Optimizing headway with ETCS and ATO

Authors:
David Morton BSc, senior specialist for ETCS, david.morton@siemens.com
Siemens AG, Ackerstr. 22, 38126 Braunschweig, Germany
Dipl.-Ing. Rupert Litterst, system manager for ETCS, rupert.litterst@siemens.com
Siemens AG, Ackerstr. 22, 38126 Braunschweig, Germany

The European Train Control System (ETCS) is the emerging ATP standard for interoperable mainline applications. Originally developed for the European railways, today ETCS is a global ATP solution which is in operation all around the world.

Automatic Train Operation (ATO) systems are typically used in mass transit networks, which are characterised by high train densities and extremely short headways.

In a study on behalf of Network Rail, Siemens demonstrated that the technology for an integrated ATO/ETCS solution is ready and has major operational benefits.

Siemens is an active member in working groups for the international standardization of ATO/ETCS systems to ensure interoperability.

1 Introduction

These days mass transit lines in the central core or urban areas are often operated close to their technical headway limits. There is a growing demand to operate metro style services with mainline trains as they enter urban areas. Such trains may have longer dwell times due to the number of passengers with luggage and because they have fewer doors compared with metro trains. Changing the track layout to increase capacity is expensive and often not possible. Even minor operational disturbances on these lines can have knock on effects leading to major delays across a wide area of the rail network and passenger dissatisfaction.

Network Rail commissioned Siemens and two other suppliers with the ‘ATO National Deployment and Implementation Design Study’ to gain confidence in the technical readiness of ATO/ETCS solutions, which facilitate automatic train operation with the protection of the European Train Control System to shorten headways, improve service consistency and perturbation recovery, and improve energy efficiency whilst guaranteeing safe train operation on mainline applications.

Siemens has a long history of separate ATO and ETCS applications. ATO is an important constituent of Trainguard® MT, a high performance CBTC (communications-based train control) system for mass transit applications, which is successfully in operation on many metro and underground lines all around the world. Trainguard 100/200 onboard equipment is a compact and modular ETCS onboard solution, which ensures safe and interoperable operation in mainline applications all over the world.

Siemens also has a test and simulation environment, which includes the ETCS trackside equipment Trainguard 200 RBC and Trainguard Eurobalise S21, to allow realistic investigations in the lab as well as an impressive 3D visualisation of train movements.

The following basic requirements and conditions were taken into account for the simulations:

- 24 trains per hour robust service
- 30 trains per hour recovery capability following operational perturbations
- Stopping accuracy of ±0.25m
- Train lengths of 205 and 240 metres
- Example track and signalling layouts provided by Network Rail
- Energy-optimized driving with variable running profiles
- Use of original software and engineering data for ATO and ETCS
- Realistic simulation of train characteristics
- Variation of the adhesion factor between wheel and rail
2 Approach

We wanted the simulations to be as realistic as possible, whilst investigating various optimizations to achieve the minimum headway with short journey times. Figure 1 shows various factors that contribute to the headway. One of the major factors is the braking curve ATO-SB, which is the service brake controlled by the ATO. This must be more restrictive (longer) than the most restrictive ETCS computed braking curve to avoid irritating warnings to the driver or brake interventions by the ETCS safety system. Other factors are the train length, block lengths, system delays and the onboard odometry confidence interval.

Figure 1: Factors contributing to headway

The following principles were used to investigate possible headway optimizations:

- The ETCS emergency braking curve ensures safety and is, therefore, calculated for worst-case conditions with a safety margin typically between 20% and 40%. The effects of varying the safety margin were investigated. Future simulations will use the new ‘Baseline 3’ ETCS braking parameters, which better define these safety factors.

- To avoid emergency brake interventions, ETCS has a set of braking curves that aid the driver with indications, warnings and service brake intervention. ATO does not need these additional curves that effectively add to the headway. We therefore investigated the effect of suppressing ‘unnecessary’ ETCS braking curves whilst ATO is active. This ‘suppression’ is not covered by the current ETCS standards, so any application would have to address this issue.

- System delay times were made as realistic as possible by using original hardware in the test system, previous lab measurements for interlocking delays and field measurements of GSM-R radio communications. Siemens Simis W interlocking, Trainguard 200 RBC and Trainguard 200 Onboard are already optimized to reduce system delays to very short times.

- ATO adjusts the amount of coasting to achieve the maximum energy efficiency possible for the required journey time between two given points. By varying the required journey times, we investigated the effects of a range of driving styles from most energy efficient (maximum coasting) to most ‘aggressive’ (as close as possible to the ETCS braking curves) for the shortest possible journey time. Following full acceleration and cruising, ATO controls the coasting time, where traction is switched off before braking starts.

