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TMM4540 - Industrial ICT Engineering Design and Materials, Specialization Project

"Latency of Remote Control in ATO"

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Preface

Information about me and relevant history, about the project and a thank you to Nils and other contributors.

This article was written for the subject TMM4540 - Industrial ICT Engineering Design And Materials, Specialization Project.

I have had no previous experience about ATO. But subject & knowledge from ...Insert subjects... has been used.

Abstract

A short summary of what the paper contains and why I have written about it.

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1 Introduction

Introduction to the paper and theories that are going to be used.

1.1 Purpose

What is the purpose of this paper. Why are we doing it.

1.2 Research Objectives

What are we hoping to answear and/or achieve during this paper

1.3 Digitalization in Railway

Railway digitalization evolved from early computer-assisted signalling and centralized traffic control, through modern Automatic Train Protection (ATP) systems, to full ERTMS/ETCS deployments and traffic management platforms. Recent steps have focused on communication-based train control (CBTC) in metros, ETCS rollout on mainlines, and the integration of predictive maintenance and data analytics tools. Projects such as national ETCS rollouts, the UK East Coast Digital Programme, and research initiatives like ATO-Cargo exemplify a shift from isolated automation pilots to system-wide modernization that combines ATO, interoperability standards (TSIs), and remote supervision concepts [1, 12].

1.4 System Overview

A section to go threw the system as it stands.

1.4.1 Components

A overview of the components in use. Also mentioning alternatives to the ones we have in use.

2 Theory

2.1 ATO

Automatic Train Operation (ATO) describes systems that automate driving tasks normally performed by a human driver. ATO implementation range from assisting the driver with speed guidance, optimized speed profiles and other information to fully unattended operation where starting, cruising, stopping and door control are automatic. The primary goals are improved punctuality, energy efficiency and safe, repeatable performance [8] .*In freight-specific research such as the ATO-Cargo project, ATO is combined with existing train protection systems (for example ETCS Level 2) and a Remote Supervision and Control Centre (RSC) to allow remote human oversight and intervention during degraded operation or faults* [1].

2.2 GoA

The Grade of Automation (GoA) classifies how much of the train operation is automated. Standards such as IEC 62290 and industry reports [6] describe the commonly used levels from GoA 0 to GoA 4. The table below summarises the practical meaning of each level.

GoA	**Meaning / operator role**
GoA 0	On-sight, manual operation without automatic protection.
GoA 1	Atomatic Train Protection (ATP) Manual driving with assisted protection rutines. Human driver performs traction, braking and door tasks while safety limits are done automatic. That includes track speed, safe routing and safe separation.
GoA 2	Semi-automated (STO). ATO handles start/stop and trajectory control between stations; a driver remains onboard for door operation, obstacle response and degraded mode handling.
GoA 3	Driverless (DTO). No driver needed for normal operation. Staff may be on board for passenger assistance and emergencies. ATO handle operational tasks including avoiding collision with obstacles and persons.
GoA 4	Unattended Train Operation (UTO). Fully automated operation without staff onboard. Remote supervision and controls are required for special incidents.

Table 1: Grades of Automation (GoA), summary based on IEC and industry sources.

GoA also changes and updates regulary because of new techonology added that shifts the definition. The figure below is UITP's definition of how GoA is graded.

Grade of Automation	Type of train operation	Setting train in motion	Stopping train	Door closure	Operation in event of disruption
GoA1	ATP* with driver	Driver	Driver	Driver	Driver
GoA2	ATP and ATO* with driver	Automatic	Automatic	Driver	Driver
GoA3	Driverless	Automatic	Automatic	Train attendant	Train attendant
GoA4	UTO	Automatic	Automatic	Automatic	Automatic

**ATP - Automatic Train Protection; ATO - Automatic Train Operation*

Figure 1: UITP's simple defintion of GoA

Source: [10]

The formal definitions and required functions per level are described in IEC 62290 and discussed in CBTC Solutions as well as UITP [2, 6, 10].

