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EXECUTIVE SUMMARY OF THE THESIS

Hardware-in-loop based performance evaluation of fixed block and moving block signalling systems in railway traffic management

TESI MAGISTRALE IN MOBILITY ENGINEERING – INGEGNERIA DELLA MOBILITA

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1. Introduction

The growth in the capacity required by the railway and the efficiency required in its operations in European corridors has hastened the need to switch to more advanced signalling architectures within the framework of the European Rail Traffic Management System (ERTMS). European Train Control System (ETCS) offers a standardized system of continuous supervision of trains and movement control of trains, which allows us to achieve higher interoperability and safety rates. Although traditional Fixed Block signalling systems as shown in Figure 1, are strong and have been extensively used, they are based on a fixed infrastructure segmentation which can frequently lead to conservative operational spacing. Moving Block signalling as showcased in Figure 2, on the contrary, presents active separation logic on the principle of real-time braking integrity and continuous communication. This thesis aims to make the systematic use of a simulation framework to compare these two signalling philosophies and measure the differences in the functioning of both under the same boundary conditions.

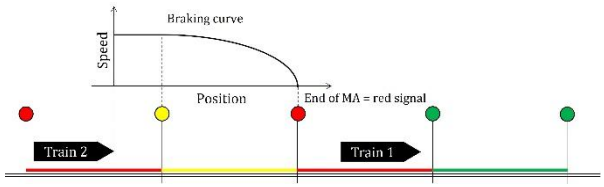

Figure 1: Signalling illustration for Fixed Blocked and block occupancy.

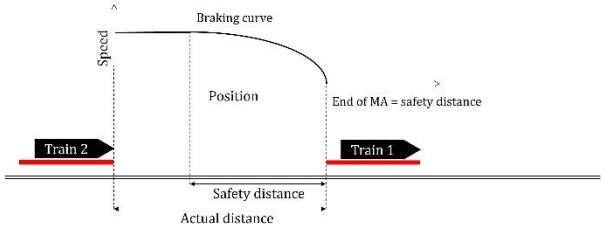

Figure 2: Dynamic Position during Moving Block signalling.

2. Simulation Methodology

The study was done comparatively within a railway simulation environment simulated by using Simulink that considered two trains moving in same directions along the same track (Leading train and Trailing train). The time of the simulation was 3000 seconds, and the maximum allowed speed was 160 km/h and the headway initially was 240 seconds. Longitudinal dynamics model combines traction and braking curves, profile of gradient, and ETCS supervisory logic such as Limit Curve (LC), Warning Curve (WC), Service Brake Intervention (SBI) and Emergency Brake Intervention (EBI). The two signalling configurations were developed in this environment. Fixed Block arrangement is found on the discrete block division and occupancy detection, in which the motion authority update is made only in those cases when the complete track segments are cleared as shown in Figure 1. The Moving Block set up releases the fixed block boundaries and computes safe separation time dynamically by braking capacity in real time and train condition and permits unlimited adjustment of movement authority as expressed in Figure 2.

2.1. Hardware-in-the-Loop Test-Bench

To further explore the research by going beyond the virtual modelling, Hardware-in-the-Loop (HiL) test bench was incorporated in the simulation platform as shown in the Figure 3. The computational architecture comprises a host PC executing the main simulation model, a Speedgoat® real-time target machine to deterministic execution and a Raspberry Pi platform, which performs some of the communication and dynamic MRSP functions. This is achieved by looking at interchange of data between computational units performed using UDP-based communication which enables distributed processing of signalling logic in real-time. Especially, the synchronization between computational nodes, fixed-step configuration of solver, consistency related to sample time, and effects of communication latency were paid particular attention. The HiL setup enabled verification of signalling behaviour within the constraint of real time and gave an insight of the practical implementation issues related to distributed railway control architectures.

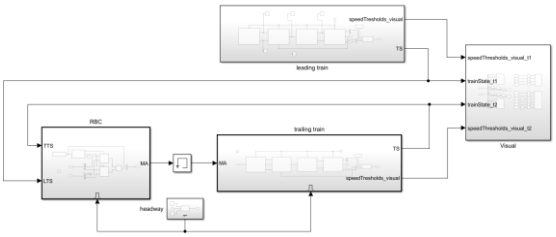

Figure 3: Block diagram of the simulation Environment.

