European Rail Infrastructure Managers EIM

WHITE PAPER

The Economic Burden of Non-Standardisation of ERTMS in European Railways

The EIM Vision to Reduce Costs for Infrastructure Managers

EXECUTIVE SUMMARY

European railways face a costly paradox. Despite decades of integration policy, from the Single European Railway Area to the 4th Railway Package and Technical Specifications for Interoperability, the sector remains fragmented in ways that systematically increase costs for Infrastructure Managers and Railway Undertakings alike. Fragmented national markets prevent economies of scale, limited supplier competition enables vendor lock-in, and multiple incompatible systems oblige to redundant authorisation processes. The result: modernisation costs of €74 to €111 billion for ERTMS deployment alone, yet less interoperability than a truly integrated network should provide. The enemy of standardisation is not the absence of specifications but the tolerance of fragmented implementation and lack of business approach.

The origins of this fragmentation are shared across the sector. Infrastructure Managers' national operational and engineering rules, often rooted in legitimate historical, operational and maintenance realities, play a significant role, but so do manufacturers' project-specific product development strategies, the partial use of TSI functionalities, and additional national layers introduced at authorisation or safety-assessment stage. Any credible path forward must therefore engage all actors in shared responsibility, while at the same time protecting the substantial investments that early adopters of ERTMS have already made in good faith.

The urgency for the sector to react was brought into sharp focus at the Copenhagen High-Level Event in November 2025, where European leaders delivered an unambiguous message: rising costs and technical fragmentation threaten rail's future competitiveness. The call for "a more industrial approach" reflects recognition that the sector's tradition of bespoke engineering has become an economic liability in an era demanding scalable, interoperable solutions.

The analysis presented here is necessarily qualitative. The sector's data gaps and absence of common cost methodologies preclude precise impact assessment — but this limitation reflects the problem itself: a fragmented sector that cannot measure its own inefficiencies cannot rationally address them. The convergence of evidence from Infrastructure Managers, Railway Undertakings, regulators, suppliers, and researchers consistently identifies the same structural dysfunction. This convergence provides sufficient grounds for decisive action.

EIM's vision on the way forward rests on two parallel and complementary streams.

The EU-Rail System Pillar must be strengthened and refocused under the next EU-Rail Joint Undertaking. The sector's proposal for research and innovation must translate into concentrated investment on strategically essential CCS projects. The System Pillar should evolve to coordinator of pre-deployment programmes delivering stable, implementation-ready specifications. The interface with the reinforced High-Level Deployment Group should operate through binding commitments: joint work programmes, synchronised timelines, active stakeholder representation, and escalation procedures when national deviations threaten coordinated deployment.

In parallel, as an effective way forward in the short run the sector must accelerate full completion of EULYNX specifications as the common standard for the interface between central equipment and field elements. Infrastructure Managers cannot wait for the complete

CCS+ package: they are launching tenders today, and each procurement based on fragmented national specifications risks locking in 20 to 30 years of non-standardisation. EULYNX already provides interface specifications, which are agreed by Europe's Rail. But actions should be taken to eliminate the causes that prevent EULYNX from fulfilling its potential, namely national variants, undemonstrated interchangeability, uncertain product availability and insufficient governance as a "open" standard, i.e.: technology neutral standard with no proprietary solutions.

In addition, as an overarching principle, the continued evolution of the ERTMS standard has to be anchored in stability. While harmonisation moves forward, those who have already invested must not be abandoned. This means that viable migration paths and, wherever technically feasible, backwards compatibility for existing systems must be central when the ERTMS standard is developed. Additionally, new functionalities must be calibrated against actual market need.

In EIM view, the proposal of reformed System Pillar and EULYNX standardisation represent two complementary responses to the same fundamental problem: the economic burden of non-standardisation in European railways.

I. THE PROBLEM DEFINITION

The Persistence of Fragmentation

European railways invest billions annually in modernization, yet technical fragmentation persists despite legal mandates, harmonized specifications, and substantial EU funding. The Independent Regulators' Group for Rail captured the situation precisely in 2024 when it described "patchy applications at European level and a potential fragmentation of national versions" even of supposedly standardised systems like ERTMS[1].