2.3 ETCS

The European Train Control System (ETCS) is a signalling and train protection element developed and included in the ERTMS initiative. ETCS provides movement authorities and intermittently or continuously supervises train speed and braking to ensure safe train separation. It replaces or complements national trackside signals by delivering standardized information to onboard equipment, enabling safer and more interoperable cross-border operation [5, 11].

2.3.1 Levels

ETCS is commonly described with levels that express how information is exchanged:

- **Level 0:** Applies to trains equipped for ETCS, but there is no ETCS trackside. Effectivly going back to regular control and legacy signalling.
- **Level STM:** Applies to trains equipped for ETCS, but runs on tracks with national system with ATP. Allowing ETCS to interface for the ATP
- **Level 1:** Spot transmission threw Eurobalises providing intermittent movement authorities and speed control while legacy signalling remain in place.

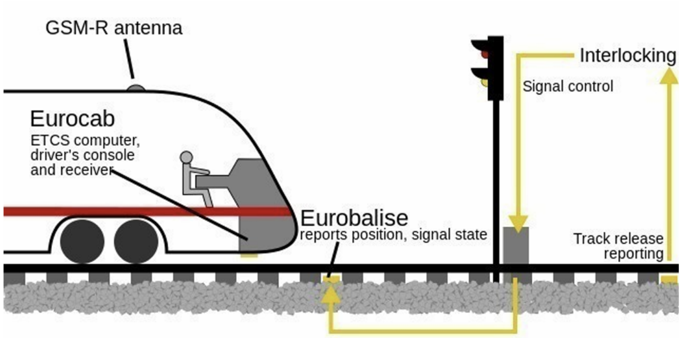

Figure 2: Train following regular signal with assisted speed and position with balises

Source: [5]

- **Level 2:** Continuous radio exchange to Radio Block Centre (RBC), typically via GSM-R or a successor. Movement authority is provided by the RBC. Eurobalises, if used, are primarily for precise positioning. Legacy signalling system are no longer needed and optional.

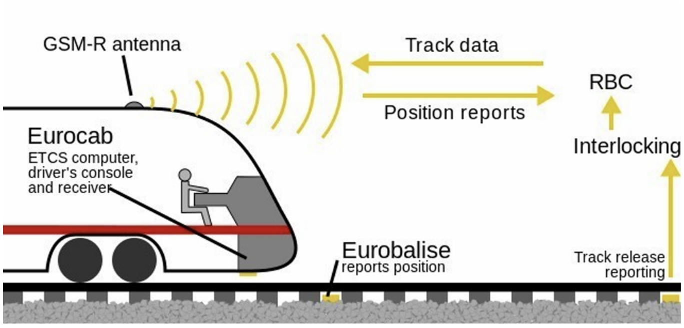

Figure 3: Train operating speed and signal with RBC threw GSM-R signal

Source: [5]

[5].

2.3.2 Modes

ETCS defines different operational modes such as Full Supervision, On-Sight, Staff Responsible, Shunting, and Automatic Driving. Modes determine how the onboard equipment supervises movement authority and interacts with ATO where present. Automatic Driving mode is used when conditions for ATO are satisfied and ETCS provides the required movement and track data while Full Supervision is when ETCS is supplied with all possible train and track data needed [5].

2.4 5G

5G is built up by OFDM, Orthogonal Frequency Division Multiplexing. Divides "Spectrum" into small subcarriers

2.5 5G URLLC

Ultra-Reliable Low-Latency Communications. How its different from other 5G networks. How to connect to it.

2.6 ERTMS

European Rail Traffic Management System (ERTMS) is a new system popular in Europa, but also countries as XX XX XX, (Source). ERTMS is built by ETCS, XX and XX togheter (Source) As of now both Norway and Sweden? har implementing ERTMS which will be crucial for all ATO projects. *Få inn bane nor her*

2.6.1 ERTMS/ATO

Because of the international rollout of ERTMS, ATO will have to follow along. ERA has designed a solution to have an integrated ERTMS/ATO solution as you can see in the figure below. It showcase how ETCS can be independent, but for ATO to be operational it is crucial for ETCS to garantee safety.