2.2. Key Performance Indicators

Comparison of performance between Fixed Block and Moving Block signalling was done on three major performance indicators which include Commercial Velocity, Line Capacity and Motion regularity from the results obtained during simulations as illustrated in Figure 4, 5 & 6. The commercial velocity was which was calculated as a ratio between the distance travelled and the effective travel time gave an operational measure of the efficiency of the service. The two signalling strategies had the same set of headway and maximum speed control, but Moving Block configuration had a smoother speed adjustment and less unnecessary braking intervals, which led to better continuity in operations. The headway relationship C = 3600 / H, was used to determine the line capacity giving a theoretical capacity of 15 trains per hour where the headway of 240 seconds gave the same result in both layouts. Whereas nominal capacity is the same when both the headway conditions are fixed, the Moving Block approach proves to be better in its dynamic use of available separation margins. Analysis of motion regularity showed that Fixed Block signalling results in deceleration phases in block clearance logic, and that Moving Block allows constant speed change and minimizes oscillatory behaviour, leading to smoother operations.

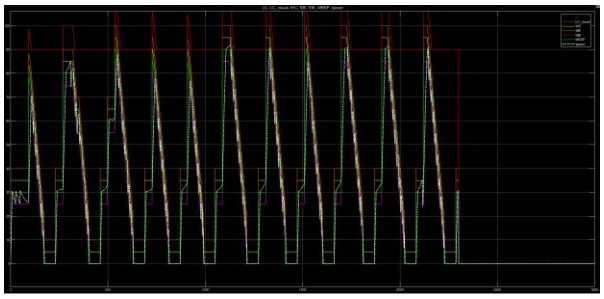

Figure 4: Trains speed profile, station stops and dynamic characteristics during simulation.

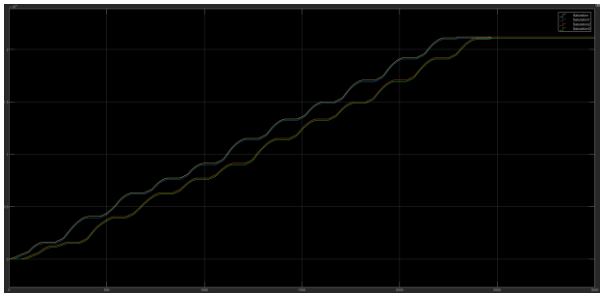

Figure 5: Position results from the simulation showcasing the virtual position of Trains.

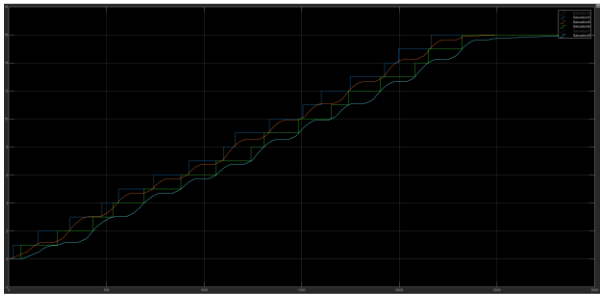

Figure 6: Block Occupancy during the phase of simulation of both Trains.

3. Result Analysis

The findings emphasize the fact that the primary difference between Fixed Block and Moving Block signalling is the meaning of safe separation. Fixed Block systems are infrastructure based and is discretized in nature and is conservative because of predefined segmentation. Moving Block systems are facilitated by continuous communication and centralized Radio Block Centre (RBC) computation to compute separation based on real braking performance and operational condition. Although the Moving Block approach adds extra complexity to both communication and synchronization demands, it has proven evident benefits in the regularity of motion and the use of infrastructure under the tested conditions. From the Figures 7, 8, 9 & 10 of Fixed Block simulation, the computation of Motion regularity, Commercial velocity and Line capacity was executed and each efficiency in performance was achieved to compare with Moving Block simulation results.

