SUMMARY

European Main Lines face an increasing challenge to improve performance and capacity. Automatic Train Operation (ATO) is now well-distributed in the field of urban transport, but its implementation in Main Line Railways has up to now been considered more complex or difficult to achieve.

Main Line Operators want ATO functions to help them deliver improved performance for varied service patterns on a mixed-traffic network and optimise speed curves in order to save energy and reduce the wear on both trains and track.

To meet these aims, a new generation of ATO is needed for Main Line Railway applications. It will make use of real-time profiles computed by the Traffic Management System, and safe and energy-efficient speed profiles computed by on-board equipment. ATO equipment must also be adapted to the train’s traction system in order to compute the most appropriate speed profiles to minimise energy consumption whilst achieving the required timetables.

Main Line ATO must respect the fundamental principles of scalability and interoperability of the ETCS system; for example, infrastructure data transmitted to trains in the same manner as is done for ETCS. To guarantee interoperability, a joint approach is required between ERTMS suppliers and Railway operators, to define the interoperability rules for ATO applications (airgap and engineering rules).

Whilst these issues were generally known, a recent study for Network Rail in the UK allowed further analysis.

1 INTRODUCTION

Many trains operated on Main Lines are now equipped with an Automatic Train Protection system (ATP) which safely monitors the driver and automatically brakes the train in case of violation of authority (overrun or overspeed). Over the past 15 or more years, European signalling suppliers and European Railway Operators have elaborated the European Rail Traffic Management System (ERTMS) and the European Train Control System (ETCS) which is now the recognised worldwide interoperable solution for ATP.

The next evolution is to assist the driver directly in driving the train, by adding Automatic Train Operation (ATO) to the ATP system. ATO leads to more deterministic travel times, following optimal speed profiles which permit an increase in the operational traffic flow on existing lines and a reduction in energy consumption.

For a long time, ATO systems have been used in service in urban application; while on Main Lines these systems are quite new because of the diversity of trains, and because of network complexity.

Main Line ATO must also cope with interoperability needs due to the multiple train operators operating on the same interconnected infrastructure.

The challenge is now to implement ATO features on complex Main Line configurations with the same level of interoperability achieved in ERTMS.

2 NOTATION

ATO: Automatic Train Operation
ATP: Automatic Train Protection
ERTMS: European Rail Traffic Management System
3 ATO FEATURES FOR MAIN LINE APPLICATIONS

The aims of using ATO are significantly different for Urban and Main Line railway operation, and consequently the ATO functions will be different for both.

ATO is seen as being beneficial to achieving capacity increase, and is therefore commonly used in urban applications. Hitherto, even though its technical feasibility is clear, ATO has been little used on Main Line rail networks. Why should this be?

Around the world, it is seen that Urban Operators want to implement ATO functions for several distinct reasons:

- In the first instance to achieve journey times and station operation times which are closer to the optimum achievable in theory, and less variable than when drivers are involved. This enables reductions in the minimum operational headway for the line (e.g. by reducing the margin between operational and technical headway), as well as improvements in journey times. The latter benefit may even reduce the number of trains required in service on a line to meet a given capacity demand.

- As a second step, to use unsupervised turnback and/or depot operation to reduce the number of drivers and trains required. This reduces staff costs, and may leave the transport system less vulnerable to disruption due to staff rostering issues.

- Following the previous step, some urban operators allow completely unmanned service train operation, to further reduce costs and vulnerability to disruption, leaving staff free to deal with other issues.

- ATO improves stability of operation, hence limits the propagation of perturbation and provides faster recovery from disturbance.

As a result of the above, many Urban ATO functions relate to controlling the entry of trains into stations, precision of stopping and the management of doors (on the trains, but often nowadays on platforms as well).

It is clear that the introduction of ATO on metros is simplified by the characteristics of most metro applications, for example:

- Lines are predominantly in protected areas (tunnel, or elevated structures)
- Each line is sufficiently self-contained to be re-equipped to a uniform standard at each upgrade during its life
- There is little inter-working between different lines
- The platforms are all quite similar
- The track layout is quite simple
- Due to the intensive services, all on-track engineering work must take place outside service periods.
- The train fleet is homogeneous and dedicated to passenger traffic
• The trains are normally allocated to particular lines

Given this combination of characteristics, the total segregation of the track with complete exclusion of people is a necessity on a busy metro line, and the trains can be made captive to an individual line. Thus, the fitment of a bespoke ATO/ATP system on a whole line and its trains is feasible.

