The European project COMBINE 2 to improve knowledge on future rail Traffic Management Systems

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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 2, co-funded by the European Union within the Information Society Technologies Programme. The objectives of the COMBINE 2 project were twofold: on one hand, to estimate the impact on rail traffic management of installing in-vehicle positioning and communication equipment, in order to reduce the technical gap between current and future signalling systems, on the other hand, to address the new generation of Traffic Management Systems (TMSs) able to efficiently manage large railway networks equipped with mixed signalling systems. To reach those objectives, COMBINE 2 has also devised new approaches for traffic optimisation and new methodologies for managing the interaction among TMSs controlling adjacent railway areas. Such approaches and methodologies have been validated through the implementation of a Demonstrator able to deal with railway networks equipped with fixed and moving block signalling systems.
Keywords: railway, mixed signalling, Traffic Management System.

1 Introduction

COMBINE 2, acronym of *enhanced COntrol centres for fixed and Moving Block sIgNalling systEms – 2*, is a follow-up of the project COMBINE (1999 – 2001), which addressed the problem of traffic regulation and optimisation in railway lines equipped with a moving block signalling system compliant with ERTMS/ETCS level 3 [1,2], and was co-funded by the EU within the Telematics Programme. The basic idea of the former COMBINE project was to analyse problems and opportunities related to the development of an advanced railway

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Traffic Management System operating in the moving block signalling environment. COMBINE developed a fully functioning TMS Demonstrator, implementing effective advanced conflict detection and resolution algorithms. The Demonstrator was based on a layered and modular system architecture, in order to make it potentially suitable for any ERTMS/ETCS compliant system and for railway networks of any size. Through such Demonstrator, COMBINE identified and analysed the most significant technical and operational parameters affecting the system performances when a single control area is within the responsibility of a single Dispatcher using an advanced TMS. The effectiveness of the COMBINE TMS has been proved through an extensive tests campaign, addressing the comparison of performance indicators such as trains punctuality, energy consumption, and speed profiles stability. Tests results showed very clearly that the benefits obtainable from an advanced TMS cannot be estimated abstracting from the specific layout and traffic pattern, emphasising the added value related to the development of a powerful tool such as the Demonstrator.

The COMBINE project somehow anticipated the next generation of TMSs, or at least a major part of them, as no significant implementation of moving block signalling was still known in the railway context.

The objective of the COMBINE 2 project was to exploit the results and the insight derived from the previous experience in order to address a more complex (and most likely in next 5 to 30 years) problem, i.e. traffic management for railway networks equipped with different signalling systems (fixed and moving block) and consisting of multiple adjacent and interconnected local control areas. Moreover, COMBINE 2 also addressed the potential impacts relevant to the adoption of low cost positioning/communication technologies for the implementation of an advanced TMS in a new signalling environment: fixed block for train control (safety) in conjunction with enhanced speed regulation (traffic management). The COMBINE 2 project, started in March 2002 from a heterogeneous Consortium composed by research institutions (Università di Genova and Università Roma Tre – I, Universitaet Osnabrueck – D), railway systems providers (Bombardier Transportation – I), railway operators (Railned and Railinfrabeheer – NL), IT-companies (CO.S.MO.S. and OnAir – I) and consultants (Holland Railconsult – NL), has been completed in December 2003.

2 Research framework of the COMBINE 2 project

The scenario devised by the Consortium for next future railway networks can be described as it follows:

- due to the investments necessary for the implementation of ERTMS/ETCS level 3 (infrastructures, radio block centres, on-board equipment, …), it is reasonable that only a subset of existing or new main corridors will be equipped with moving block signalling systems (e.g. high speed lines);
- targeting the exploitation of other main lines without incurring in huge investments, the adoption of low costs positioning/communication technologies will be considered for enhancing traffic management

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effectiveness, while relying on fixed block signalling as far as safety issues are concerned (train separation);
- a number of secondary lines will be managed through the “traditional” fixed block signalling systems.

Given the different type of traffic (e.g. passengers vs. freight, international vs. regional or local, …), the different traffic regulation objectives (e.g. minimum travel time vs. punctuality with respect to the timetable or energy consumption reduction) and the different management approach characterising such different types of lines, it is reasonable that their responsibility will be distributed among different Dispatchers, thus identifying a number of local control areas. On the other hand, the need to decompose a railway network into several local control areas also derives from the complexity of the optimisation problem whenever the network size and the number of controlled trains make it hard to compute effective solutions within the short time limits available [3,4]. Of course, as long as interactions among local control areas are possible (trains exchanged between or submitted to connection constraints among adjacent control areas), a co-ordination for the “global” network has to be granted by a network controller, since decisions taken to manage the traffic of a given control area may affect the traffic of control areas which are adjacent to it. This is the research framework of the COMBINE 2 project, which has defined, developed and validated an advanced Traffic Management System architecture suitable for railway networks of any size or composition complexity.