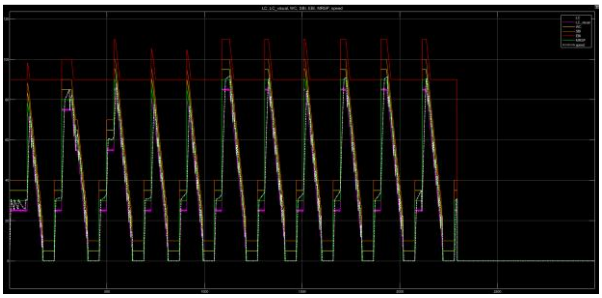

Figure 7: Leading Train speed profile during Fixed Block simulation.

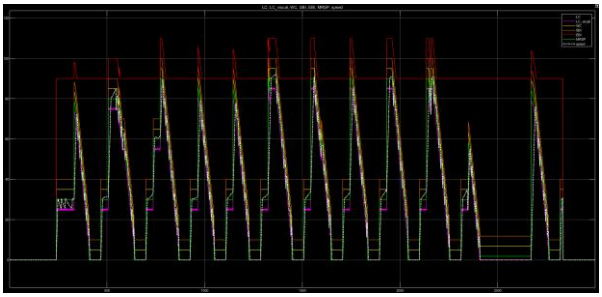

Figure 8: Trailing Train speed profile during Fixed Block simulation.

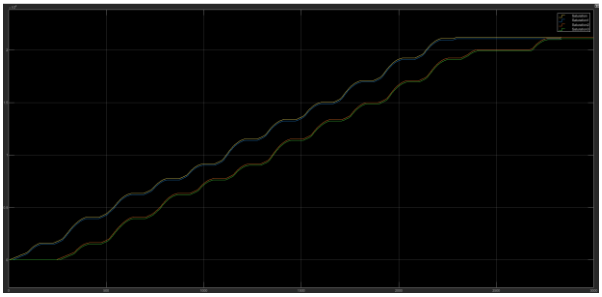

Figure 9: Both trains dynamic positioning during the Fixed Block simulation.

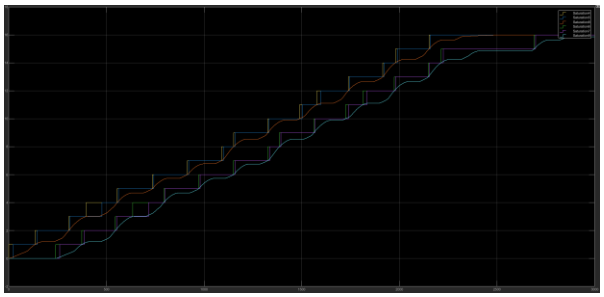

Figure 10: Both trains dynamic block occupancy during the Fixed Block simulation.

When using the same simulation conditions (maximum speed 160 km/h, total simulation time 3000 s, and headway 240 s), the Moving Block configuration has quantifiable benefits concerning the efficiency of the operations in comparison to the Fixed Block system as shown in Figures 11, 12, 13 & 14. Both the signalling strategies have the same theoretical line capacity of 15 trains/h since this is limited by the given headway of 240 s. Nonetheless, variances are presented in the dynamic performance indicators. The commercial velocity shown in the Fixed Block simulation is about 28.4km/h (17.75% efficiency), and the Moving Block arrangement has shown a commercial velocity of about 30.7km/h (19.2% efficiency), with a 1.5% efficiency improvement which is a better continuity of speed and less conservative braking behaviour. On the same note, the motion regularity increases to about 0.74 during the Moving Block operation compared to 0.70 in the Fixed Block case, which shows a 4% efficiency improvement that the velocity change is more gradual, and the deceleration stages are not so sharp. Even though nominal capacity is not affected by fixed headway conditions, the Moving Block system shows the obvious increase of dynamic efficiency in terms of commercial velocity and the improvement of the regularity of the movement without the decrease in the safety constraints of the ETCS.