The same goals, mentioned above, may be shared by Main Line Operators on a small number of routes; for example those carrying intensive inner suburban and cross-city services. But, on the remainder of the main line network, even the trains forming these intensive services find themselves sharing tracks with a variety of other traffic – after all, this is the essence of a main line network.

For a Main Line Operator, the benefits of ATO functions lie in different areas to the urban case, for example:

• To manage the delivery of varied service patterns on a mixed-traffic network, according to the real-time schedule defined by the Traffic Management System, in order to improve the punctuality of trains (with consequent benefits for passengers) and to minimise the impact of disruptions (train delays, localised equipment failures, etc.). Benefits gained in this way may be used to increase the resilience of the network to disturbances and/or to increase network capacity (as for urban applications).
• To optimise speed curves in real time, in order to save energy (e.g. by not running faster than is necessary to arrive at a junction at the correct time, and by avoiding conflicts with other train movements)
• To reduce the mechanical wear on both trains and track, by travelling only as fast as is necessary, thereby reducing maintenance costs.

However, the operational constraints of main line networks are significantly more complex than they are for urban ones:

• The track layout is larger and more complex
• The roll-out of new systems across the network takes many years, resulting in most journeys spanning lines with significantly different levels of fitment of infrastructure
• A lot of different train types (with different performance and door layout)
• The trains are not all dedicated to a particular line; they may go anywhere on their national network, and in certain cases anywhere in Europe.
• Absolute exclusion of people (as well as animals and other obstructions) from tracks is not practically achievable throughout a national network, with vast lengths of fencing to maintain, and a multiplicity of overbridges, road level crossings, footpath crossings, open platforms, etc.
• Many journeys have to take place during periods when substantial on-track engineering work is in progress.
• Infrastructure owners and train owners and operators are independent – and sometimes, other parties are also involved – such as train leasers

Consequently, complete automation by removal of the driver is not completely feasible for main line services.

So, the actual question is not “how to apply ATO developed for Urban applications on Main Lines”, but rather “what ATO functions are needed to achieve the operational goals for the Main Line network”, e.g. to improve punctuality and resilience of services, save energy, and reduce mechanical wear, by using information coming from the Traffic Management System (real time profiles and management of timetabled paths).
4 ETCS AS A TRAIN PROTECTION SYSTEM FOR ATO

Automating the driving of trains requires safe Automatic Train Protection (ATP) as underlying functionality, to ensure that the ATO system does not exceed the limits of the Movement Authority issued to the train, either in terms of running too fast at any location on the route, or of running too far along the track.

It has often been suggested that ATO could be provided using ERTMS/ETCS as the underlying ATP system. However, ETCS was designed primarily for train protection (“Class 1 functions”) on national main line and high speed railway networks, and the needs of ATO were not explicitly considered when specifying ETCS functionality. So, some consideration is needed of the suitability of standard ETCS for this purpose, and/or the level of changes that would be needed to ETCS to permit this.

In a recent ATO design study for Network Rail in the UK, three ETCS suppliers demonstrated the technical feasibility of ATO with ETCS, and worked together to study standards for future interoperable ATO. The authors used a Test Bench such as is used for factory testing of ETCS Level 2 schemes for the demonstration. Production Alstom ETCS Radio Block Centre (RBC) and ETCS on-board equipment were linked by a GSM-R simulator, and connected to simulators for the traffic management/interlocking (to enable routes to be set), and to a train movement simulator to simulate to the on-board equipment the movement of the train along the track (providing odometry inputs, balise telegrams at appropriate locations, etc.).

Whereas testers working on ETCS Level 2 schemes usually “drive” the on-board equipment manually, to allow each test scenario to be investigated, for the ATO tests the unmodified EVC, compliant with SRS 2.3.0d was linked to a service-proved on-board ATO unit, which generated the traction and braking demands to the train, in place of the manual operator.

Tests were carried out using data from sections of two distinct high-density urban lines. One had high-speed operation through a busy station with longer-than-average dwell time, and the other represented a low-speed close-headway operation through unequally-spaced stations. Further tests were carried out to demonstrate strategies for unattended turn-back of trains at terminals, and also to simulate ATO operation and traffic regulation over longer distances, both with passenger and freight trains.