This persistence reveals a structural failure that policymakers must confront. The costs of non-standardisation are systematically underestimated because they require longer-term financing perspectives that government budget cycles rarely accommodate. Infrastructure Managers, operating under financial constraints, base procurement decisions on upfront capital costs rather than lifecycle considerations. This is a short-term rationality that risks producing long-term inefficiency. Perhaps most worryingly, the costs of non-standardisation prove extremely difficult to quantify in business cases, creating an asymmetry where the visible costs of standardisation are weighed against the invisible costs of fragmentation. The persistence of fragmentation also has deeper structural causes that must be acknowledged. National variants are not only the product of national preference: in many cases they reflect deeply embedded operational and maintenance rules, historical network architectures and legitimate project constraints. Maintenance concepts, which are often overlooked in harmonisation debates, can also drive genuine differences between networks. Alongside this, manufacturers' product development strategies (which in a project-focused market tend to tailor solutions to each contract) and the partial use of TSI functionalities further reduce the reusability of

[1] IRG-Rail (2024), "Network access challenges following the deployment of ERTMS" — https://irg-rail.eu/download/5/1073/20245IRG-railNetworkaccesschallengesfollowingthedeploymentofERTMS.pdf

solutions and the scope for economies of scale. Finally, additional national layers introduced during authorisation or safety assessment by National Safety Authorities can recreate complexity even where specifications are, in principle, harmonised. A realistic diagnosis must therefore recognise that fragmentation is produced jointly by Infrastructure Managers, the supply industry and the authorisation chain. Addressing it requires commitments from all three.

The challenge of quantification

A fundamental methodological challenge confronts any analysis of non-standardisation costs: the opacity of data across the sector. The European Commission acknowledged this in its 2019 ERTMS business case analysis, noting that cost data sharing remained "very difficult" with "no common view of the system cost description," leading to "a lack of understanding of cost drivers at European level." When an industry cannot accurately describe its own cost structure, rational decision-making becomes very difficult, if not impossible[2].

This paper therefore is based on qualitative rather than quantitative analysis - not by choice, but by necessity. The sector treats procurement and operational costs as commercially sensitive information and no standardised methodology exists for comparing costs across different national implementations. Hence, the question: what would Infrastructure Managers spend to maintain or replace fragmented national systems in the absence of ERTMS? - remains unanswered.

The absence of precise quantification, however, should not be mistaken for absence of evidence. There are multiple evidence sources to demonstrate the cost burden: official deployment estimates reveal market inefficiencies, industry position papers documenting operational friction, procurement outcomes showing limited competition and inferential analysis of structural cost drivers inherent in fragmented markets. The convergence of qualitative evidence from independent sources from Infrastructure Managers, Railway Undertakings, regulators, suppliers, and academic researchers, consistently points to the same conclusion. When every stakeholder in a sector independently identifies the same problem, the absence of a single authoritative cost figure should not obscure the underlying reality.

The Copenhagen wake-up call

The urgency of this challenge came into sharp focus at the Copenhagen High-Level Event on 5th November 2025, convened by the Danish Presidency of the Council together with DG MOVE, ERA, and Europe's Rail Joint Undertaking. The message from European leaders was unambiguous: rising costs and technical fragmentation have created a negative spiral that threatens rail's future competitiveness[3].

ERA Executive Director Oana Gherghinescu offered her diagnosis, arguing that "rail becomes a masterpiece only when built on standardisation" and urging the sector to "abandon its habit of crafting masterpieces and take a more industrial approach." This metaphor captures a

[2] European Commission (2019), "ERTMS business case on the 9 core network corridors" — https://transport.ec.europa.eu/transport-modes/rail/ertms/state-play_en

[3] See: https://www.unife.org/news/eu-danish-presidency-high-level-event-discussion-cutting-costs-in-rail-harmonised-rules-and-innovative-processes-solutions-for-a-market-oriented-railway/

fundamental truth: the railway sector's traditional pride in bespoke engineering excellence has become an economic liability in an era demanding scalable, interoperable solutions[4].

