EUROPEAN RAIL:

THE HOLISTIC CHALLENGE

SAFETY, SECURITY, RESILIENCE: NOT SEPARATE PROJECTS, BUT THREE PROPERTIES OF THE SAME SYSTEM.

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ABSTRACT

The article highlights how the modernisation of the European railway sector, driven by the Europe's Rail Joint Undertaking, calls for a profound transformation towards a highly digitalised, automated, and interoperable ecosystem. In this cyber-physical scenario, total resilience becomes the top priority: the system must be designed to withstand not only extreme weather events and physical crises, but also growing cybersecurity risks and attacks. Such an approach requires moving beyond traditional sectoral silos in favour of an integrated Safety–Security–Resilience model, in which cybersecurity is embedded right from the earliest design stages (security-by-design). Only by guaranteeing this multi-layered protection can technological innovation – from advanced freight transport (DAC) to ERTMS signalling – translate into a truly reliable European network. In this context, Italy has the potential to assume strategic leadership in the development of secure and certified digital infrastructure.

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THE CONTEXT: THE HISTORICAL CHALLENGE FOR EUROPEAN RAIL

Imagine a train traveling across Europe without running into technological or national barriers. A train capable of communicating in real time with the infrastructure, preventing breakdowns, and connecting people and freight in a fast, safe, and sustainable way. This is not merely a vision of the future: it is the challenge Europe faces today.

The European railway sector is undergoing a decisive phase. On one hand, it is called upon to contribute to the Green Deal objectives and the decarbonisation of transport; on the other hand, it must respond to growing demand for sustainable mobility, cost pressure, the need for interoperability between national networks, and global competition in railway technologies.

The question is no longer whether the European railway system needs to change, but how quickly it will be able to do so.

STRATEGIC VISION AND PILLARS OF INNOVATION

To meet this challenge, the Europe's Rail Joint Undertaking (EU-Rail) has developed a strategic vision based on a core principle expressed in the document "Designing the Future of Rail Innovation": the future of rail cannot be built through isolated initiatives. A

systemic approach is required, linking infrastructure, rolling stock, control systems, digital services, data, and emerging technologies.

The current programme has a budget of approximately €1.2 billion (2021–2031) backed by investments from the Connecting Europe Facility and TEN-T policy. However, the most critical shift is cultural: research becomes a permanent capability of the system. The challenge of the coming decade can be summed up by the formula: research, industrialise, deploy.

THE THREE PILLARS OF RAILWAY TRANSFORMATION

- **A simpler, more integrated system:** Overcome technological and organisational fragmentation by strengthening interoperability between national networks, promoting common standards, and accelerating the digitalisation of processes. The evolution of ERTMS (European Rail Traffic Management System) acts as the guiding tool.
- **A freight transport revolution:** Shift increasing volumes of freight from road to rail by introducing Digital Automatic Coupling (DAC), operational automation, predictive maintenance, and logistics data sharing to make the service sustainable and cost-effective.
- **Digitalisation as the primary engine:** Artificial intelligence, big data, FRMCS, digital twins, and cloud computing form the foundation of a more connected, autonomous, and data-driven network.

