ETCS for Military Mobility

Overview

The European Train Control System (ETCS) is a standardised Automatic Train Protection (ATP) system designed for interoperability across European rail networks. As part of the European Rail Traffic Management System (ERTMS®), ETCS replaces fragmented national systems to enable seamless cross-border operations.

ETCS, originally designed and implemented for civil use, possesses certain characteristics that make it potentially suitable for military applications. This paper provides a summary of the key features and suggestions for further analysis, open points, and fallback solutions.

ETCS operates in three levels: 0, 1 and 2, with Level 0 designed for trackside areas that provide only limited supervision but at least of the maximum speed. Level 1 offers full supervision with a decentralised trackside architecture with trackside beacons (Eurobalises). Level 2 provides full supervision with radio based movement authorisations a centralised trackside architecture (Radio Block Centre), and continuous radio-based supervision. Both Level 1 and 2 offer functions for the protection of safe speed and distance compliant to the highest Safety Integrity Level (SIL) 4. Moreover, ETCS provides additional functionality, (e.g. to automate driver's actions) depending on track conditions (e.g. lower pantograph for the change of energy systems).

Key features useful in military environments

The roll out of ETCS for civil rail operations also directly benefits military mobility. ETCS features useful for the military operations include:

- **Interoperability:** Standardised technology allows trains to operate across EU states without reconfiguration of the trainset or vehicle, and therefore reduces border crossing delays, and it also eliminates the need to change the train driver.
- **High safety integrity (up to SIL 4):** Automatic overspeed protection, movement authority calculation, safe in-cab signalling.
- **Reliability & fallback:** High reliability (>23.000h MTBF[1] for ETCS on-board) and inherent fallback if trackside equipped with ETCS Level 1 and 2.

1 Meantime between failure (MTBF) is a key reliability metric in engineering, manufacturing, quality assurance, and maintenance contexts, representing the average (mean) time elapsed between consecutive failures of a repairable system, component, or product during normal operation.

- **Security:** PKI[2], encrypted radio communication and secure key management, interoperable end-to-end security by use of TLS[3].
- **Various operational modes:** Full Supervision (FS) for control by ETCS; Staff Responsible (SR) for manual overrides in degraded scenarios (e.g. trackside failure).
- **Scalability:** Modular design supports upgrades, to integrate additional communication technologies apart from radio (e.g. satellite communication).
- **Cost efficiency:** Lower lifecycle costs compared to national systems (e.g. multi-vendor interoperability, product obsolescence, capacity gains).

Military requirements awaiting definition for validation of ETCS (open points)

To enable ERTMS® stakeholders to validate ETCS specifications and products against military needs and pinpoint weaknesses, requirements for military mobility related to ETCS could be defined, such as:

- **Cyber threat profiles:** Military protection profiles, specifications on resistance to EMP[4], jamming, and insider threats, penetration testing protocols for ETCS constituents
- **EMC[5]:** Requirements for electromagnetic compatibility with military radars and jammers, beyond civil EN 50121 standards.
- **Data handling:** Guidelines for secure transmission of train data for start of an ETCS mission (SoM).
- **Degraded mode durability:** Requirements for operation in power-outage or radio-denied scenarios.
- **General attack scenarios:** Types of attacks and their probability and impact.

Based on this, specific trackside implementation rules could be established for critical infrastructure implementations, such as underground control centres. In addition, signalling and ETCS fallback solutions could be designed to further improve resilience to attacks, as described in the following section.

ETCS signalling - resilience and fallback

Situations may arise when the standard control system is taken out of service. Then, a fallback solution needs to be deployed.

2 Public Key Infrastructure (PKI) is a framework of technologies, policies, processes, and hardware/software components that manages digital certificates and public-key encryption to enable secure electronic communications. PKI provides the foundation for establishing trust in digital identities, ensuring that entities (users, devices, or servers) are who they claim to be, and is essential for protocols like TLS (which relies on PKI for certificate-based authentication)

3 Transport Layer Security (TLS) is a cryptographic protocol designed to provide secure. TLS is the successor to Secure Sockets Layer (SSL) and is widely used to encrypt data in transit, ensuring confidentiality, integrity, and authentication between clients and servers.

4 EMP (Electromagnetic Pulse) refers to a burst of electromagnetic radiation that can disrupt, damage, or destroy electronic systems, devices, and infrastructure (e.g., power grids, communication networks, or control systems) by inducing high voltages and currents.