The Commission reinforced that cost reduction must accompany any new investment, showing sympathy for the industry's call for €3 billion in research and development plus €15 billion in pre-deployment funding—but making clear that such investment must deliver genuine efficiency gains, not simply finance continued fragmentation.

The Copenhagen conclusions deserve particular attention from policymakers. Participants agreed that reducing regulation alone cannot solve the problem; indeed, further harmonisation is needed. They called for streamlined vehicle authorisation processes, acknowledged that making ETCS cost-effective remains essential, and emphasized the need to remove persistent national rules that undermine the stability of the European regulatory framework. These conclusions represent a consensus that the status quo is unsustainable[5].

The continuity of this debate was also visible in the ERA ERTMS 2026 Conference in Valenciennes[6], which dedicates entire sessions to the challenges, status and outlook of ERTMS deployment and, notably, to a consolidated overview of the cost drivers affecting ERTMS implementation across trackside and onboard projects. The fact that the Agency has placed, ERTMS deployment, controlling ETCS costs and cost drivers at the centre of its flagship event confirms that the concerns articulated in Copenhagen are neither isolated nor rhetorical: they are clearly shaping the European ERTMS agenda.

II. THE COST OF TECHNICAL FRAGMENTATION

The vendor lock-in trap

When an Infrastructure Manager procures a signalling system, they enter what typically becomes a decades-long relationship with a single supplier: a relationship characterised by fundamental asymmetry. Modern signalling systems are complex, software-intensive products where system logic, data structures and interfaces are proprietary to the manufacturer. The Infrastructure Manager depends on this supplier for maintenance, upgrades, capacity expansions, and eventual replacement; the supplier faces no comparable dependency.

The consequences ripple throughout the system lifecycle. When capacity expansion is needed on a line equipped with a particular vendor's interlocking, the Infrastructure Manager faces a stark choice: procure additional equipment from the same vendor at whatever price is offered or undertake costly system replacement. When software updates or cybersecurity patches are required, the timeline depends on the vendor's priorities, not the Infrastructure Manager's operational needs. When spare parts are needed for aging equipment, the supplier operates as a monopolist for components unavailable from alternative sources.

[4] See: https://tripbytrip.org/2025/11/14/rail-should-be-functional-not-fine-art-eu-leaders-call-for-standardisation-and-lower-costs/
[5] https://www.railtarget.eu/interviews-and-events/copenhagen-eu-rail-harmonisation-cost-efficiency-11403.html
[6] For more information see: https://www.era.europa.eu/content/ertms-2026-conference

This lock-in is compounded by insufficient economies of scale and is exacerbated by rapid technological changes.

It is essential, however, to locate the origin of this fragmentation accurately. Responsibility is genuinely shared. National specifications are in large part a product of Infrastructure Managers' own operational and engineering rules, reflecting national habits, legacy architectures and a conviction that each network's particular characteristics justify particular solutions.

At the same time, the supply industry has contributed to fragmentation through project-specific product development strategies, the proliferation of bespoke variants outside target product lines and the partial implementation of TSI functionalities, all of which have undermined the emergence of a genuinely industrial product base. The supply industry responds, rationally and commercially, to what Infrastructure Managers specify: when a tender encodes national operational assumptions into technical requirements, suppliers engineer to those requirements. But they also make strategic choices of their own about how far to invest in a single, harmonised product line.

The result is a project-focused industry rather than a product-focused one. This causal chain has a demanding implication: resolving vendor lock-in requires Infrastructure Managers to exercise collective discipline over their own specifications, and the supply industry to commit to a genuine industrial approach based on single target product lines with transparent upgrade paths.

Today, each national market requires different specifications, forcing suppliers to develop and maintain parallel product lines rather than amortizing costs over larger production volumes. A manufacturer producing 1,000 identical signalling units annually achieves lower unit costs than one producing 50 units each of 20 national variants. The political message from Brussels that rail needs a more industrial approach reflects recognition that European railways' preference for customization systematically drives up costs.

The digital transition, which brings new possibilities and functions, makes this problem more urgent, not less.