3 The COMBINE 2 TMS architecture

The COMBINE 2 TMS architecture reflects the needs for network decomposition deriving from both the optimisation complexity and signalling system heterogeneity. The basic idea of the devised architecture was to split a complex network into a number of local control areas, each one characterised by homogeneous signalling system, stated that other network decomposition criteria, as for instance the one based on geographical extension, can also be supported. COMBINE 2 proposes that each area is controlled by a local TMS, and several local TMSs are co-ordinated at a higher hierarchical level. System architecture is depicted in Figure 1, where two local TMSs only are shown for keeping small and readable the picture, stated that the proposed architecture is applicable to a larger number of local areas.

The Network Controller is responsible for taking decision affecting the global network, composed by several local areas, each one under the responsibility of a local Dispatcher and a local TMS instance. The Network Controller communicates with both the local Dispatchers and with the TMS Coordinator, which is the system allowing to supervise the whole network and to take decisions that are sent to the local TMSs. Whenever a local TMS makes a new plan for its own controlled area, the TMS co-ordinator automatically checks the feasibility at the global network level. Should be feasibility missing, an automatic coordination process starts till a global feasible solution is achieved.

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Local TMSs are decomposed into three hierarchical levels. Each level of the TMS has its conflict detection process and keeps as valid the current information (plan, goals, targets, etc) coming from its upper level until a new solution has been validated and accepted. The modular and layered structure of the local TMS is described in the following:

- Layer 2 is devoted to manage high level decisions that should be checked and guided by the local Dispatcher intervention (e.g. cancel a train, change train stopping pattern); in other words all actions that cannot be fully automated and lead to a new updated timetable.
- Layer 1 is devoted to manage medium level decisions with the objective to create a conflict free (local) plan, as close as possible to the timetable coming from Layer 2. This Layer is responsible of the train scheduling and routing.
- Layer 0 manages low level decisions with the objective to respect the conflict free plan coming from Layer 1. This Layer is responsible for controlling the traffic in real time and with great details.

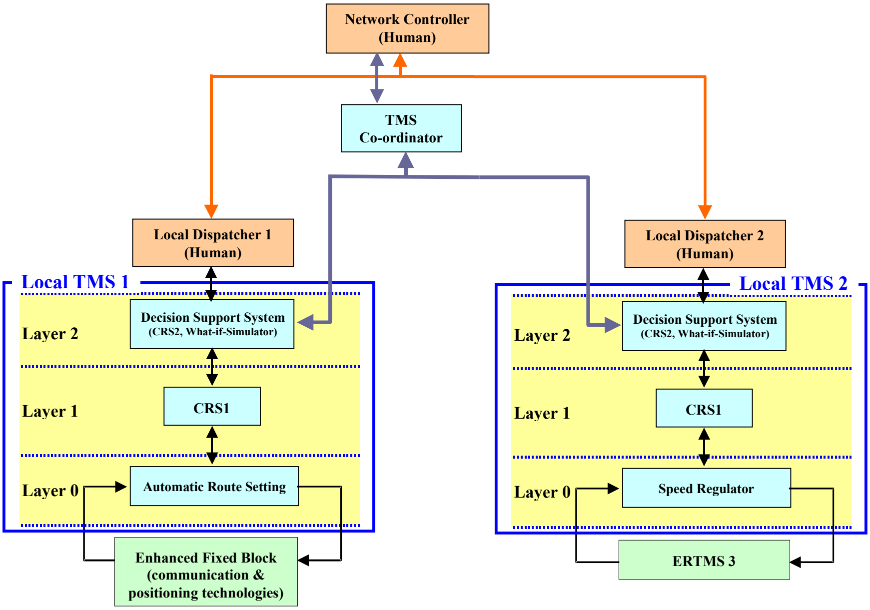

Figure 1: Example of the COMBINE 2 TMS architecture (two control areas).

Particular attention was paid by the Consortium to study modelling techniques for conflicts detection and resolution, as well as optimisation algorithms, in a railway scenario characterised by a mixed signalling system. The result of this study, which represents one of the most valuable achievements of the project, allowed the design of a fully flexible and modular architecture utilising a unique modelling approach (for both fixed and moving block signalling systems) based on the *alternative graph* theory.