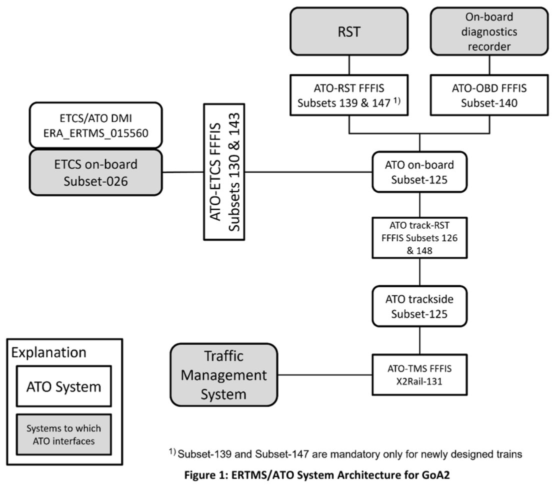

Figure 4: Architecture of ERA's ERTMS/ATO solution

Source: [11]

Showcasing different ATO working togheter with different responsibility and how they communicate with eachoter [11].

2.7 Latency

Latency is the time delay between when a command or data packet is sent and when it is received or acted upon. In railway automation, latency is critical for control loops, including brake initiation following an emergency command, and for ensuring the onboard ATO and remote systems remain synchronized.

The impact of latency, such as excessive one-way delay or variable delay can degrade braking calculations, delay alarm propagation, and reduce the margin available for safe intervention. For real-time safety commands systems are designed with strict latency and reliability budgets and use prioritized and redundant communication channels.

2.7.1 Latency Measurements

There is many ways to measure and structure latency. Some of the most commonly refered to are:

- **Round-Trip Time (RTT):** Refers to the total time it takes for a data packet to travel from the source to the destination and back again to the source. It is commonly used to assess the overall latency of a network connection.
- **One-Way Delay (OWD):** Refers to the time it takes for a data packet to travel from the source to the destination in one direction. This measurement is particularly important for applications requiring real-time responsiveness, such as train control systems.
- **Glass to Glass (G2G):** Refers to the total latency from the moment a signal is generated until the corresponding action is observed. This measurement includes image capture, encoding, transmission, decoding and displaying.
- **End to End (E2E):** Refers to the total latency from the initial source of a command or data packet to its final destination, including all intermediate processing and transmission steps. This measurement includes G2G as well as operator response time, sending control signals, transmission time and system processing delays.

Following the different structure of latency measurements, there is different protocols and methodes to get these measurments.

Internet Control Message Protocol (ICMP): With ICMP we can use two effective methodes, Ping and Traceback. Both return RTT latency but in different ways. Ping sends data packets to a spesified destination, and report the time it takes before a the same data packets is recieved. Traceback also sends data packets waiting for return, but tracks routes and notifies if certain routes use to long time. [4].

Two-Way Active Measurement Protocol (TWAMP) and One-Way Active Measurement Protocol (OWAMP): Protocols designed for measuring one-way and two-way latency, often used in network performance testing. [3].

Request for Comments (RFC) : Is a seriers of publications from IETF and other describing methodes and protocols for measuring latency.

Institutions: international Telecommunication Union (ITU): has published recommendations on measuring network performance, including latency, using protocols similar.

Internet Engineering Task Force (IETF): has defined standards for network performance measurement, including latency measurement techniques.

2.7.2

describe measurement methods and test tools. Measurements are typically expressed in milliseconds and include metrics for delay variation and loss [3].

2.8 Regulations

Railway automation must satisfy national and EU regulatory frameworks. In the EU, the *Technical Specifications for Interoperability* (TSIs) notably the Control-Command and Signalling (CCS) TSI — define safety and interoperability requirements for ETCS, ATO interfaces and signalling subsystems. The European Union Agency for Railways (ERA) provides technical guidance, variables coordination and ERTMS documentation [11, 12].