Electronic interlocking lifecycles have shortened to 15-20 years compared to 40 to 50 for relay interlockings 80 years for mechanical interlockings. Infrastructure Managers will face more frequent procurement decisions, making vendor lock-in an increasingly expensive constraint. Early experience with EULYNX[7]-based procurements offers some encouragement: according to the EULYNX Annual Report 2024, in certain tenders, such as those conducted by DB InfraGO and SBB that used standardised EULYNX specifications, each attracted four qualified bidders compared to the typical one or two bidders for traditional procurements[8]. Open

[7] For more information on EULINX see: https://eulynx.eu/

[8] EULINX Annual Report 2024: https://eulynx.eu/resource-hub-documents/?eeFolder=Reports&eeListID=1&ee=1 For the sake of completeness, it should be noted that experts also pointed out that the outcomes of similar procurements in UK and Sweden have been more mixed, with procurement structure and procurement volume appearing to be at least as influential as the use of EULYNX specifications alone. Nonetheless, the broader point stands: open, properly governed standards create the conditions for competitive markets, while proprietary specifications tend to perpetuate monopoly pricing.

standards which serve the whole life-cycle of the products / systems create competitive markets; proprietary specifications perpetuate monopoly pricing.

The financial burden on Railway Undertakings

While Infrastructure Managers bear the cost of trackside fragmentation, Railway Undertakings operating internationally face an equally visible burden: equipping trains with multiple incompatible train protection systems. High-speed services like Eurostar require six to eight different systems per trainset. Each system demands dedicated onboard equipment, software, installation, testing, certification, and driver training. These are financial burdens that standardisation would largely eliminate. In the absence of open standards, Railway Undertakings are equally locked into proprietary onboard solutions that are not built upon the principle of affordable, incremental updates and upgrades. As a result, keeping onboard equipment aligned with evolving European requirements becomes disproportionately expensive or, in practice, simply does not happen, delaying fleet modernisation and undermining the very interoperability that ERTMS was designed to deliver.

The cost trajectory is alarming. In April 2025 the European Commission's ERTMS Deployment Management Team reported that retrofitting costs for ERTMS onboard equipment grew from €450,000 to €900,000 per vehicle between 2018 and 2022, while upgrade costs increased from €200,000 to €400,000 over the same period, effectively doubling in four years. The study warned that the sector is "closer to the worst-case scenario" regarding costs[9].

Extrapolating across the European fleet, already in 2017 the European Court of Auditors estimated that equipping the approximately 22,000 locomotives operating in Europe with ERTMS would have required €11 billion for onboard equipment alone[10].

Beyond equipment costs, authorisation delays impose hidden but substantial burdens.

Software approval for an international vehicle takes "at least a year" on average, what the railway undertakings' associations call "an enormous bottleneck for cross-border traffic and a major cost driver for operators."[11] Each National Safety Authority independently validates systems already approved elsewhere, duplicating effort without adding safety value. Since June 2019, ERA has authorized 80,000 vehicles, with 83% covering multiple EU countries, demonstrating the demand for cross-border operation and the scale of authorisation overhead that fragmentation imposes[12].

Maintenance, skills, and innovation costs

The cost burden extends throughout equipment lifecycles. Infrastructure Managers collectively operate over 20 different signalling systems, each requiring dedicated spare parts inventories sized to ensure availability for maintenance and emergency repairs. When equipment reaches

[9] See: https://op.europa.eu/en/publication-detail/-/publication/89f05852-1680-11f0-b1a3-01aa75ed71a1/language-en

[10] ECA, Special Report 13/2017 — https://www.eca.europa.eu/en/publications/SR17_13

[11] AERRL/ALLRAIL/ERFA Joint Position Paper (March 2025) — https://aerrl.eu/wp-content/uploads/2025/03/2025-03-20_AERRL-ALLRAIL-ERFA-Position-paper-ETCS-FRMCS.pdf