4 Verification test sites

The validation of the COMBINE 2 TMS, dealing with the verification of the correct implementation of its design requirements and the overall assessment on its behaviour, has been carried out through the most accurate approach among those affordable for a research project like COMBINE 2. A state of the art demonstrator, that is a simulation environment where the TMS functioning can be studied through a field simulator replicating a suitable test site, has been utilised. In order to test the most important characteristics of an advanced TMS, the COMBINE 2 test site configuration had to satisfy the following requirements:

- include three areas, each one controlled by a local TMS in order to verify the ability to co-ordinate a network of TMSs;
- at least one area equipped with fixed block signalling and one area equipped with ERTMS level 3 signalling;
- big enough to be general and small enough to allow to perform a wide range of numerical tests.

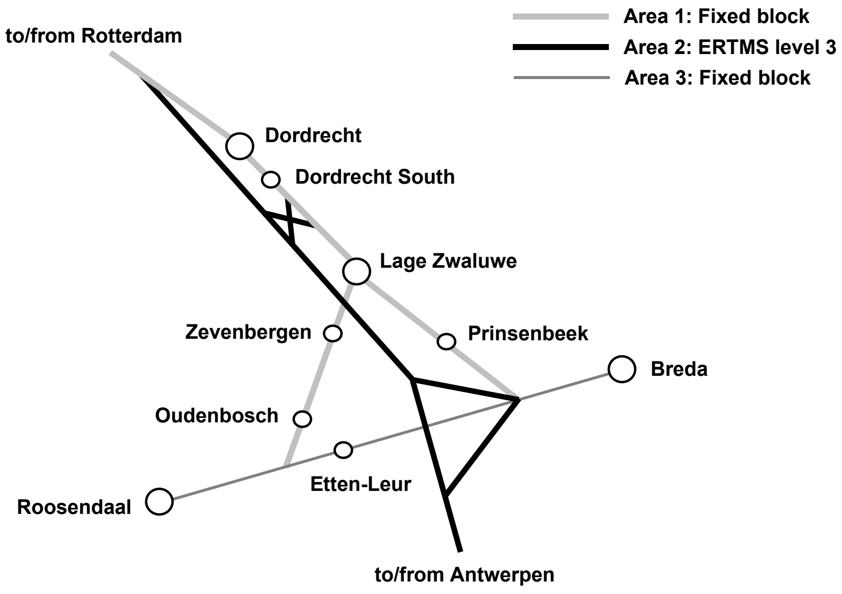

Figure 2: COMBINE 2 test site.

Figure 2 shows the verification site proposed for the COMBINE 2 Demonstrator. It is derived from the actual Dutch railway network connecting Antwerpen – Breda – Rotterdam – Vlissingen, and it is fully compliant with the aforementioned requirements being characterized as it follows:

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- heterogeneous traffic (heavy freight trains, High Speed trains, International, Interregional and Commuter trains);
- a combination layout (number of tracks) - timetable (number of trains) leading to capacity shortages;
- ETCS level 3 safety system assumed to be present on the main line Rotterdam-Breda-Antwerpen;
- traditional block-based safety system (Dutch NS54) applied on the other tracks (with block length between 300 m and 1500 m);
- tracks slope determining speed constraints (e.g. minimum speed for freight trains);
- each main corridor identifying a control area which has to be managed by the relevant local TMS.

The following differences between the real layout and traffic scenario and their representation in the simulated site have been assumed in order to allow the most profitable use of the Demonstrator for validation purposes:

- junctions between lines have been added in order to increase the complexity of traffic stream interactions and therefore the complexity of the network co-ordination task;
- big stations have been modelled with simplified lay-outs and trains scheduling constraints (e.g. connections and order) have been considered.

5 Evaluation results

In this section the authors present the results of the activities carried out to estimate the expected impacts of the COMBINE 2 application as far as traffic regulation performances are concerned. In particular two major features have been investigated:

- impacts related to the adoption of positioning and communication technologies in a railway system equipped with a fixed block signalling system, where traffic regulation is performed by an advanced TMS;
- capability and effectiveness of coordinating multiple control areas in a railway network equipped with heterogeneous (moving and fixed block) signalling systems.

In the following the acronym EFB will be utilised to identify the case when the TMS relies on punctual information on trains position (collected through GPS receivers on trains) and has the possibility to suggest an advisory speed to train drivers (by means of GSM communication).

The acronym FB will be utilised to identify the reference case, where position information is given by track circuit occupancy in a conventional fixed block environment.

Utilising Area 1 of the test site described in the previous section and introducing stochastic delays on the trains entering that area, the performances of the EFB and FB cases have been estimated.

In Figure 3 the distribution of absolute deviation from the timetable is shown for the trains exiting Area 1 in both scenarios, together with entry disturbances.

