

From CBTC fixed/fixed block sections to ETCS-ATO (inspired by [18])

Towards Automatic Train Operation for long distance services: State-of-the art and challenges

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Conference paper STRC 2017

Automatic Train Operation for long distance services: State-of-the-Art and challenges

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May 2017

Abstract

The Automatic Train Operation of a metro line is not so difficult to implement: almost no junction or crossing between lines, rolling stock homogeneity, double track operation, relatively low speed, very simple station track layout, mostly rubber-mounted, and specific site continuously fenced with no level crossing. Tunnels and platform screen doors complete the picture to prevent almost totally the presence of an obstacle or a person on the tracks. But how can Automatic Train Operation for a metro line be transposed into a long distance train line or further into a country wide network?

This paper reminds firstly the different Grades of Automation. Then, it shows Automatic Train Operation used in conjunction with the Communication Based Traffic Control that drives Automatic Train Operation of a metro line. Some information about Automatic or Automatic-like Train Operation Systems are also given in a traditional rail network context and what it is possible to do right now. Finally, the paper presents some alternatives to face challenges met in a Semi-Automatic Train Operation context and in an Unattended Train Operation context.

To resume, the actual use of the Packet 44 of the European Train Control System is sufficient for Semi-Automatic Train Operations. Nevertheless, a speed information should complete the actual definition of timings points to obtain a more efficient Automatic Train Operation system. Unattended Train Operation is thinkable in the future, namely with the help of video/infrared cameras in front of the train. Images processing and remote control will then deal with risks and degraded situations.

Keywords

Automatic Train Control (ATO), European Train Control System (ETCS)

1. Introduction

Capacity maximizing, energy efficiency, and minimizing the operating costs are factors to be more and more considered.

The Automatic Train Operation (ATO)¹ is suitable for maximizing of the use of the capacity in very dense traffic areas. Therefore, more and more metro lines or even Mass Rapid Transit lines are equipped with ATO through proprietary Communication Based Traffic Control (CBTC) systems.

ATO are also efficient in energy saving for main line traffic when each train trajectory has almost no chance to conflict another one. By knowing track and train characteristics, optimum algorithms can be used. In fact, the only one and constant constraint is the timetable arrival time at the next planned stop. At contrary, if the Automatic Train Supervision System (ATS) has to manage conflicts to ensure that the overall train operation is optimised, algorithms are much more sophisticated. Today, no ATO using such complex algorithms are in operation on main lines.

The paper is divided in five chapters. The chapter 2 gives general definitions about ATO systems. The chapter 3 presents some systems helping the driver on main lines and ATO system in use inside city. The chapter 4 lists the main challenges to be faced for the use of ATO for long distance trains outside city. Eventually, the chapter 5 resumes the main conclusion. Acronyms, references and an annexe detailing ATO data over ETCS stand at the end of this contribution.

2. Metros and GoA4 (ATO-UTO)

2.1 Definition of GoA, ATO, ATS and ATC

There are various degrees of automation and each author, supplier, Train Operating Company, Infrastructure Manager, uses their own language and abbreviations [1]^{2,3}. UITP develops a simple classification of SATO and ATO systems based on five Grades of Automation (GoA).

¹ Acronyms' definition are summed up below the conclusion chapter

² Number in brackets refers to references given at the end of this article

³ A lot of other acronyms are used in the literature but each of them has an equivalent item in the GoA classification

How to categorize the examined system depends on which person or device fulfils four specific operation tasks: door closure, setting train in motion, stopping the train, operation in event of disruption, and ATP [2].

Table 1 Main characteristics of the five Grades of Automation (GoA)

| Grade of Automation | Door Closure | Setting train in motion | Stopping train | Operation in case of disruption |
|---------------------|--------------|-------------------------|----------------|---------------------------------|
| 0 - ROS | Driver | Driver | Driver | Driver |
| 1 - ATP | Driver | Driver | Driver | Driver |
| 2 - SATO | Driver | Automatic | Automatic | Driver |
| 3 - ATO-DTO | Attendant | Automatic | Automatic | Attendant |
| 4 - ATO-UTO | Automatic | Automatic | Automatic | Automatic ⁴ |

Normally, an ATO system does not drive the train as fast as possible but follow a driving strategy in respect, of course, of the ATP system that has the highest level of safety. The simplest strategy is to match as much as possible with the planned timetable. A better way is to match the planned timetable only at planned stops but to drive smoothly and save energy between stops. However, risks of conflicts between trains increase as soon as the density of traffic increases. Then, a sub-network-wide best strategy should be managed centrally by a Traffic Management System (TMS). The main stone of a TMS is the Automatic Train Supervision System (ATS) managing an Automatic Route Setting system (ARS) and, if convenient, an Automatic Train Regulation (ATR) as well. It is then rightful to talk about Automatic Train Control (ATC) only with such centralized management realized in a GoA4 context.

