gaining information on the TMS performances in a broader operation context, the second set of tests...
(referred in this paper as “test cases”) were performed. Traffic conditions considered in the test cases were similar to those relevant to the “Normal Traffic”, but planned speeds were lower than the maximum train or line speed. Moreover, Shuttle traffic inside the mini-station near the Belgium border was carried out over secondary lines, allowing the TMS to use the mini station for headway/hindering conflict resolution. As for the scenarios tests, test cases were performed by applying disturbances to the scheduled traffic, but disturbances were defined in order to cause specific conflicts and to analyse how the TMS would have managed their resolution for each involved train.

3.2 Evaluation of COMBINE TMS performances

The analysis of the data resulted from the tests described in the previous section allowed to carry out some significant assessments concerning the added value of the COMBINE project and the effectiveness of the advanced optimisation algorithms implemented by its TMS. Such assessments turned out from the comparison of the “TMS On” solutions with respect to those provided by the reference case, i.e. the “TMS Off” solutions. As previously described, two different sets of tests were performed, considering very different infrastructures utilisation philosophies on the same, realistic, test site:

- As far as scenarios tests were concerned, the two options showed similar delay figures (distribution, mean values, standard deviations etc.) with only minor benefits from the TMS On option as far as energy consumption was concerned (this was due to the COMBINE TMS ability in avoiding trains speed instability, a known problem related to moving block operation).

- As far as test cases were concerned, TMS On solutions revealed definitely better performances with respect to those provided by the TMS Off, from both punctuality and energy saving viewpoints (an example of test case results is reported in section ). In particular, such tests demonstrated the benefits deriving from the implementation of optimisation algorithms which take decisions based on the knowledge of the global traffic status.

Evaluating the COMBINE added value in terms of punctuality increase and energy savings, the comparison with the reference case leads to different assessments when the results of the two test sets are considered. In fact, for the particular traffic conditions addressed in scenarios tests, the implementation of the advanced optimisation algorithms of the COMBINE architecture seems to be redundant with respect to a trivial control rule such the one based on simple "First In - First Serve" criteria. On the other hand, for the traffic conditions considered in the test cases, the benefits of the COMBINE solution become apparent and definitely significant.

Such difference, in the added value assessment for the two cases, is itself one of the major value added by the COMBINE project in its application context. In fact, tests demonstrated that the benefits obtainable from an advanced Traffic
Management System cannot be estimated abstracting from the specific infrastructure layout and network traffic planning practice. This makes the COMBINE demonstrator not only a pre-prototype for an advanced TMS operating in ERTMS Level 3 environment, but also an outstanding, powerful decision support tool for railways authorities and their suppliers, when investments in signalling and traffic management systems are to be evaluated.

3.3 Test case example

In the following, the description and the results for a test case example is presented. Results are reported in Figure 3 showing entry and exit delays for each observed train, and overall energy consumption for both TMS On and TMS Off options. Moreover, a Delay Index (D.I.) is also shown:

\[
\text{Delay Index} = \frac{\text{Total adjusted train delay}}{\text{Number of observed trains}}
\]

Where the Total adjusted train delay is the sum, in seconds, of positive delays (trains exiting the control area before their planned exit time are considered as “on schedule”, and associated to a delay equal to “0”). Trains are identified through their type and number.

3.3.1 Description

TGV 102 and 104 from Belgium to Rotterdam enter the control area with large delays (490 seconds). Such delays are the source of possible convergence/headway conflicts with Shuttle 138601 and 138605 from Breda to Rotterdam when they join the high speed line.

3.3.2 Analysis

**TMS Off:**

Shuttles 138601 and 138605 run with the speed scheduled by the original plan. They approach the convergence point before the delayed TGV (102 and 104 respectively) and join the high speed line preceding them, causing headway/hindering conflicts. TGV delays cannot be recovered.