The conclusions of this work can be summarised as follows:

- An ATO can drive a train very close to the ETCS supervision curves within any route that allows ETCS Full Supervision mode. However, to optimise performance, the ATO and ETCS supervision curves must be well-matched.
- The headway achievable with an ETCS/ATO system can approach that achievable with a metro train control system. Its performance is limited by the fixed block train detection system inherent in Level 2 ETCS. In the future, the use of Level 3 ERTMS may improve performance further.
- ETCS specifications assume that a physical action of a driver, for example opening and activating a train cab and entering personal and train data, is essential for main line operation. When ATO is considered, fully-automatic operation within each journey is entirely possible technically with ETCS, but some manual intervention is needed when the train reverses direction at a terminal. Various possible approaches were studied to automate these Start of Mission and End of Mission processes, without radically affecting the operational basis for main line trains. In practice, this means finding a way in which the End of Mission, and more importantly the Start of Mission, processes are carried out during a station dwell period, so that the time taken does not increase the headway between trains.

5 ATO - AN INCREMENTAL APPROACH

Because of the great diversity of trains and infrastructure in Main Line operations, an ATO system must be conceived with the highest possible level of flexibility. Indeed, the ATO functional features depend strongly on the signalling system implemented at the trackside and on-board.
At the minimum, an ATP system must be available, giving the maximum permitted speed for the train. With this minimum information, the ATO is able to assist the driver in performing automatic speed control at the highest possible speed (or a lower maximum speed set by the driver). In the ERTMS world this first set of ATO features is possible, in principle, on track equipped in any ETCS level (1, 2 or 3).

A second step of ATO features is achieved when the trackside equipment is able to send to the train additional information relating to platform configuration: the side(s) for opening the train doors, the platform length, the stopping position at the platform, etc...

In this functional step, the on-board ATO/ATP is able to assist the driver in managing the operation in stations by selectively and safely releasing the doors according to the platform configuration. In the ERTMS world, this second set of ATO features is possible with additional balises in level 1 while, in level 2, platform configuration data could also be sent from the Radio Block Centre (RBC) via the GSM-R connection.

A third step of ATO features is achieved when operational data from a Traffic Management System (TMS) are available to define the train’s journey; that is to say, the expected arrival and departure times at the requested stopping or passing locations. In this case, the TMS must compute the arrival and departure times according to:

- The theoretical time table, which usually includes reserve time;
- Traffic regulation algorithms, which typically delay some trains in order to maximise the global throughput of the network.

Because of this, a majority of trains could use some of the reserve time to arrive a little later in stations, and have less extended dwell time before their scheduled departure; in other words, some of the reserve time can be better used in running slowly and reducing energy consumption.

In this third step of features, the ATO adapts the train’s speed profile to achieve, as far as possible, the arrival times computed by the Traffic Management System.

In this step, the train is driven according to an optimal speed profile which:

- Minimises the energy consumption
- Leads the train on-time to the requested passing and stopping points

Permanent data connection with the Traffic Management System permits the real-time rescheduling of the train and the changing of its journey data (e.g. addition of an extra stopping point).

The journey data could be communicated to the train either via the balises (in ETCS level 1) or the GSM-R connection (in ETCS level 2) or via another radio connection.

The figure below shows the three steps for functional ATO features.
The steps are incremental, in such a way that the on-board ATO adapts its own behaviour according to the infrastructure configuration.

6 INTEROPERABILITY PRINCIPLES FOR ATO

In defining a truly interoperable main line ATO system, it is important to consider which of the various stakeholders of a national or international main line railway network should be made responsible for the provision, validation and subsequent updating of particular types of information. The original specifiers and designers of ERTMS were aware of this point; in ETCS, data concerning the infrastructure is stored in ETCS infrastructure systems, where it can be maintained during the life of the system (e.g. updated when the track layout is modified). Portions of this data are sent to trains in messages, as needed. The on-train ETCS equipment stores data about the characteristics and performance of that particular type of train, where it can be maintained as the train is modified and upgraded during its life.

Integrating technical standards with the operational rules for systems is important to ensure user acceptance of the system. In the case of the ATO studies, this used operational concepts and principles generated in projects in various countries, including the UK.

Since all trains are presumed to be capable of running anywhere on the network, unless constrained explicitly, the ETCS on-board systems can implement a complete range of pre-defined behaviour. The behaviour of each train that is appropriate to the line it is running on is caused by reception of messages from the ETCS infrastructure on the route.