All railway lines whose trains run in the UTO mode are equipped with an ATC system commonly named Communication Based Train Control (CBTC). The safety of the movements of trains is guarantee thanks communications in both direction between trains (on-board) and ATS (trackside): trains transmit mainly their position to the ATS, and ATS transmit mainly track data or speed limits to trains as well. In particular, ATS transmit the very important position a train must never trespassed. It is called Vital-Movement Authority Limit (V-MAL).

⁴ According to the importance of the disruption, the train can also be driven at a distance or a staff member has to board.

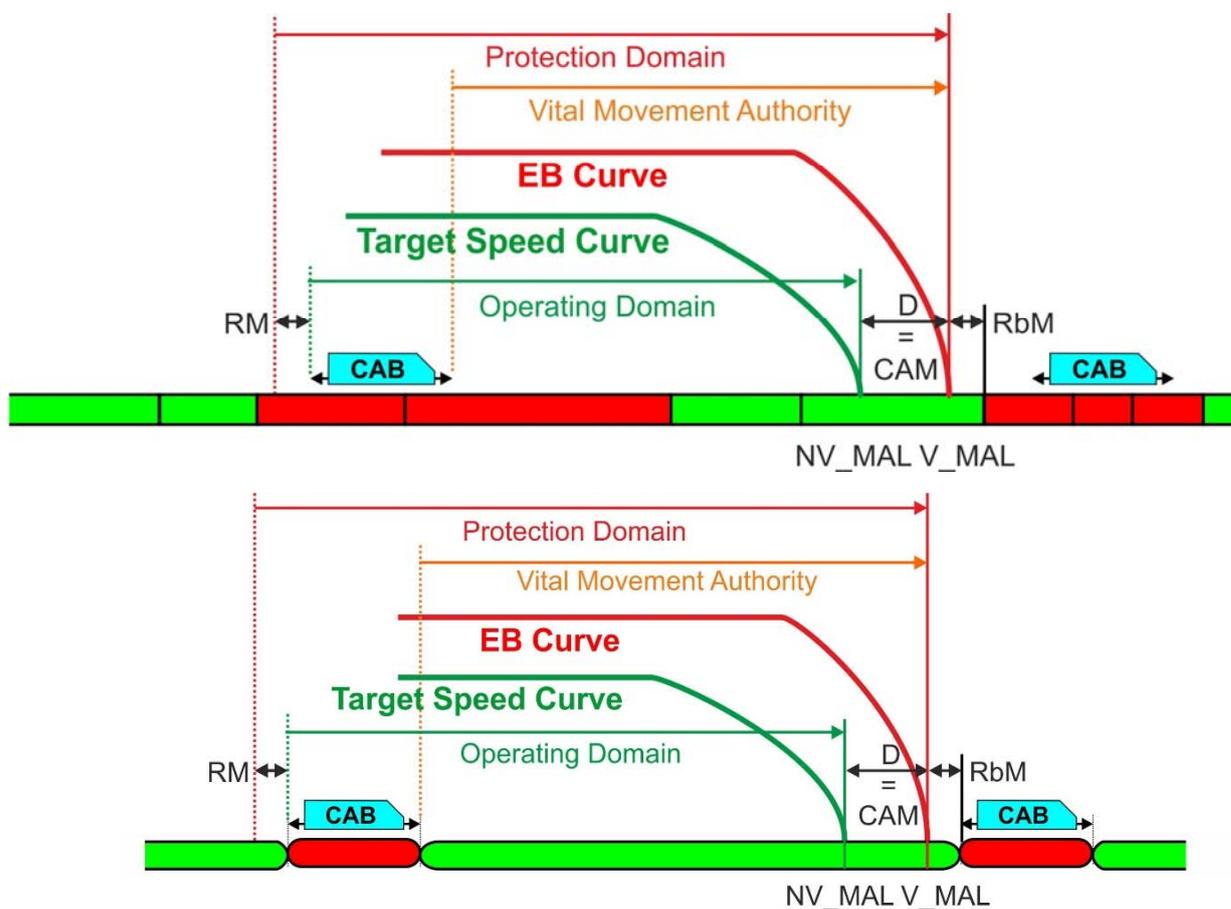
2.2 Main characteristics of GoA4 operation