THE CORE OF TRANSFORMATION: CYBER-PHYSICAL VULNERABILITY AND TOTAL RESILIENCE

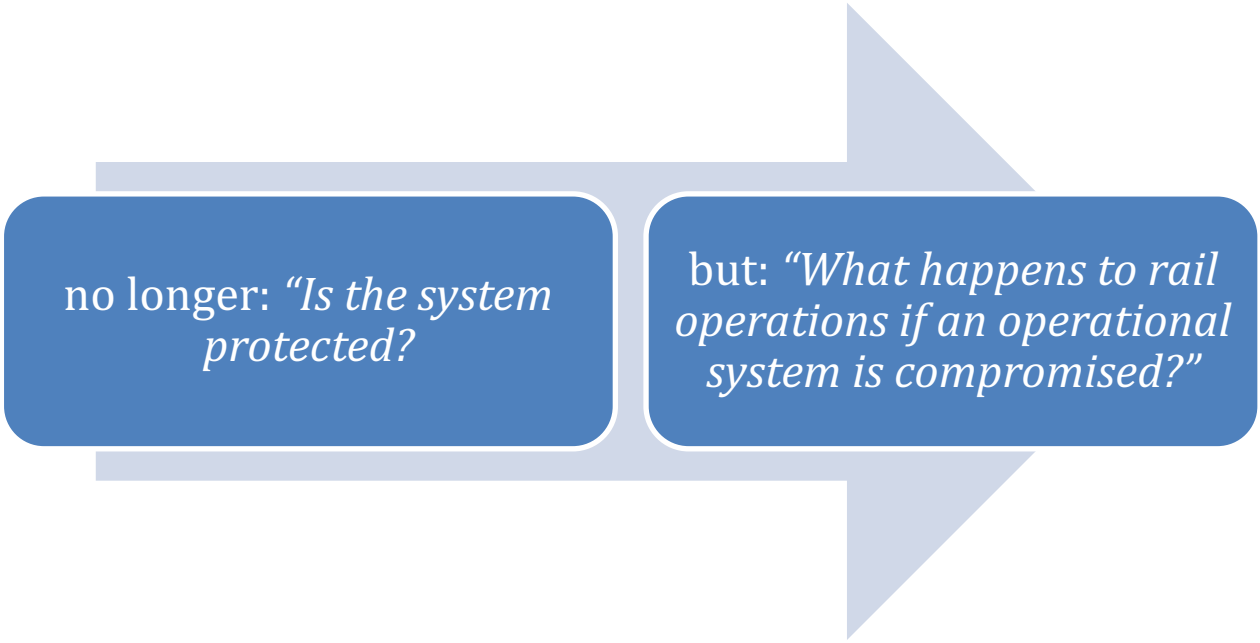
The more reliance on digital technology grows, the more the railway evolves into a true cyber-physical system. The very infrastructure that relies on sensors, software, telecommunications, and automation to achieve efficiency becomes strictly dependent on the availability, integrity, and security of those technologies.

Climate change, extreme weather events, supply chain disruptions, and cyber threats make resilience a strategic priority. The railway of the future must be capable of **preventing, responding to, and recovering** from disruptions.

FROM IT CYBERSECURITY TO RAILWAY OPERATIONAL SAFETY

For years, cybersecurity was managed primarily as an IT issue (servers, PCs, administrative data). In the modern railway sector, this approach is no longer sufficient: IT systems and Operational Technology (OT) systems — such as signalling, interlocking, SCADA, traffic management, and control centres — are inextricably linked.

The Paradigm Shift:



A cyber incident in the OT domain does not cause a simple IT outage; it can impact infrastructure availability, traffic management, and the safety of passengers and workers alike.