5 EMC (Electromagnetic Compatibility)

The following points are triggers for deployment of fallback signalling solution:

- Infrastructure damage - destruction or disablement of railway signalling infrastructure due to bombing or missile strikes, sabotage or cyberattacks.
- Military conflict or hostile actions that compromise railway operations, such us occupation or disruption of strategic transport corridors, then use of railways for military logistics requiring secure fallback signalling.

In this case, a simplified emergency operation must be implemented with a backup control system, such as fallback solutions for interlockings.

For more detailed information about a concept and technical design of such a fallback interlocking, please consult the attachment to this factsheet: "Fallback Interlocking – Portable Signalling System".

Conclusion

Key features of ETCS render it equally suitable for military mobility. In comparison to legacy ATP systems (Class B), it offers interoperability, inherent fallback capabilities, and state-of-the-art security. As a European system, it enjoys substantial ERTMS® stakeholder support, ensuring its continuous maintenance and enhancement under the lead of the European Union Agency for Railways (ERA), the ERTMS® system authority[6] facilitating the harmonised uptake of improvements to ensure a future-proof ETCS.

The rapid deployment of ETCS is crucial for enhancing the efficiency of the European railway network, both for civil and military purposes. To accomplish this objective, the implementation of the following key points is essential:

- Accelerated phase-out of national systems (Class B).
- Elimination of national requirements for ETCS.
- Reduction of customer/user specific requirements for ETCS
- Reduction of administrative complexity associated with the certification and authorisation of ETCS trackside and vehicles.
- Strict governance and coordination of the stakeholders and work streams.
- Depending on the installed technology of the line, fall back scenarios for the major corridors shall be defined based on ETCS solutions
- Fixed traffic signs and signals, especially speed indicators and basic visuals, should remain on lines to support ETCS fallback operations.

ANNEX I

Fallback Interlocking – Portable Signalling System
Concept of the new system for emergency operation

Overview

The Fallback Interlocking system is a portable, simplified electronic signalling solution designed to temporarily support railway operations at intermediate stations. It is particularly suited for emergency deployment in cases where standard signalling or interlocking systems are unavailable due to failure or infrastructure limitations.

This system ensures safe train movements on single-track or double-track lines, with operational speeds within the station up to 40 km/h, and is compliant with ETCS standards.

Purpose and Application

- **Emergency Signalling System:** Enables continued train operations during outages of permanent signalling systems.
- **Temporary Deployment:** Ideal for intermediate stations requiring short-term signalling solutions.
- **Operational Flexibility:** Can be installed and operated by a small team (minimum 2 persons), ensuring rapid deployment and minimal disruption.

System Capabilities

- The system is universal, pre-configured for any track layout configuration.
- Track Coverage: Secures up to four traffic tracks, including complex branching configurations.
- Signal Aspects:
  - Red – Stop
  - Green – Proceed
  - Flashing White – Call Signal (used for train approach or request)
- ETCS Integration:
  - Pre-programmed LEUs (Lineside Electronic Units) for Level 1 Limited Supervision (L1 LS)
  - Switchable Balises for ETCS L1 LS functionality in station and track areas
  - Set of fixed Balises for entering L1 area
- Speed Limitation: 40 km/h due to universal installation across any railway station.
- Ensures fail-safe operation, even under degraded conditions.
- Operated under ETCS Level 1 due to possible absence of GSM-R/FRMCS communication.

Installation and Operation

- Deployment Time: Designed for full installation within 24 hours by two trained personnel.
- Operational Team: Requires only two operators for full functionality.
- Storage and Interconnection:
    - All system components are delivered in boxes, each clearly labeled with:
        - Part numbers
        - Weight specifications (maximum weight per box is 100 kg)
        - Installation instructions
    - These boxes are interconnected using supplied cables, featuring waterproof connectors to ensure reliable and safe communication between components.
    - For communication between object controllers at both ends of the station, cable, satellite communication (e.g. STARLINK equivalent), or mobile wireless communication may be used.