During the last decades, many metro lines were operated in GoA2 mode, even if they are fitted for GoA3. The main advantage is the fallback solution in case of non-availability of the automatic part of the system: the driver can resume the train control easily and operation can continue with only a little decrease of quality due to the dispersion of drivers' driving techniques.

Today, the availability rate of CBTC system allows removing driver or attendant from the train. In case of disruption, the Traffic Management System (TMS) has some remote train control facilities. Platform doors drastically mitigate the risks of people to fall from platform to track, or to be trapped by a train door.

GoA4 is inseparable from Full Supervision (FS). That means that a speed limit curve (EB curve) must never be trespassed. For that, an Emergency Brake Intervention (EBI) curve is calculated. A Target Speed Curve, staying always under the EBI curve is then established as guidance curve for the ATO system (Figure 1).

Figure 1 CBTC domains with fixed virtual sections and dynamic virtual sections (below) (cf. [18], pp.345-348)



The four main characteristics of actual lines operated with GoA4 (ATO-UTO) in a CBTC context are:

- Exclusive right of way with physical barriers and no level crossings;
- Platform doors;
- Staff able to join the train in some minutes in case of disruption that cannot be solved by - or through - the TMS only;
- No maintenance works near or on adjacent track during operation periods.

3. Today Automatic Driving Systems for long distance services

Today, GoA4, GoA3, and even GoA2 are not used for long distance services. Under the supervision of the driver, some devices can act on the train controls to keep a given speed (cf. §.3.1) or to stay under a certain speed alternating conveniently traction, dynamic braking and coasting phases to save energy (cf. 3.2). In §.3.3 are shown two examples of long distance services that have also an urban service through a big city. For these two last cases, the driver is no more responsible for operating the train inside city.

3.1 Cruise speed keeper (GoA1)

As we know that changes of the speed limit are very frequent in Europe - and in Switzerland in particular -, drivers do not use frequently the cruise speed keeper on national conventional network. Indeed, using it give them at a false safety feeling as they stay responsible to brake enough the train to respect a lower speed limit. Furthermore, such devices give often bad results in terms of comfort, energy consumption and wear and tear.

3.2 TripOptimizer© (GoA1)

TripOptimizer© is a GE Electric product for saving fuel along long distance fret services [21]. Based on an individual plan based for each train on a given territory, TripOptimizer© controls automatically throttle and dynamic braking of each engine of the train.

This optimization is made under the driver supervision. The driver can take the control of the train at any time, in particular when the train has to decelerate thanks to the friction brakes of wagons.

Parameters - like wind effect, adhesion, engine health, and of course an arrival time target offering a consistent time margin that may be freely distributed along the trip – help

TripOptimizer© to operate more smoothly and to use fuel more efficiently. 3-17% fuel saving are obtainable versus human driving, depending on train and terrain characteristics.