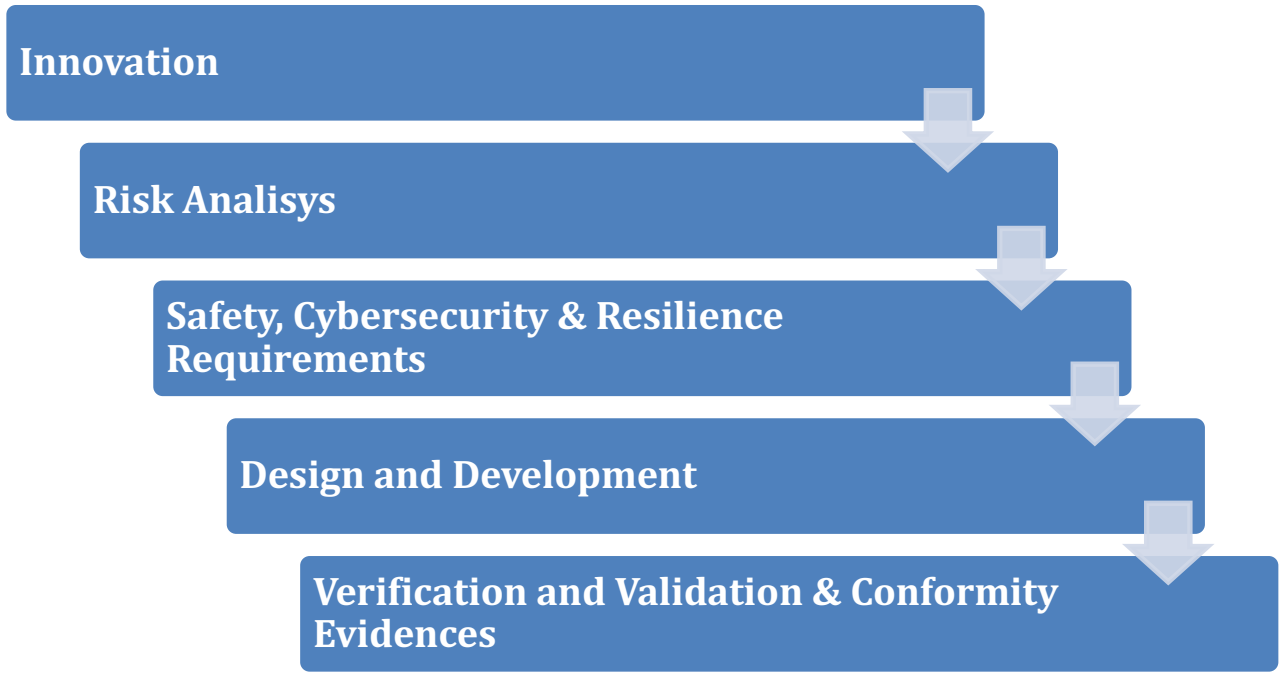
THE INTEGRATED MODEL: SAFETY – SECURITY – RESILIENCE

Safety and security cannot be treated as downstream checks or functions added as an afterthought. Compliance must serve as a guiding criterion from the very earliest design phases (by-design).

The ultimate goal is an integrated compliance model covering Safety–Security–Resilience, combining the three primary European regulatory pillars:

Dimension	Regulatory / Technical Framework	Scope of Application & Objectives
Security (Cyber)	NIS2 Directive (EU 2022/2555)	Cyber risk management, supply chain security, incident response, and business continuity.
Resilience (Physical)	CER Directive (EU 2022/2557)	Critical infrastructure capacity to prevent, resist, and recover from adverse events.
Safety (Operations)	Directive 2016/798, CSM Reg. 402/2013, TSI, CENELEC Standards (EN 50126, 50128, 50701)	Operational risk management, assessment of system changes, and railway traffic safety.

THE INTEGRATED METHODOLOGICAL FLOW (BY-DESIGN)



When introducing a new technology (e.g. ATO, new telecommunications), it is necessary to prove not only that it works, but that associated risks have been identified and mitigated to preserve overall safety standards.

THE MOMENT OF TRUTH

Europe stands at a crossroads. Incremental improvements are no longer enough: a systemic leap is required.

This leap will not be purely technological; it lies in the capacity to govern risk within an integrated environment. Physical resilience must dialogue with cybersecurity; cybersecurity must integrate with railway safety; safety must advance hand in hand with interoperability.

Resources have been mobilised, technologies are arriving, and the vision is set. The true test will be the ability to convert ideas into secure, operational systems in the real world. The time has come to move from experimentation to transformation: this is the moment of truth for European rail.

FUTURE OUTLOOK AND STRATEGIC OPPORTUNITIES

Looking ahead to the Horizon Europe 2028–2034 programming cycle, the sector is already laying the ground for the next public-private partnership. The primary objective will be to move beyond laboratory testing and deliver certified solutions to the market.

A technology is not "European" simply because it was developed by multiple countries, but when it can be seamlessly integrated, authorised, and safely maintained across different networks.

In this landscape EU holds an extraordinary opportunity:

- Building on its extensive experience in High-Speed rail, infrastructure management, and research programmes, the country can strengthen its industrial role across ERTMS, FRMCS, and DAC supply chains.
- Above all EU can take the lead in developing methods, architectures, and skills for cyber-resilient railways, designing digital networks according to the principles of security-by-design, safety-by-design, and resilience-by-design.