[12] See: https://www.era.europa.eu/content/5th-anniversary-era-authority-vehicle-authorisation-safety-certification-and-ertms#:~:text=With%20the%20processes%20defined%20in,placing%20the%20infrastructure%20in%20service.&text=The%20introduction%20of%20OSS%20revolutionised,training%20for%20applicants%20and%20NSAs;

obsolescence (including because original manufacturers exit the market for instance, as the result of a merger with a former competitor) sourcing spare parts become prohibitively expensive, or premature replacement becomes necessary. As Trafikverket observed, "standardisation streamlines the demands for spare parts as well as skills supply for maintenance personnel."[13]

Skills fragmentation compounds the problem. Maintenance staff trained on specific systems cannot transfer skills without retraining when countries operate different technologies. The EULYNX Academy, which trained over 700 professionals in its first year with a target of 5,000 by 2028, exists precisely because this shared knowledge base is currently absent. In a standardised environment, based on a "one problem - one solution approach", equipment manufacturers would provide training, technical colleges would offer standardised curricula, and labour markets would naturally develop the required skills[14].

Innovation suffers equally. When a supplier develops an improved signalling component, the potential market is constrained by compatibility requirements. When one Infrastructure Manager achieves an operational improvement, that knowledge cannot easily transfer to others operating different systems. Best practices remain localized; each Infrastructure Manager must independently discover solutions to common problems. Engineering resources devoted to managing national variants add cost without adding functional value[15].

Innovation suffers equally, and here rail must confront a deeper structural question. When a supplier develops an improved signalling component, the potential market is constrained by compatibility requirements. When an Infrastructure Manager achieves an operational improvement, that knowledge cannot easily transfer to others operating different systems. Best practices remain localised; each Infrastructure Manager must independently rediscover solutions to common problems. Engineering resources devoted to managing national variants add cost without adding functional value.

Part of the explanation lies in a persistent tendency to treat rail as an island. Rail has historically approached technical challenges as though they were unique to the sector, developing bespoke solutions to problems that other industries (energy, aviation, automotive, telecommunications) have already resolved. This instinct to look inward rather than outward is costly. Where robust, proven industrial standards exist, rail should adopt and build upon them rather than layering railway-specific requirements on top of already sound practice. The question that should precede every specification exercise is not "how do we adapt this product to our processes?" but "are our processes still justified, or should we adapt them to what already works?"

This demands a continuous evaluation of goals versus means. Requirements that made sense when legacy systems were designed may no longer reflect operational reality, yet they persist because processes have grown around them. Standardisation offers the opportunity to break this cycle, not merely by harmonising what exists, but by deliberately importing solutions from

[13] Swedish National Implementation Plan (NIP) 2024, Annex1: https://transport.ec.europa.eu/document/download/d3d44a22-2204-46e3-9389-ebd1be8bf179_en?filename=NIP_ERTMS_2024_SE.pdf
[14] See: EULYNX Annual Report 2024 – EULYNX Academy — https://eulynx.eu/
[15] See: https://www.globalrailwayreview.com/article/120/benchmarking-ertms-implementations/

outside the sector, resisting the accumulation of railway-specific add-ons, and aligning rail's innovation culture with the broader industrial world from which it has for too long remained apart

The ERTMS paradox

The European Rail Traffic Management System (ERTMS) was conceived in the 1990s as a solution to fragmentation, yet its deployment has become an illustration of how non-standardisation drives up costs. According to the European Coordinator for ERTMS, €37.2 billion is needed for trackside deployment on the entire TEN-T Network, plus €5 billion for rolling stock. When associated works are included - track circuits, interlocking upgrades, interface adaptations-total costs reach €74 billion or even €111 billion depending on scenarios[16]. It should be noted that the balance between ETCS-specific costs and the costs of associated systems varies considerably across Member States: the experience of some infrastructure managers, such as in Belgium, shows that ETCS deployment costs can be significantly lower than the cost of interlocking renewal and adaptation, suggesting that the wider system environment - not ETCS itself - is often the dominant cost driver.

These figures are sometimes cited as evidence that standardisation is expensive. This interpretation inverts the causality. ERTMS deployment costs are high precisely because Europe lacks standardisation - not only in train protection, but across the multiple technology layers that make up a complete signalling and train control system.