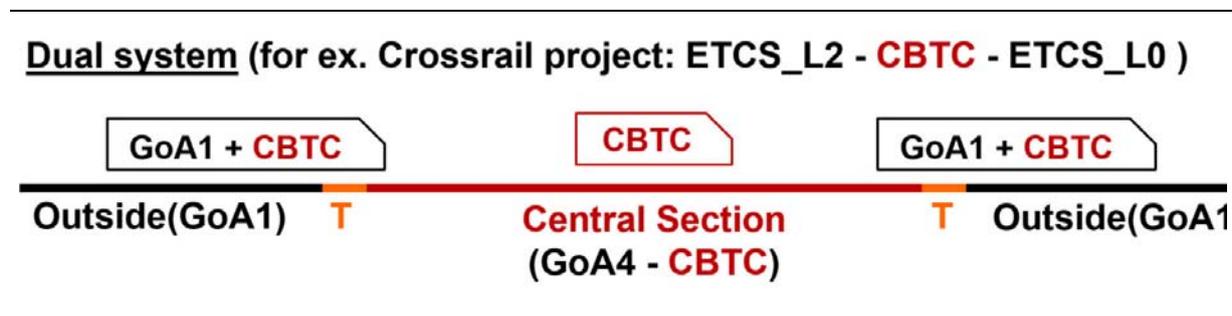
3.3 ATO for long distance services

3.3.1 ATO for long distance services inside cities

The two first implementations of ATO for long distance trains are concerning London City. The problematic is the same for both cases. To maximize the use of the capacity of the central section of the line, crossing long distance trains have to be equipped with an ATO system. However, the solution retained on the Crossrail project is totally different of the Thameslink project.

For the Crossrail project [7, 8], the long distance trains are equipped with two different supervision systems: the first is the ATP system that can be or not the ETCS system and the second is a classical CBTC system. Long distance trains have no ATO capability outside city, but, at contrary, ATO provided by the CBTC system is compulsory inside city (cf. Figure 2). The transition “T” between the two different ATP systems and the commutation to the CBTC-ATO operation of trains is mastered by Siemens [9, 10].

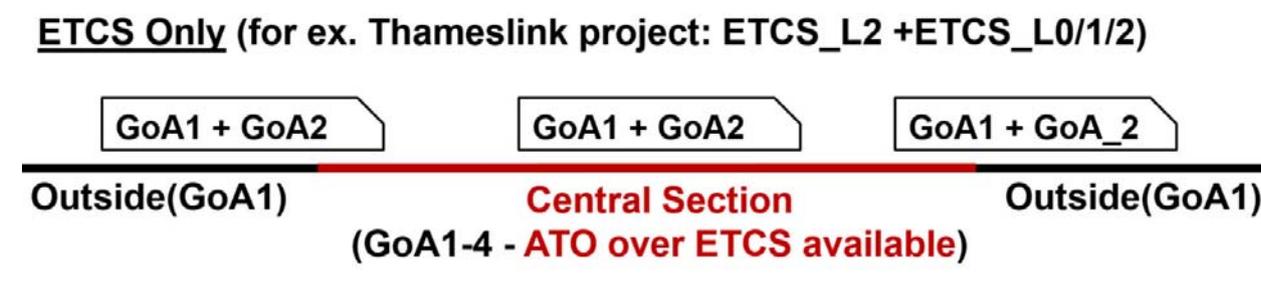
Figure 2 Crossrail project: Dual system for long distance trains
ATO available only inside city



Such a project is very interesting but give no future way to develop ATO outside cities.

For the Thameslink project [12], the long distance trains are not equipped with CBTC operation capabilities. As the Thameslink project goal is to increase the use of capacity inside city as the Crossrail project does also, ATO is only provided in the central section of the line where ETCS Level 2 can deal with very short block sections. The transition is quite easy. The system tell the driver when ATO is ready and driver decides – or not - to choose ATO operation for the train. The driver is informed when the train is about to leave the ATO available section.

Figure 3 Thameslink project: ETCS-ATP system long through
ATO over ETCS could spread outside city



It is important to notice that the objective of 24 trains/(hour*track) is the same for Thameslink project as for the CBTC Crossrail project. In fact, ETCS Level 2 can use short real block sections. The V-MAL and NV-MAL jumped together one section ahead each time the train ahead let a section free. CBTC acts the same with a fixed virtual block section strategy. The loss of capacity using a fixed block section strategy instead of a pure virtual block section strategy is not very significant (cf. Figure 1). Indeed, the M14 (Meteor) line in Paris, using a fixed block section strategy is able to manage 30 trains/(hour*track).

For more information about current ATO over ETCS, see Annexe I.

3.3.2 ATO for long distance services outside cities

Today, no ATO system is in operation on a national railway long distance line outside city (cf. [4]). The development of ATO over ETCS is limited by the speed of development of the ERTMS system itself. Therefore, suppliers are developing specific and mainly proprietary solutions. The solution for the Thameslink project is well adapted to the actual state of development of ERTMS and deals with the city central section capacity problematic. For ATO in a wider geographical scope (complex railway nodes, critical junction with low performance freight trains) the set of data developed for ATO (see Annexe I) should be slightly enhanced (see §.4.1.3).