Considering a main line ATO system, the responsibilities should be broadly similar, for instance:

- The Infrastructure Manager is ultimately responsible for the correctness and accuracy of the description of the track network (distances, gradients, curves, the location and details of platforms, etc.).
- The Train Owner or Maintainer is ultimately responsible for the correctness and accuracy of the train data and performance characteristics (length, wheel diameter, maximum speed, acceleration and braking rates, etc.) stored on-board, and used to compute braking curves etc. during operation.
- The Traffic Manager, who is usually part of the Infrastructure organisation, but is actually responsible for agreeing a traffic plan with the Infrastructure Manager (considering the availability of lines for service, temporary speed restrictions, line blockages, etc.) and Train Operators (considering the availability of trains, real-time restrictions on train performance due to faults or loading, changes to stopping patterns of services, etc.) is ultimately responsible for defining the
schedule of traffic to be implemented on a particular day. This schedule may start to deviate from the originally planned schedule, following delays or faults.

As a result of thinking carefully about such high-level principles, significant differences begin to emerge between a main line ATO system and a metro ATO system. For example, on a metro:

- It is often most convenient to store the details of the infrastructure on the line over which the train operates (which is finite, and usually modest-sized), on board each of the line’s trains. The rationale for this is that the underlying infrastructure is changed relatively rarely, and all the trains return to one of perhaps two, at most, depots each night and can be updated there if there is a change to this database.

- As the metro train fleet operates through the same stations all the time, pre-determined details of energy-saving strategies for each inter-station run (e.g. the location at which to start coasting to achieve (say) a 5%, 10% or 15% increase in interstation run time) can be thoroughly studied during the testing phase of the system, and then stored on-board each train.

- As in the previous point, the Traffic Management system on a metro can be given explicit information (based on historical data) about the likely effect on journey times of various faults on board the train (e.g. failure of a single traction package). It uses this information to make regulation decisions to maintain service intervals, in the event of a train suffering reduced performance.

In the Main Line case, a train may, in principle, go anywhere on the network, and should ideally be capable of offering ATO operation on any ATO-equipped sections of the route where it finds itself. This means:

- A main line ATO system must store all the details of each network segment in the infrastructure system, and send it to trains as they approach the area. In this way, any train’s on-board ATO can be sure of having the correct up-to-date infrastructure data, wherever it happens to operate on a given day.

- Some modern main line trains, even without any knowledge of their forward schedule, are capable of adopting innovative energy-saving strategies. For example, diesel units may beneficially stop one engine on long interstation runs, to reduce wear and tear on the engine itself, and to save energy. Skill in this area is already seen as a differentiating factor between rolling stock suppliers. When ATO is added to such a train, there are significantly improved opportunities for energy-saving strategies to be developed; an ATO train has information about its forward route (usually further than the current end of Movement Authority), and if it is told the required arrival time at a location further ahead on its journey. Thus, it can calculate and adopt the optimum strategy to reach that location at the required time, whilst minimising energy consumption.

- Following on from the above, an “intelligent train” with knowledge of its own status and loading, the route ahead and the required arrival time at a timing point, can respond to the Traffic Management system if it is unable (for whatever reason, including on-board faults) to achieve the required timing. This enables the Traffic Management system to reschedule traffic to maintain passengers’ connections, and to minimise the spread of delays to other parts of the network.

The above comparison of metro and main line ATO data partitioning shows that a well-structured main line ATO system not only achieves the goal of “go anywhere” trains, but also enables the main line operator’s goals of more intelligent traffic regulation and energy saving to be met.

To ensure highly reliable performance of an interoperable ATO system, a set of performance specifications and on-board and infrastructure engineering rules are needed. Again, consideration of the approach previously adopted by the specifiers of ETCS is instructive.

Taking just one example, the accuracy of stopping position at platforms depends on characteristics of both the on-board and the trackside ATO subsystems. Performance requirements and Engineering rules allocate constraints to both subsystems to ensure a sufficient performance level for the system. Accuracy of balise detection and odometer will certainly be the on-board challenge, when the trackside will have to determine the number, the position and the accuracy of positioning for the ATO relocation balises, taking into account the
allowed locations for the Eurobalise antenna on the trains. Moreover, the stopping accuracy requirements may vary between lines, hence various performance levels should be considered – for instance when platform screen doors are used.

Detailed rules can be expected in several areas, for example:

- A very clear understanding of the measurement datum point(s) for infrastructure data defining longer distances ahead of trains, and the effect that cumulative errors in distances might have on future ATO trains.
- More prescriptive rules concerning the positioning of relocation balises relative to platforms where precise ATO stopping is required.
- Some constraints on the permitted use of ETCS operational modes and functions, to ensure that an ATO train can operate continuously in a mode that is able to support ATO.
- Safety aspects of using ATO with ERTMS: when running in Full Supervision mode, ERTMS sometimes transfers the responsibility back to the driver. In such situations, there must be ways to enforce the driver taking the control of the train.