The comparison with the reference case allows to give evidence that, when the TMS operates with the EFB signalling system:

- the number of trains exiting the control area with deviation from timetable lower than 60 s is increased of about 47%;
- the number of trains leaving the control area with deviation higher than 10 minutes is reduced of about 20%;
- the mean value of the deviation from the timetable for trains leaving the control area is reduced from 210 to 167 s (being the variance approximately the same). Considering a confidence level of 95% and thanks to the significant sample size, the confidence interval for the two mean values is (210 ± 17) s and (167 ± 17) s, so that there is no overlap between the two intervals.

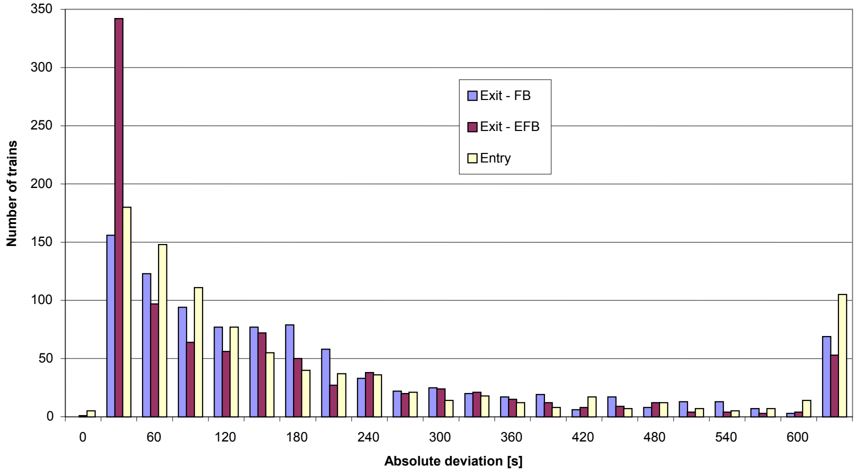

Figure 3: Distribution of absolute deviations from the timetable (EFB – FB).

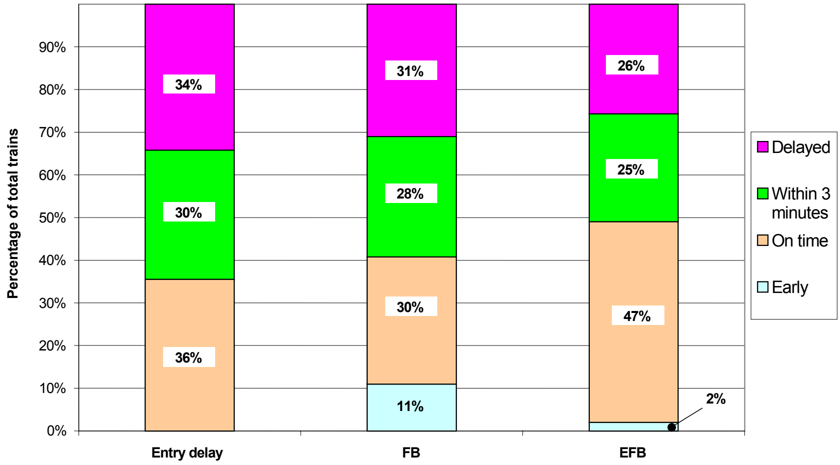

Figure 4: Regularity comparison between EFB and FB.

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When the comparison is carried out on the basis of the punctuality (or regularity) of the trains, adopting criterion largely accepted among railway operators, the results can be presented as shown in Figure 4, where trains punctuality is evaluated as it follows:

- trains are considered *on time* when they reach their target within 1 minute (earlier or later) from the time interval centred on the timetable target time;
- trains anticipating the target for more than 1 minute are considered *early*;
- trains are considered *delayed* when the delay on the target achievement is larger than 3 minutes
- trains reaching their target with delays between 1 and 3 minutes are shown as *within 3 minutes* as the threshold of 3 minutes is considered to discriminate between ordinary and noteworthy delays (e.g. to be considered for delay announcement to passengers).