**TMS On:**

The TMS slows down Shuttles before the convergence point so that they join the high speed line just behind the delayed TGVs. This action has negligible consequences on Shuttles punctuality, but allows the TGVs to recover a significant part of their initial delay, running at maximum speed throughout the control area.

**Energy Consumption:** Consumption values are reported in Table 3 in MWh and normalised to the reference case.
Table 3: Overall energy consumption

<table>
<thead>
<tr>
<th></th>
<th>Energy consumption [MWh]</th>
<th>Normalised energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMS Off (reference case)</td>
<td>29</td>
<td>100%</td>
</tr>
<tr>
<td>TMS On (COMBINE TMS)</td>
<td>26.5</td>
<td>91.4%</td>
</tr>
</tbody>
</table>

Figure 3: Comparison between entry and exit delay for each observed train

4 Identification of technical and operational parameters

The impact of technological parameters on TMS performances was addressed identifying such parameters and providing an interesting and consistent analysis about relationships among them. A valuable result is that the most important subset of parameters can be viewed as one parameter only, the so-called control loop delay, as far as the impact on TMS performances is concerned. This analysis also showed the importance of an information exchange among adjacent TMS systems in order to efficiently handle trains leaving a controlled area and about to enter in the adjacent one. Moreover COMBINE proposed a technically sensible approach for identifying the maximum allowed parameter values once the network layout and the traffic pattern are given.

5 Users acceptance

The COMBINE project proved itself as a very effective experience as far as users acceptance is concerned, as it was also testified by the very positive judgement from Railned, the direct user within the Consortium. The following key points summarise the elements for such judgement:
- Users ideas about the practice of traffic control/management were included;
- A fruitful match with industrial and scientific knowledge on traffic management was reached;
- A very useful demonstrator was developed;
A step towards the practical implementation of TMS was made;
- User requirements for an advanced TMS were made explicit, thus allowing improvements in the specifications of related systems;
- The functional requirements were well met, as assessed by the verification tests, and the system's layered architecture suits the present practice in traffic control;
- The system performs automatically when traffic regulation stays within the existing plan (timetable, order of trains, routes), while if changes of plan are necessary, this must be approved by the dispatcher who is supported by the "what-if-simulator" in his decisions.

6 Conclusions

Verification and evaluation results prove that the COMBINE project represents a successful pioneer research in the field of Traffic Management in a moving block railway system:
- from technology implementation point of view, COMBINE presents a fully functioning TMS, implementing effective advanced conflict detection and resolution algorithms. Its layered, modular system architecture, makes it suitable for any ERTMS/ETCS compliant system and for railway networks of any size. Moreover, COMBINE analysed the most significant technical parameters affecting TMS feasibility and performances, providing the knowledge required to select the most suitable technologies to be adopted and/or developed for the relevant data acquisition, communication and processing tasks.
- from the actual benefits estimation point of view, the Demonstrator developed within COMBINE provides an outstanding simulation platform, integrating a decision support module, a realistic MMI for the dispatcher, an effective conflict detection and resolution system and a consistent ERTMS/ETCS level 3 environment simulator. Taking into account detailed infrastructure description, rolling stock characteristics, planning policies and technology constraints, the Demonstrator represents a powerful tool for many purposes, ranging from feasibility studies to costs/benefits analysis, from planning support to personnel training.

The effectiveness of the COMBINE TMS has been proved through an extensive tests campaign, showing very clearly that the benefits obtainable from an advanced TMS operating in the ERTMS level 3 environment are strictly related to the specific infrastructure layout and network planning practice, and emphasising the added value related to the development of the Demonstrator.

Beside the reported results, the most apparent prove of COMBINE success lays in its sequel: COMBINE 2 a new project extending the COMBINE research domain has been co-funded by EU Directorate-General Information Society within the IST Programme. This new project, with a broader and strengthened
Partners list, is going to deal with multiple control centres managing interconnected railway networks equipped with mixed signalling systems.

References