- The effects of varying the block lengths were first investigated using Falko®, which is a powerful tool from Siemens for simulating headways, constructing and validating timetables. It can also be used online for dispatching.

- Additional balise groups on the approach to the operational stopping points allow ATO to have precise positional accuracy and control braking for quick and accurate stopping. For an application, these balises would need to be accurately measured after placement for the ATO/ETCS data to achieve the desired stopping position on a platform.
Figure 2 and Figure 3 show the ATO and ETCS braking curves with a 20% safety factor on the emergency brake (EB) deceleration. It can be seen that the ATO braking curve is flatter when all standard ETCS braking curves are active, thereby adding to the minimum headway possible, as shown by ‘ATO-SB’ in Figure 1.

The flattening effect also depends upon the onboard odometry confidence interval because the EB curves are supervised from the danger point with the ‘maximum safe front end’, whereas the other curves are supervised from EOA (end of authority) with the ‘estimated front end’. When the confidence interval grows, the EB curves effectively move towards the SB curves, flattening them more and increasing headway further. This effect would add 30m to 50m or about 4s to the minimum headway possible at 50 km/h. This is significant with such challenging headway targets.

The safety margin of 40% on the emergency braking curves increases the headway still further. Highest capacity is achieved with suppression of ‘unnecessary’ ETCS braking curves and no more than the minimum necessary confidence interval for the emergency brake deceleration.

Figure 2: ATO braking curve (green) with ETCS supervision of all standard braking curves

Figure 3: ATO braking curve (green) with ETCS supervision of emergency braking curves only
3 Method

Simulations were done in two different ways:

1. Demonstrator

   (Diagram showing system components and connections)

   - ATS: Automatic Train Supervision (route setting function)
   - CFM: Communication Functional Module
   - DMI: Driver Machine Interface
   - I/L: Interlocking
   - MVB: Multifunction Vehicle Bus
   - PC: Personal Computer
   - TG: Trainguard
   - TUS: Test environment including speed sensors and ETCS antennas
   - 3D: 3 dimensional large display with simple track environment

   Figure 4) with original product hardware, software and engineering data provided a realistic simulation environment.

2. Simulation tool Falko, Siemens tool for offline design and validation of timetables and online dispatching, was used for comparison and to optimize block sectioning.

   Test scenarios were agreed with Network Rail for realistic operational situations.
To measure headway, at least one train must follow another as close as possible. The demonstrator provides one simulated train with original product software running on a PC and one train with original product ATO/ETCS hardware and software including the ETCS DMI (Driver Machine Interface). Baseline 2.3.0d ETCS equipment was used together with a realistic simulation of the train’s driving dynamics.

The trackside automatic train supervision (ATS) and interlocking systems are simulated by the Falko tool running on a PC. Trainguard 200 RBC software and data were used for the RBC (Radio Block Centre), which ran on a PC. The Communication Functional Module part of Euroradio simulated the GSM-R radio transmission between track and train.

ATO provided an output for train door control, which was visualized on the ATO-DMI, taking the timing of platform screen door operation into account. The doors are permanently released. In a real application, ETCS or the driver would release the relevant doors to ATO control. ATO checked that the train had actually stopped within the small limits set for the accurate stopping positions before opening the doors.

A large screen provided a realistic 3D presentation of the trains running on the required track layout with gradients and curves together with signals, stations and balises. The ETCS marker boards were represented by signals so that the signal aspect could be seen as the train passed. Figure 5 shows the demonstrator equipment and a transportable version of the system.

Test runs could be analysed in real-time with speed-distance graphs, simulated energy consumption, and measured journey and dwell times for each train.

Figure 4: Architecture of the demonstrator system
4 Simulation Results

The ATO Study included two example track layouts: Track 1 (‘urban high speed’) and Track 2 (‘urban low speed’). The position of signals, marker boards and block sections were only supplied for Track 2. We were, therefore, able to experiment with Falko to determine the optimum block spacings, before designing the RBC and interlocking data.

We found that a metro style optimization was the most effective. With short distances between the stations, the dominant factor for the headway is the platform reoccupation time. The minimum possible headway is the platform occupation time (dwell time) and the platform reoccupation time (the time that the first train takes to clear the platform and the following train to come to stand at the stopping point). Figure 6 shows that the reoccupation time can be minimized by shortening the block sections along the platform. For a real application, this would be achieved by adding axle counters or track circuits. This may sound expensive but it is only required at the most critical stations and we also found that signals/marker boards between closely spaced stations could be removed because the first train would already be at the next station before the following train departed. Some of the marker boards shown in Figure 6 for convenience would not be necessary since they are not operational stopping points.