In most cases, the challenge goes well beyond ETCS. While ETCS addresses the train protection layer, Infrastructure Managers must also deal with signalling, traffic control and traffic management systems that remain entirely national. Despite several European-level attempts to develop common solutions for these layers (EURO Interlocking, INESS, and others) no harmonised specification has yet reached maturity. The System Pillar has now created the ground for such common solutions, but they are not yet available for deployment. In the meantime, Infrastructure Managers deploying ERTMS must integrate ETCS with nationally specific systems across all these layers, maintaining parallel technologies during a transition stretching across decades. The costs and complexity of this integration - not of ETCS per se - are a primary driver of the high deployment figures[17].

The slow progress is the consequence of lack of common solution for the infrastructure manager’s side. In fact, if standardisation offer clear economic advantages, a “rational” Infrastructure Managers should voluntarily converge on common solutions.

As consequence the deployment has progressed slowly: by the end of 2023, ERTMS achieved only 15% deployment for ETCS and 61% for GSM-R on the Core Network Corridors[18]. This

[16] IRG-Rail (2024), citing European Coordinator for ERTMS — https://irg-rail.eu/download/5/1073/20245IRG-railNetworkaccesschallengesfollowingthedeploymentofERTMS.pdf. For more information see also The European Coordinator's work plans (First Work Plan 2020 and Second Work Plan 2022 by Matthias Ruete)

[17] The problem is compounded by the architecture of the ERTMS specifications themselves. The ETCS function catalogue contains more than one elementary "brick" for the same operational problem, which means that different infrastructure managers can (and do) make different specification choices while remaining nominally compliant with the European standard. This creates the conditions for national "specification walls" that undermine the very interoperability ERTMS was designed to achieve.

[18] www.era.europa.eu/system/files/2024-06/Report%20on%20Railway%20Safety%20and%20Interoperability%20in%20the%20EU%202024.pdf

market behaviour itself constitutes evidence: slow adoption suggests that transition costs from installed base systems may exceed the net present value of switching, that benefits accrue primarily to Railway Undertakings rather than Infrastructure Managers who bear deployment costs, or that coordination problems prevent collective realisation of benefits even when individual rationality would support convergence. The precise weighting of these factors cannot be determined from available data, but the behavioural model is unmistakable. The ERTMS Users Group explained at RailTech Belgium 2025 event that major Infrastructure Managers "couldn't build a business case" for deployment due to costs being "currently too expensive" with time overruns creating "a risk profile that is unacceptable for quite a few countries." Countries like Norway and Denmark proceeded because they "saw it as a necessity", i.e.: decisions driven by operational imperatives rather than economic rationality[19].

Furthermore, these costs can eventually result even higher than originally planned if no additional measures are taken to control the cost of the remaining lifecycle.

In the case where a more radical approach has been taken, as in Denmark, where Banedanmark is implementing an "ERTMS-only trackside" solution without maintaining legacy train protection systems, infrastructure managers are confronted with a further structural problem: vendor lock-in. The absence of open, standardised interfaces between ETCS and the underlying signalling and control systems means that, once a contract is awarded, the infrastructure manager becomes dependent on a single supplier for the entire lifecycle of the installation. This drives up long-term costs significantly, often making lifecycle expenditure unaffordable even when initial deployment costs are controlled.

Clearly a common European solution for the interface specifications is a necessary pre-condition for addressing this problem, but it is not sufficient on its own: additional measures such as the standardisation of interfaces between central equipment and field elements (as pursued by the EULYNX initiative), open procurement frameworks, and mechanisms to ensure product interchangeability, are essential to break the vendor lock-in and bring lifecycle costs under control.

As for railway undertakings, their assessment is stark: "*The current situation is even worse than before the introduction of ETCS. The regulatory framework and the lack of coordinated trackside [version] deployment have made ETCS so costly that its costs outweigh its advantages. The ongoing ERTMS crisis jeopardises profitability and, consequently, the competitiveness and development of the railway sector.*"[20]

The diagnosis is clear. Spending billions to achieve a common ERTMS standard has created fragmented implementation, which costs more than doing nothing, while delivering less interoperability than a truly integrated system would provide.