Functional Architecture

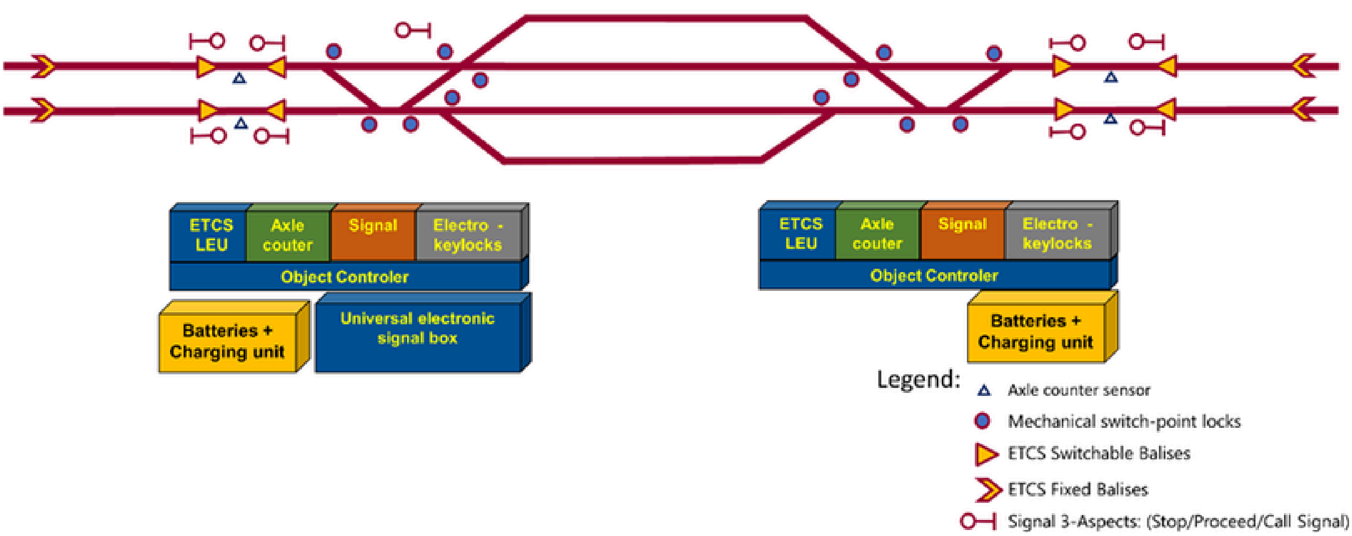
- Electronic Signal Box:
    - Central control unit for signalling logic
    - Digital HMI (military-grade design) with physical buttons
    - Communication with object controllers
- Object Controllers:
    - Monitor and control the position of switches using electromagnetic locks
    - Control entry and departure signals
    - Manage ETCS Movement Authority via ETCS LEUs
- Interlocking Logic:
    - Switch locks ensure dependency between turnout positions and signal aspects
- Axle Counter System:
    - Provides real-time monitoring of track occupancy
    - Optionally transmits track clearance and direction of permitted train movement

System Components

- Signal Box:
    - Digital HMI for configuration and control
    - Touch controls and electromechanical locks for turnout keys
    - Safeguards train movements between stations
    - Supervises train movements within the station
    - Issues movement authority via signals
    - Commands ETCS and issues movement authority under L1 LS

- Portable Light Signals:
  - Easily deployable and weather-resistant three-aspect signals
- Turnout Locks:
  - Mechanical devices for securing turnout positions with pre-defined keys
- Power Supply:
  - Rechargeable batteries with 6–8 hours of autonomous operation
  - Includes charging unit for extended use
- Connectivity:
  - Waterproof cables with secure connectors for interconnecting all boxes
  - Optional wireless communication between signal boxes
- Enclosures:
  - Steel dustproof housings for protection of electronic components

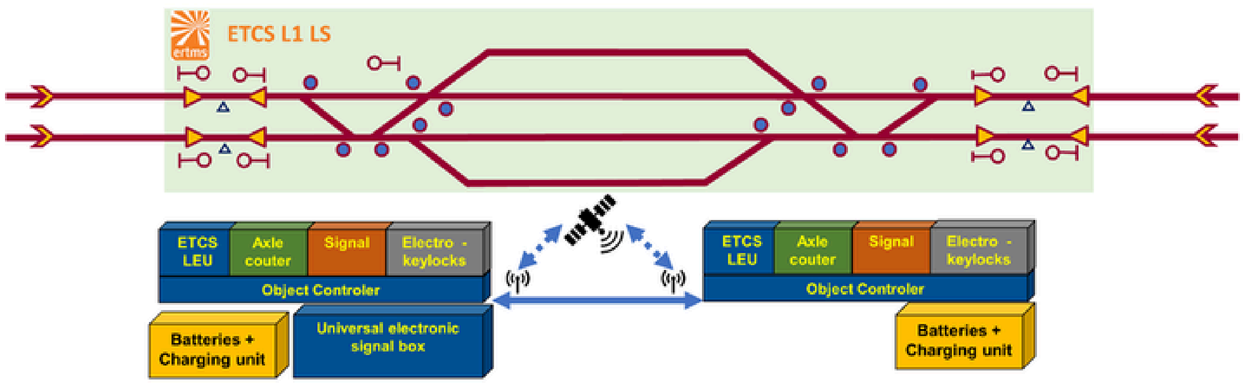
Fallback Signalling
Portable Signalling System