Optimum results were achieved with spacing for 6 second intervals for each track section to become free when the train departs with maximum acceleration. This is equivalent to moving block using ETCS Level 3 with 6 second intervals between position reports.

![Figure 6: Optimum block distribution at station platforms](image)

Figure 7 shows the speed-distance graphs measured on the demonstrator system for Track 1, using the optimum block spacing described above and an onboard safety margin of 40% for the emergency brake. The lower speed-distance graph shows a dip on the approach to the first stopping point. However, the requirement of a two-minute headway (30 trains per hour) with a 60-second dwell time at the first stopping point was achieved. The graph was smoother with a safety margin of 20%.

The stepped speed restrictions were defined in the information supplied for the ATO Study. They may improve headway but prevent maximum energy efficiency and lengthen the journey times: ATO uses maximum acceleration to reach line speed and then coasts (running without traction) as much as possible.
Figure 8 shows the speed-distance graphs measured for Track 2, using the signalling plans supplied and an onboard safety margin of 20% for the emergency brake. Again, the lower speed-distance graph shows dips or a ‘saw tooth effect’ on the approach to the stopping points. However, the requirement of a two-minute headway (30 trains per hour) with 45-second dwell times was achieved.

The upper speed-distance graphs in Figure 7 and Figure 8 are smooth, indicating that the required ‘robust’ headway of 24 trains per hour is achievable for both tracks.

The ATO braking was fine-tuned so that there were no ETCS brake interventions whether the ‘non-vital’ ETCS braking curves were suppressed or not. Measurements showed that headway was not significantly affected; however, distracting driver warnings were eliminated with suppression.

The results discussed above are for the shortest journey times. We were able to demonstrate that increasing the journey times by only a few seconds between stations led to energy savings of up to 30 percent.

Reducing the ETCS wheel/rail adhesion factor flattened the braking curves, which increased journey times and the minimum headway possible.
5 Summary and Conclusions

Siemens successfully demonstrated with the simulations for the Network Rail ‘ATO National Deployment and Implementation Design Study’ that the ETCS onboard unit Trainguard 100/200 can be integrated with the Trainguard MT ATO and that the performance benefits of a mass transit ATO system can be combined with the advantages of a fail-safe, interoperable mainline ATP system.

We also demonstrated that all headway requirements could be achieved, although further optimization of the positions of signals, marker boards and overlaps for Track 2 (urban low speed) would make the speed-distance graph smoother and thereby improve performance in recovery situations.

The safety margin for the emergency brake deceleration is a trade-off between safety and headway. ETCS baseline 3 (BL3) defines new factors that determine the confidence level more precisely. Preliminary values for the BL3 factors are equivalent to the 20% safety margin for BL2.

Similarly, suppressing the non-vital ETCS braking curves reduces the minimum headway possible and eliminates distracting driver warnings. However, it is a non-standard solution, so conformity and homologation issues would have to be addressed in a real application.

Journey times and headway depend upon many factors and all of them must be optimized to achieve the best possible results. Simulations clearly showed the importance of block spacing, braking curves, driving style and system delays. They also showed the enormous potential for reducing costs and carbon emissions by controlling journey times to save energy whilst adhering to the timetable.

Headway also depends upon consistent driving styles. ATO removes variability between drivers and can be dynamically adjusted by a trackside ATS (Automatic Train Supervisory) system to optimize punctually over a large area by varying the driving style of individual trains from most energy efficient to as fast as possible, which is more aggressive than could be achieved by a human driver without causing brake interventions by the ETCS safety system.

An ATO/ETCS solution is a relatively low cost method of increasing line capacity and passenger satisfaction, whilst reducing energy costs and carbon emissions, and improving safety.

The benefits are further summarized below:

- Increased safety by stopping trains before they could reach a danger point
- Increased capacity with shorter headway
- Fewer train delays with better traffic flow coordination and faster resolution of perturbations
- Consistent, smooth and optimized driving styles
- Reduced energy costs and carbon emissions
- Reduced maintenance costs for rails, wheels and brakes with smoother driving
- Accurate stopping suitable for platform screen doors and access by disabled passengers
- Automatic door operation

In addition, the demonstrator with its realistic 3D graphics attracted much interest from training schools and we successfully demonstrated the feasibility of unsupervised reversal.

The demonstrator is currently being upgraded to support the ETCS baseline 3 braking curves and Siemens is participating in a TEN-T working group led by Network Rail on behalf of the EEIG ERTMS User Group. The group is aiming to standardize the communications between track and train for interoperable ATO/ETCS operation throughout Europe.