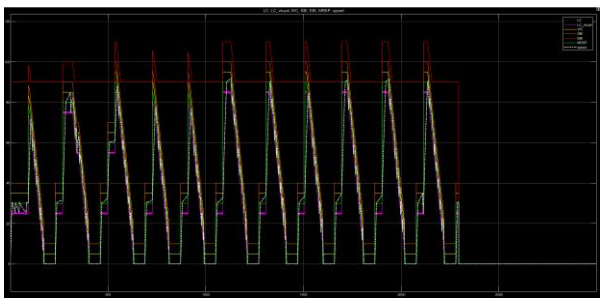

Figure 11: Leading Train speed profile during the Moving Block simulation.

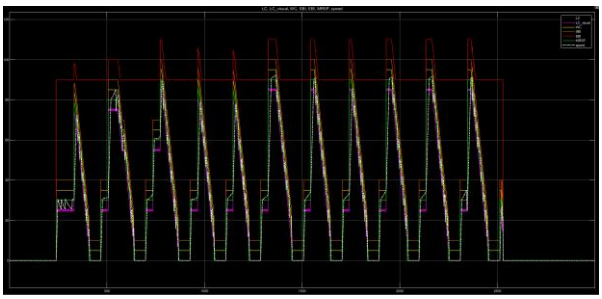

Figure 12: Trailing Train speed profile during the Moving Block simulation.

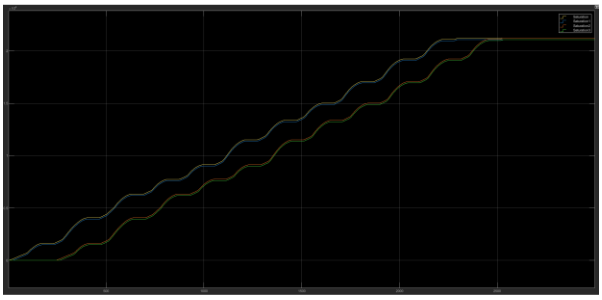

Figure 13: Both Trains dynamic positioning during the Moving Block simulation.

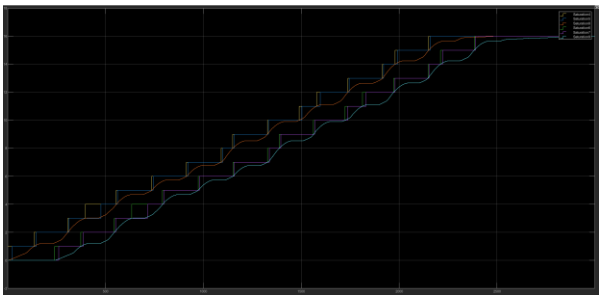

Figure 14: Both Trains dynamic block occupancy during the Moving Block simulation.

4. Conclusions

The thesis offers a systematic comparative analysis of Fixed Block signalling and Moving Block signalling in an ETCS based system with a Hardware-in-the-Loop implementation. The work balances theoretical modelling and practical implementation issues, with the combination of simulation-based performance analysis and real-time validation. The results show that Moving Block signalling improves smoothness and efficiency of infrastructure operation and safety margins that are implemented by the ETCS

supervision logic. The research is relevant to the idea of the operational consequences of signalling evolution and a quantitative foundation on forthcoming migration into dynamic railway traffic management systems.

5. Further Improvements

Although the current research entails a systematic comparative analysis of Fixed Block and Moving Block signalling under regulated simulation settings, there are various enhancements that would make the analysis deeper and more broadly applicable. First, headway of both set-ups was set at 240 seconds, which limited the theoretical Line capacity to 15 trains per hour. An extension of this study would be to gradually decrease the headway through the Moving Block arrangement to find out the real lowest safe distance that can be achieved with the control of ETCS. This would enable a more realistic evaluation of the potential capacity gain ability of dynamic separation strategies.

The Hardware-in-the-Loop could be enhanced with more synchronization between distributed computational nodes, real-life railway communication protocols rather than simplified UDP exchange, and higher-frequency real-time execution verification. The fidelity of the real-time test bench would be enhanced by integration of ETCS Level 2/3-specific message structure and finer Radio Block Centre logic.

Lastly, incorporation of extension to route level analysis, which would entail interactions between multi-train on longer routes such as high-density intercity routes, would enable assessment of network-level effects. This extension would give more quantitative information about infrastructure usage, perturbation recovery and scalability of the Moving Block signalling in a real-world situation.

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