The enemy of standardisation is not the absence of specifications but the tolerance of fragmented implementation and the lack of European vision on the ERTMS versions.

[19] 15. RailTech.com (April 2025), "Wake-up call from Europe's biggest ERTMS players" https://www.railtech.com/all/2025/04/02/wake-up-call-from-europes-biggest-ertms-players

[20] AERRL/ALLRAIL/ERFA Position Paper (March 2025) — https://aerrl.eu/wp-content/uploads/2025/03/2025-03-20_AERRL-ALLRAIL-ERFA-Position-paper-ETCS-FRMCS.pdf

The early adopters: protecting the investments made

Any honest discussion of the economic burden of non-standardisation must engage directly with the position of Infrastructure Managers and Railway Undertakings that have already committed substantial investments (in several cases, billions of euros) to the current generation of ERTMS. These investments were made on the basis of specifications and TSIs that were, at the time, understood to deliver a truly interoperable product.

These early adopters now find themselves in a particularly exposed position. Successive specification revisions, the introduction of new baselines and system versions, and the ongoing migration from GSM-R to FRMCS all carry the real risk that suppliers will pass the costs of migrating their unharmonised product lines onto Infrastructure Managers and Railway Undertakings through upgrade projects that had not been anticipated when initial contracts were signed. In the absence of clear migration paths and backwards compatibility obligations, early adopters may effectively be financially penalised for having moved first.

Furthermore, the pace at which new functionalities are introduced into the ERTMS specifications must be calibrated against demonstrated market need. Where innovation is pursued without a transparent business case acknowledged by those who will ultimately pay for it (i.e.: Infrastructure Managers, Railway Undertakings and taxpayers) the effect is to widen the gap between existing applications and future harmonised products, keeping the cost of ERTMS high both for new deployments and for those upgrading.

The principle that should guide the sector is therefore clear: harmonisation must move forward, but not by abandoning those who have already invested. Every harmonisation initiative, every new revised TSI, and every specification revision should be assessed against its impact on existing investments, with explicit migration paths and, wherever technically feasible, backwards compatibility.

A positive business case acknowledged by those who are set to pay must be a prerequisite for the introduction of new functionalities. This principle should also shape the work of the reformed System Pillar described in Section IV, as stability of specifications, maturity of products and protection of prior investments are not trade-offs against innovation and harmonisation. They are the conditions under which the deployment of harmonised solutions becomes politically and economically sustainable.

III. SYSTEM-LEVEL CONSEQUENCES

The compounding cost of delays

Deployment delays transform theoretical savings into actual losses. Academic research examining Danish ERTMS deployment found that actual project schedules exceeded initial estimates by a median of 75%, concluding that ERTMS projects are "inherently more susceptible to risks than their initial estimates.[21]" The aggregate effect of these delays points to a structural problem beyond individual project management. The end-to-end cycle from specification initiation to commissioning of a first operational line routinely spans a decade, a

[21] Managing ERTMS Project "Springer": https://link.springer.com/chapter/10.1007/978-3-032-04774-8_3

timeline that carries a double risk. Financially, capital is committed years before benefits materialise, while the original business case bears decreasing resemblance to economic reality at delivery. Strategically, a ten-year cycle means that technical choices made at the outset risk obsolescence before the system enters service, creating pressure for mid-cycle specification changes that compound delays further. A deployment model requiring a decade to produce a first operational result is structurally incompatible with the pace of technological change that rail digitalisation demands.

The fundamental driver is the installed base dilemma. Infrastructure Managers cannot simply switch off existing signalling and replace it overnight. Legacy systems must remain operational during transition, requiring complex migration strategies where old and new technologies coexist. This coexistence multiplies testing complexity and requires adaptation layers and protocol translators. The European Coordinator found that a "dual on-board migration strategy" produces better economics than a "dual track-side strategy"[22]. But this insight merely confirms that migration paths are costly rather than straightforward system replacement.