National authorities, for example the Norwegian Railway Directorate and the Norwegian Railway Authority, implement national legislation, issue national safety rules, and specify how EU TSIs map to national processes; operators must demonstrate compliance with both national rules and applicable TSIs for approval and operation [7, 9]. For freight ATO trials (such as ATO-Cargo), project teams must prepare evidence on safety, human factors (remote supervision ergonomics), communication performance and conformity with the CCS TSI and national rules before trials are permitted [1, 12].

From [11] 8.2 ATO 2: Supervision and regulation 8.2.1 ATO 2.1 - Supervise train operations During ATO operation, it shall be possible to: • Supervise train location by monitoring trains automatically using train identification and status (including delay information) to recognise deviations from normal operation as soon as possible; 8.2.2 ATO 2.2 - Manage the train service During ATO operation, it shall be possible to: • Input the journey profile from the planning system; • Start the journey profile; • Dynamically modify the journey profile in real time to take account of changes in operating conditions including: disruption management; re-routing; re-timing. • Adapt the train's journey profile to meet any update of the operational timetable; • Regulate trains to avoid bunching of trains and to reduce delays to trains in the case of disturbances; • Dispatch ATO trains to harmonise the starting of ATO trains, corresponding to results of train regulation and ensuring connecting services; • Operate both ATO and non-ATO trains simultaneously.

I think this could be very useful: Commission Regulation (EU) 2016/919 of 27 May 2016 on the technical specification for interoperability relating to the 'control-command and signalling' subsystems of the rail system in the European Union

3 Related Work

3.1 Other Experiences

Experiences from other simialar fields, self driving cars, drones, maybe other remote controlled trains in different countries

In accordance to UITP, of all fully automated metro lines, 87% use CBTC (communications based train control) [10]

As mentionted in ERA's ERTMS. Commission Regulation (EU) 2016/919 of 27 May 2016 on the technical specification for interoperability relating to the 'control-command and signalling' subsystems of the rail system in the European Union [11]

3.2 Remote Control

How remote control works, how it is set up. Why its relevant for this project.

3.3 Human factors

All the ways human error can effect the results from the tests. All the ways human control needs to be adjusted for in acceptance levels.

3.4 Acceptance levels

Connect up to what other projects have set as acceptance level, and why. What we can accept and why we choose these limits.

3.5 Ethics

Who is responsible. Fully automated, or remote driver. What obligation do we have in a project like this.

3.6 Cyber Security

How we can protect the system from attacks. What regulations are in place.

3.7 Calculation of latency

The math behind calculations of latency. How to measure most precisely and what errors we find in the calculations.

3.8 Other Experiences

3.8.1 ATO-Cargo Project

The ATO-Cargo project, led by the German Aerospace Center (DLR) in cooperation with DB Cargo AG, Digitale Schiene Deutschland (DSD), and ProRail B.V., focuses on developing and testing highly automated technologies for freight trains. The goal is to enhance rail freight efficiency by optimizing speed profiles, improving route utilization, and increasing competitiveness with road transport [1].

A key component of the project is the integration of an Automatic Train Operation (ATO) unit on locomotives in combination with the European Train Control System (ETCS) Level 2. This setup allows for real-time automation while maintaining human oversight. In case of system malfunctions or degraded operation, human operators at a Remote Supervision and Control Centre (RSC) can take over tasks such as remote monitoring, diagnosis, and manual control.

The project also emphasizes human factors engineering, ensuring that the RSC is ergonomically designed for operator efficiency and safety. For this project, researchers have employ virtual reality tools to simulate realistic control room environments and train personnel for future remote supervision tasks. Tests are being conducted on Betuweroute, a freight only railway, linking Rotterdam and the Ruhr region to validate the technical and operational readiness of this automation concept. The ultimate goal is to establish a European reference model for automated freight train operation [1].

4 Method

Describe the tests that are going to be run.

4.1 Methodology

In what way are the test done. Why so. How are we performing the measurements.

5 Expected Results

A page with all the test, how and what and the results.

6 Discussion

Discussion of the result from the measurements, what they could mean and possible use cases for the inforation gathered

6.1 Theory v. Practical test

Compare from the PreDraft of what expected result and hopes were, and discussing them with the information of what happend in the test and measurments.

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