Application of Fallback system

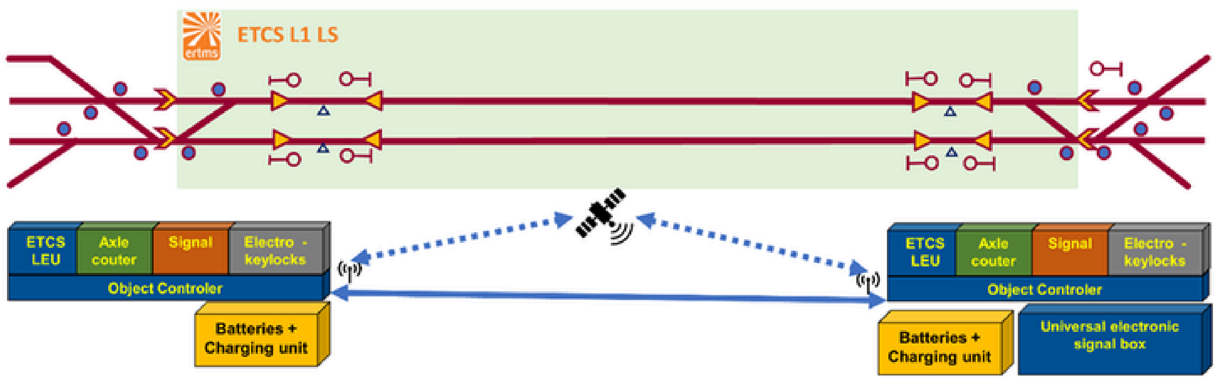
Station Interlocking System

Fallback Signalling
Portable Signalling System
Application as **Station Interlocking System**



Open Line Signalling

Fallback Signalling
Portable Signalling System
Application as **Open Line Signalling**

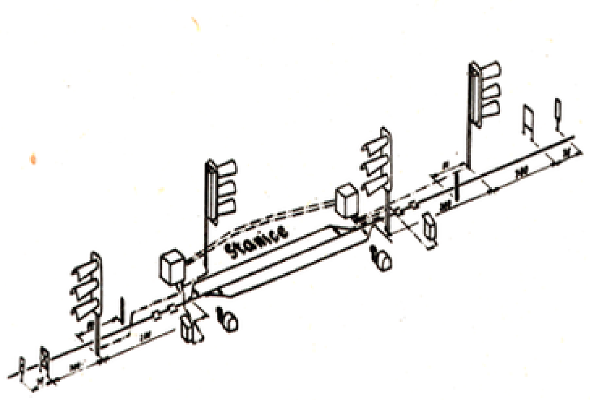


Historic Reference

Portable Signalling System ZZ0500 - Developed during the early 1950s in response to Cold War tensions, the ZZ0500 system was a sophisticated mobile railway signalling solution used by the Czechoslovak railway troops. Unlike its predecessors (ANP and ZZ0400), ZZ0500 featured light signals dependent on switch positions, train detection mechanisms, and interlocking logic.

Each unit consisted of 17 labeled transport boxes and additional components, including relay interlockings, turnout locks, nickel-steel batteries, and motorised charging units. The system was designed for field deployment without external power sources, using lightweight signal optics and tree-based masts. It enabled temporary restoration of station operations, as demonstrated in Moravská Třebová (1962 just in 18 hours) and Novosedly, and remains a key historical reference for modern fallback signalling concepts. Czechoslovak Troops and Railway organisation had about 50 sets of this Signalling system.

Block diagram of ZZ 0500 signalling system



Seven ZZ0500 sets in the SSHR CZ Administration of State Material Reserves warehouse

Boxes 1 and 2 contain the control and dependent signal box

Boxes 11 and 12 contain four light signals and their equipment

Light panel and light signal shades. When installing the signal, two suitable trees first had to be felled and their trunks used to make poles; after securing them in the ground with fastening kits, the signals were installed

Two sets of the simpler ZZ0400 system in the Administration of State Material Reserves warehouse