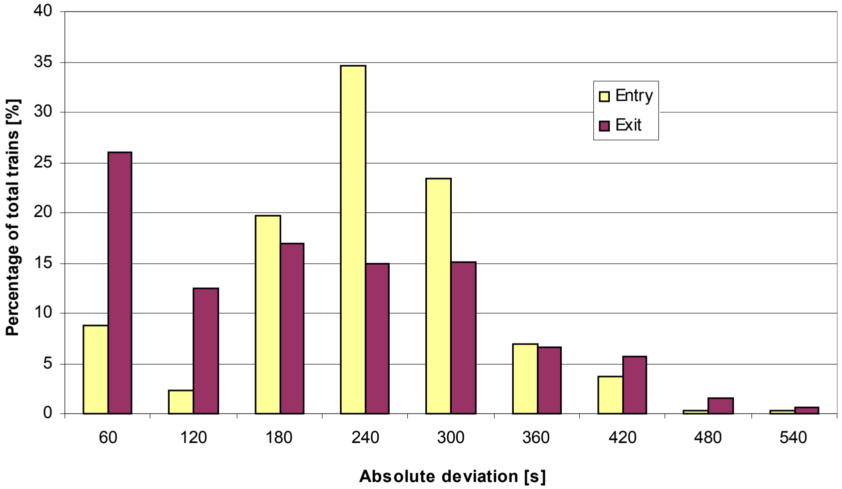

Figure 5: Absolute deviations distribution from the timetable (mixed signalling).

The results depicted in Figure 4 show that the regularity of trains is largely improved through the adoption of the EFB: *early* trains are decreased of about 9% and an overall gain of about 17% is achieved for trains reaching their target *on time*. Moreover the overall punctuality of trains, i.e. the percentage of trains reaching their target without noteworthy delays, is increased of about 5% when the EFB is implemented.

As far as the results dealing with the coordination in a mixed signalling environment are concerned, two scenarios have been addressed, each characterised by a suitable stochastic distribution of the trains entry delay applied to the same traffic planned over the whole test site. As an example, Figure 5 and Figure 6 show the results of the simulations related to the first scenario, which is

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characterised by moderate entry disturbances (mean value of about 210 s). Figure 5, where entry and exit deviations from the timetable are depicted, testifies the effectiveness of the actions taken by the COMBINE 2 TMS, being the distribution of the exit deviations skewed toward smallest values, with an average value of about 160 s.

In Figure 6 the performances of the full operating COMBINE 2 TMS are compared with those achievable when TMS Coordinator is switched off.

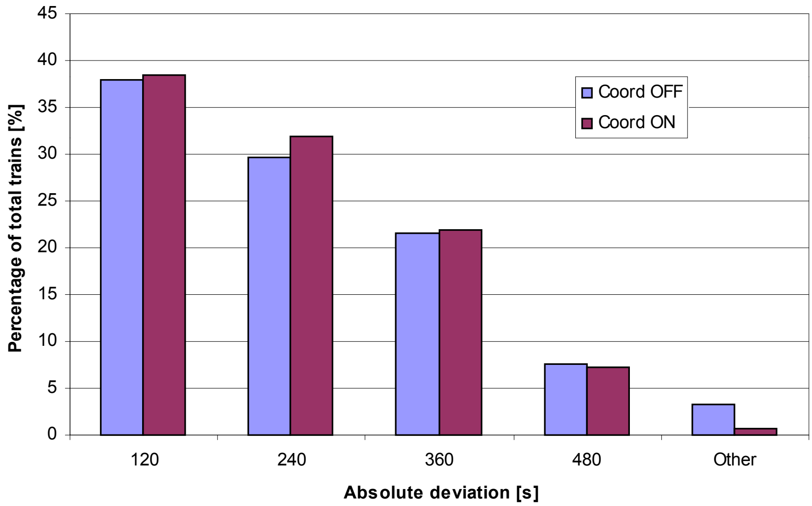

Figure 6: TMS performances with (ON) and without (OFF) coordination.

It is worth noting that no conflict detection and resolution functionalities are available at the network level when the TMS Coordinator is switched off, and information about a train approaching a local control area is available just a few minutes before its actual entry time. The effects of the TMS Coordinator on traffic regulation performances can be summarised in an overall reduction of exit deviations, which is more apparent when the highest ones are considered. In fact, the benefits of the coordination functionalities are more evident when the results of all the simulations, included those relevant to higher entry disturbances, are analysed, as shown in Table 1 for a sample size of about 700 trains.

Table 1: Measures on entry and exit delay distributions.

	Entry	**Exit – OFF**	**Exit – ON**
Mean value [s]	296	275	249
Standard deviation [s]	153	197	175
Confidence interval (90%) [s]	296 ± 10	275 ± 13	249 ± 11

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6 Conclusions

In this paper the authors have presented the objectives, the approach and the evaluation results for the COMBINE 2 project. Stated that quantitative results are relevant to the considered test site only, the qualitative analysis of the project achievements allows to conclude that improvements in railways traffic regulation can be obtained through the development and implementation of a new generation of TMSs. COMBINE 2 indicates the road to take. For further information just visit the project website at www.combine2.org.

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