Building on the outputs of the study for Network Rail, a European TEN-T project has now been started, to enable a number of railways and suppliers to develop the necessary standards and engineering rules in this area.

7 ATO - A WAY TO SAVE ENERGY

Energy saving is achieved mainly in two ways:

- By avoiding conflicts and unnecessary train stopping (Traffic Management);
- By defining an optimum speed profile compliant with the requested arrival times (Train Operation).

The first of these is performed by the Traffic Management System (TMS); while the second is performed by the on-board ATO on the basis of the journey profile defined by the TMS.

There are many alternative traction and brake control strategies that could be adopted, when a specific journey time is needed by Traffic Management. The optimum choice of strategy is highly dependent on the train design characteristics and the specific route profile. So, for example, the strategy for a train with regenerative braking may be different to that for a train with purely friction braking; in the first case, energy consumed in accelerating the train (apart from train resistance and system losses) can be recovered during braking, whereas in the second case energy consumed in accelerating the train will all be lost. Similarly, a run downhill out of one station and uphill into the next will require a different strategy to a level track profile.

If the on-board ATO knows the train performance characteristics, it can determine a strategy that will deliver the journey time required by the traffic management (assuming that the ATP speed profile for the route permits it to be achieved). But the easiest strategy may not be the most energy-efficient.

Alstom is leading the GreenRail program which involves industry partners, operators and technical high schools. The aim of this program is to define efficient EcoDriving strategies.

This research program has led to the definition of algorithms using the most up-to-date optimisation approaches (heuristic greedy type algorithms). The “GreenRail algorithms” optimise the energy consumption, taking into account the required travel time. These algorithms consider the whole travel including the acceleration phase, the cruising/coasting phase and the braking phase.

The current prototype has been trialled on actual Belgian Railways lines. It provides a real time computation of an optimised driving style which:
• Respects the travel time requested by the Traffic Management System;
• Minimises the energy consumption.

These results have demonstrated that the energy consumption can be reduced by typically:
• 12% comparing with typical manual driving;
• 20% comparing with “tight” running.

The following figure shows actual results of a test campaign performed on the line “Welkenraedt-Verviers”, on the Infrabel Belgium Network.

This figure gives the speed (in Km/h) according to the distance (in m). It represents several runs performed by several drivers in normal service with passengers. These runs are compared with the optimised speed profile.

![Figure 2: Test results at "Welkenraedt-Verniers"](image)

The following table gives the travel time and energy consumption associated with these runs.

<table>
<thead>
<tr>
<th></th>
<th>Travel time (in sec.)</th>
<th>Energy Consumption (in kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver 1</td>
<td>750</td>
<td>148.85</td>
</tr>
<tr>
<td>Driver 2</td>
<td>713</td>
<td>195.49</td>
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<tr>
<td>Driver 3</td>
<td>1041</td>
<td>173.57</td>
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<tr>
<td>Driver 4</td>
<td>682</td>
<td>178.35</td>
</tr>
<tr>
<td>Optimised speed profile</td>
<td>750</td>
<td>116</td>
</tr>
</tbody>
</table>

*Table 1: Travel time and Energy Consumption per run*

The optimised speed profile is always less energy consuming than the other runs:
• 35% less compared to the fastest profile (driver 4);
• 22% less compared to a driver who ran without the help of the GreenRail algorithms, but achieved the same travel time (driver 1).
The results clearly show that, of course, increasing the travel time and running at lower speed with lower acceleration and deceleration rates permits energy consumption to be reduced. But, it also shows that the same travel time can often be achieved with different speed profiles with different level of energy consumption.

8 CONCLUSION

The studies have shown that the combination of ETCS and Automatic Train Operation (ATO) can provide significant benefits to the operators of Main Line networks and train services. As well as maximising the capacity of the busiest urban or cross-city lines, ATO can help Traffic Management systems to implement revisions to schedules to optimise connections and throughput at key junctions on a mixed traffic network. ATO can also help train operators to achieve on-time arrival at timing locations whilst significantly reducing energy consumption. All these benefits contribute to improving the capacity and stability of network operation.

The extension of ETCS design principles to cover ATO functions offers the possibility of a truly interoperable ATO system, but suggests that the architecture of a Main Line ATO system may need to differ from that of a typical Metro ATO system. Interoperability requires co-operation by railways and suppliers, and further initiatives are in hand to progress this.

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