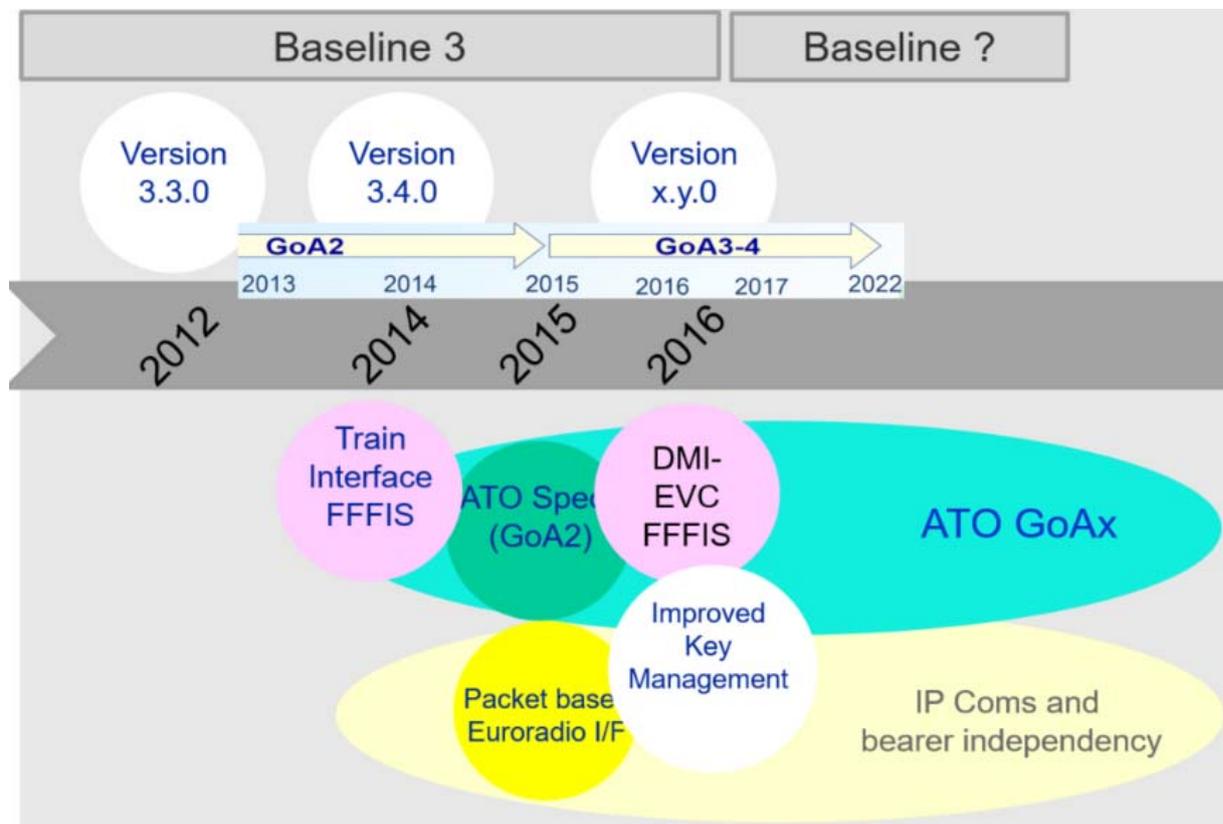
According to Figure 4, GoA2 should have been fully integrated in the ETCS system by now, but the European Railway Agency is speaking of 2018/2019 for GoA2 and even of long term for GoA3 or GoA4!

3.4 ETCS and ATO

For many years, adding ATO functionalities to ETCS is pursued (by ex. [3], [13] and [14]). However, the stabilization of the set of instructions for operating correctly ETCS Level 1 or Level 2 in a huge variety of situations that exist in Europe was the first priority. Nowadays, the

ETCS Baseline 3 has reached this stability and exhaustively, in particular by the inclusion of the new “Limited Supervision” Mode (L1LS). Nevertheless, the market still does not offer component based on this new baseline though it was developed many years ago.

Figure 4 Development of ETCS-ATO [13]



The integration of ATO in the ETCS need to develop a full set of new ETCS Messages and packets that are neither defined nor provided. Without waiting ten or fifteen years, NetworkRail, the British Infrastructure Manager encouraged the ETCS main suppliers to develop ATO needed exchanges between trackside and on-board via ERTMS [19]. The only mean at their disposal to realize this operation in respect of baselines 2 or 3 was to use the multi-purpose ETCS Packet #44 [15].

In fact, exchanges between trackside and on-board are strictly codified in ETCS. Exchanges are made by the mean of directional messages [16]. Each message contains one or many packets [15]. In a ERTMS Baseline 3 context, 21 messages are defined for the track to train direction and 17 messages for the opposite direction. Among the 54 packets, one of them has a very particular status: the packet #44. It is the only one to be not processed by the ETCS European Vital Computer (EVC) on-board but transmitted without any further processing to systems independent of ETCS. In the other direction, the EVC collects packets #44 from on-board systems and transmits them to trackside without any further processing.

3.4.1 ATO for long distance services outside cities

The packet #44 is very flexible and easy to send, as an optional packet, embedded either in a track to train message or in an opposite direction message (cf. [16]). Furthermore, many packets #44 can found place in the same message (cf.[16]8.4.1.4.1). In particular, for the track to train direction, packet #44 can find place in the very common and frequent #8_MA_Message, in the #37_In_Fill_MA_Message or in the #24_General_Message. In the train to track direction, packet #44 can find place in the very common and frequent #136_Train_Position_Report Message and in the #157_Start_of_Mission_Position_Report_Message.

The packet #44 is introduced by three compulsory values: NID_PACKET (=00101100) that means 44, L_PACKET (13 bit length) that indicates the length of the packet and NID_XUSER (9 bit length) that point the Infrastructure Manager ID able to manage the rest of this packet #44.

The data set developed by the supplier group (cf. [19] and Annex I) was sufficient to provide a powerful ATO for passenger services inside city, where the main challenge is to maximise the use of the capacity on short interstation track section. The timing points are targets to be reached. Each target has three attributes: type (essentially: departure, passing and arrival), location and time. Unfortunately, no speed information is associated with timings points. Then, ATO algorithms cannot be optimised regarding global punctuality and energy savings in complex congested areas (cf. [20] and references cited by [20]).

Table 2 “ATO” system on main lines

| System | State | GoA | Supervision | Goal | Targets |
|--------------------|-----------------------|-------------------|-------------|-------------------------|------------------------------|
| “Cruise Control” | Realized | GoA1 | Driver | Punctuality | Cruising Speed Keeping |
| OptiMizer© | Realized | GoA1 | Driver | Energy saving | Time- Location |
| “ATO over ETCS” | Thameslink project | GoA25 or above | ETCS-L2 | Increase of Capacity | Time- Location |

4. Challenges to realize a performant and standardized ETCS-ATO system for long distance services

4.1 Remaining main challenges to run with GoA2 on main lines

4.1.1 Human Impact

The main question in a GoA2 context is how to keep self-motivated and skilled drivers if their tasks are reduced to initiate the driving system, to supervise the journey, to trigger an emergency braking in some rare instances, to drive the train only in case of technical problems and to handle shunting moves? (cf. [17]).

The answer is not obvious but the operational rules on the GoA2 fitted lines of the Parisian Metropolitan Network can help to solve this challenge of keeping the driver “in the loop”. Drivers drive manually their train when the traffic density is low. At peak hours, drivers must use the ATO (*Pilotage Automatique PA135*). Nevertheless, more and more lines are very busy the daylong.

On main lines, a well-used capacity and short performance margins request punctuality and running controls that only ATO can provide. Such line capacity management keeps drivers “out-of the loop”. One solution is that drivers spent more time with driving simulators to learn and maintain skills for driving correctly their train in case of emergency or exceptional conditions.

4.1.2 Standardization of the interface ETCS-ATO

Each supplier is developing today its own proprietary solution for ATO supervised by the standardized ETCS ATP system (cf. [5], [6], and [11]).

While waiting for a coordination of ATO with ERTMS (see §.4.3.2), it is recommended to develop, as soon as possible, a standard between the on-board ETCS-DMI and ATO sub-systems.

4.1.3 ETCS-ATO improvement

Inside city, capacity management is the main challenge. Bottlenecks are at station entrances if preceding trains have not quit in time platforms following trains have to enter. When the track design is more complex, many hundreds of itineraries can impede each other. If a train is late, one or many other trains have to reduce their speed or to stop in front of signals. Speed advices

have to be given so not forecast train stops can be avoided and then reduce the global delay on one hand, and allow passenger comfort increase and wear and tears reductions on the other hand. It is important for delayed trains to follow an optimal speed profile, especially for freight trains that take very long time to reach their speed limit again. Therefore, the current ETCS-ATO (cf. [19] or Annexe I) have to be enhanced. In fact, timing points of a Journey profile of the ETCS Packet #44 must become four-dimensional entities: type, location, time, and speed.

4.2 Main challenges to run with GoA3 and GoA4 on main lines

As shown above, remaining last difficulties for ETCS-ATO with GoA2 could easily be solved on main lines equipped with ETCS-FS whole along.

However, some new challenges occur when no driver is in the cab (GoA3 and GoA4). They are mainly due to long distances between stations, opened spaces along the line, and maintenance works on adjacent line during train operation periods.

4.2.1 Train working order and surrounding observation

When drivers are in the cab, they listen, "feel" their engine and observe measuring instruments. Therefore, some difficulties are not solved automatically nowadays as, for example, the possible correlation between the detection of a noise or a shock with the impact of a block of ice catapulted by a crossing train.

One way to mitigate this risk for the rolling stock is to add more sensors in the train and to correlate their results (for example, shock and snow/ice under the train, or specific short on a windows happening during train crossing).

When two trains are crossing, each driver observes the other train. If irregularities are detected like floating tarps, for example, the observing driver sends the convenient information by radio. If persons or animals prowl near the track, driver sends the convenient information by radio. These checks may be abandoned, but each decision acting in the direction of less safety is probably not welcomed in the launching phase of driving automation for long distance services.

One solution is to replace these visual checks by developing more sophisticated and more numerous devices on-board. A best way is probably to delocalize most of these checks from train to trackside. Each Infrastructure manager has already its own Wayside Train Monitoring System. The density of the control points in the network can be increased and new control functionalities added.

4.2.2 Obstacle on the track visually detected

A living creature or an object can lie on the tracks. Even if it is impossible to stop before the impact, an immediate emergency braking is expected, as well as a horn sound if convenient. Without drivers, a video/infrared camera in front of the train with an image process recognizing automatically some forms, movements and living creatures should enter into consideration.

4.2.3 Possible obstacle on the track

The higher probabilities to encounter an obstacle are at level crossings, at road bridges, and when railway lines borders some steep embankments with rock fall occurrences. Such risks are already addressed by connecting level crossings, vehicle falling detectors and fence crossing detectors to the signalling system. When the risk appears, the train is forced to stop. When drivers are in the cab, signallers can authorize them to run “On Sight” (OS). That means drivers can run – without trespassing 30-40 km/h – at such a speed the train can be stopped in front of any obstacle encountered.

In case of a false positive information, the time to re-initiate the system is very short after the train has passed the critical section.

Without drivers, attendants have to board the cabin and the authorized speed for running “On Sight” will probably be quite low.

4.3 More main challenges to run with GoA4 on main lines

4.3.1 Running “On Sight”

Running “On Sight” is probably one of the main challenge GoA4 has to face. In many situations, this driving mode is prescribe to the driver:

- Driver must run “On Sight” and is responsible to stop the train if another train is in front of it or if a switch is in a wrong or critical position, in case of q signal at danger due to malfunctioning of the interlocking is encountered;
- Driver must run slowly and possibly stop in front of a rock or a trunk on the track when a main signal is at danger when a fence-crossing detector give a positive information;
- Driver must move carefully the train taking into consideration the risk to collide a road vehicle when a signal indicates a cross level malfunction;
- Driver has to drive carefully the train when some kind of works are realized on an adjacent track or surroundings;
- Driver must normally run and “On Sight”, with the permission of the signaller, until a certain location after an emergency braking;
- Driver has to run according the “Staff Responsible” (SR) mode and has to give a Track Ahead Free (TAF) confirmation if the system loses or does not know the precise location of the train running with ETCS_L2.

All these example show than “eyes” have to be present in the cab to look at the track ahead. In a GoA3 context, the attendant can go in the cab, collaborate with trackside staff members and stop immediately the slow running train in case of danger.

With GoA4, it seems compulsory to have a few video/infrared cameras and a very performant image processing coupled with the braking system of the train, like in a GoA3 context. Adding remote control facilities seems to be compulsory.

4.3.2 Better Coordination between on-board ATO and ETCS

The last but not least challenge is to add information from and to on-board ATO to the ETCS message set (cf. [16]).

As the Non-Vital Movement Authority Limit is in close correlation with the Vital Movement Authority Limit, it is convenient that the European Vital Computer mixed NV-MAL received from the TMS with V-MAL. In a ETCS context, V-MAL can be deduced from the End of Authority (EoA) message possibly completed by information about Supervised Location (SvL).

5. Conclusions

Nowadays, passenger long distance services are driven with performant ATP (GoA1) but with no ATO.

A solution to level up to GoA2 is already offered today for trains running with ETCS_L2. This solution, using the ETCS packet #44, should be slightly enhanced by adding speed information to target points.

To level up to a full automation (GoA4), a lot of new challenges have to be faced. Many necessary running modes like “On Sight” have to be maintained. Video/infrared cameras and a very performant image processing system has to be coupled with the braking system of the train for triggering emergency braking if needed. This video circuit has also to offer remote control facilities. Finally, a better way to transmit ATO data and to combine them with ATP data has to be searched in a global ERTMS-ATO system.

Acronyms and references

| | | | |
|--------|--------------------------------------------|---------|--------------------------------------------------------------------|
| ARS: | Automatic Route Setting | FS: | Full Supervision (ETCS Mode) |
| ATC: | Automatic Train Control | GoA: | Grade of Automation |
| ATP: | Automatic Train Protection | MA: | Movement Authority |
| ATO: | Automatic Train Operation | NV-MAL: | Non-Vital Movement Authority Limit PSD: Platform Screen Door |
| ATR: | Automatic Train Regulation | RbM: | Rollback Margin |
| ATS: | Automatic Train Supervision | RM: | Rear Margin |
| CAM: | Collision Avoidance Margin | ROS: | Run On Sight |
| CBTC: | Communication Based Train Control | SATO: | Semi-Automatic Train Operation |
| D: | Distance | TMS: | Traffic Management System |
| DMI: | Driver Machine Interface | TP: | Timing Point |
| DTO: | Driverless Train Operation | UITP: | Union Internationale des Transports Publics |
| EB: | Emergency Braking | UTO: | Unattended Train Operation |
| EBI: | Emergency Brake Intervention | V-MAL: | Vital Movement Authority Limit |
| ERTMS: | European Rail Traffic Management System | | |
| ETCS: | European Train Control System | | |
| EVC: | European Vital Computer | | |

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Annexe I: ATO information thanks to NID_ATO_HEADER of Packet #44

The fourth value of the packet #44 proposed by suppliers is NID_SYS, 18 bit length, that indicates which system outside ETCS packet #44 refers to. In our case, NID_SYS matches with the ATO system. The fifth value proposed is M_INTERFACE_VERSION, 8 bit length, which identifies the interface version. The sixth value is the time stamp T_TIME, 32 bit length.

The NID_ATO_HEADER, 5 bit length, has 6 reserved values for train to track ATO types of information and 4 reserved values for track to train ATO types of information. These 4 types of information are: Journey Profile, Segment Profile, Platform Data and Platform Screen Door Data.

The **Journey Profile** is the list of Timing Point (TP) times for the journey sent by the ATS. Each TP is qualified: departure, pass, arrival, end of journey, or end of ATO fitted area.

The **Segment Profile** is the list of geographical data linked to the TP of the Journey Profile. Data contained in the Segment Profile are more comprehensive than those given by the classical packet "Track Condition - #68": Gradients but also curve radii and tunnel diameters.

The **Platform Data** part contains the platform ID and side, the usable platform length and start location and the stopping accuracy required. Minimum dwelling time is provided as well as capacity to operate reversal operation. The classical packet "Track Condition Station Platforms - #69" provides information about platform side and height.

Finally, **Platform Screen Doors (PSD) Data** give information about number and position of PSD. By the way, no obvious reason is given why such data are sent separately from other Platform Data information.

Even if the lot of information is supposed to fulfil the need of the highest Grade of Automation (UTO) and the support the whole procedure to enter and to leave automatic driving, one important lack is the absence of a speed information for timing points.

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