FRMCS: the risk of repeating ERTMS mistakes

The Future Railway Mobile Communication System (FRMCS) presents both an opportunity and a warning. GSM-R, deployed on over 130,000 kilometres of track with 90,000 activated cab radios, is approaching obsolescence as a 2G technology designed over two decades ago. FRMCS, based on 5G, will be essential for railway digitalization, enabling train automation, remote control and enhanced data transmission[23].

However, FRMCS deployment risks in the European mismatch implementation of FRMCS on the trackside and onboard causing vehicles not to be able to run anymore on certain lines. The survey launched by the EU-Rail “FRMCS European Deployment Group's” in July/September 2025 revealed concerning disparities: GSM-R switch-off dates vary from 2035 to 2044 across countries; only two Infrastructure Managers indicated financing schemes are available and most respondents reported financing plans as "under study" or "no plans yet." With FRMCS specifications not yet finalized and compatible products unlikely before 2029, the conditions that led to ERTMS fragmentation are being recreated.

ERA's Technical Opinion on ETCS-FRMCS compatibility highlighted risks of fragmentation if different technical approaches are adopted. [24] EIM's December 2024 statement emphasized concerns regarding "the tight schedule for retrofitting several thousands of vehicles, product availability, and sunk costs.[25]" The EU-Rail High-Level Deployment Group is one of the key actors to facilitate coordinated action to ensure FRMCS integration does not create another

[22] European Coordinator ERTMS Work Plan 2022. https://transport.ec.europa.eu/system/files/2023-09/ERTMS_work_plan-second_edition.pdf , page 59 “If we do not impose a hard obligation to equip ERTMS onboard, we will still have a rolling stock with only class B systems on-board fifty years from now, thus, class B trackside would have to be kept. As a result, we would have a dual on-board and dual trackside strategy for decades”

[23] https://www.criticalcomms.com/content/features/5g-for-railways-gathering-speed

[24] See: https://www.era.europa.eu/content/opinion-eraopi2024-3-european-union-agency-railways-regarding-etcs-frmcs-compatibility

[25] EIM Statement - On the Opinion of ERA regarding ETCS-FRMCS compatibility". https://eimrail.org/2024/12/09/eim-statement-on-the-opinion-of-the-european-union-agency-for-railways-regarding-etcs-frmcs-compatibility-era-opinion-era-opi-2024-3/

moving target due to parallel development paths. Yet its role is not yet fully recognised by the management of many rail companies.

Market structure digital transformation and competitive failure

Some final considerations need also to be made on the market structure consequences of non-standardisation. A potential new entrant to the signalling market faces the prospect of developing products for over 20 national markets, each with distinct specifications, testing requirements, and certification processes. The investment required to enter multiple markets simultaneously is prohibitive. But the alternative of entering one market limits addressable volume to levels where fixed costs cannot be adequately amortized. Limited competition justifies higher prices, but higher prices reflect the costly fragmentation that limits competition.

This competitive failure damages rail's position against other transport modes. Rail freight's modal share has stagnated at 16-17% of inland freight, well short of the EU's 30% target for 2030, while road freight captures 75-76% of the market through operational simplicity. The already cited ERA 2024 Report observed that "railways have not increased their modal share in the transport mix in the past decade, despite being the most sustainable mode of transport." Non-standardisation systematically undermines both cost competitiveness and operational flexibility.

The digital transformation that could revitalise rail depends on capabilities (traffic management, predictive maintenance, automated control, dynamic capacity management) that require standardised data formats, interoperable communication protocols, and common technical interfaces. This requires additional standards on top of standardised functionalities. Fragmented specifications prevent the data integration these capabilities require. For instance, a predictive maintenance algorithm developed for one vendor's equipment cannot apply to another's if diagnostic data is formatted differently.

IV. THE EIM VISION FOR A SOLUTION

The EIM vision for addressing the economic burden of non-standardisation rests on two parallel and complementary streams:

1. Strengthening the EU-Rail System Pillar to drive pre-deployment innovation and
2. Promoting full completion and adoption of the already existing EULYNX standard as the sector reference.

Neither alone is sufficient; together, they offer a reasonable path toward successful rail standardisation approach.

1st VISION: Refocusing the EU-Rail System Pillar under the next EU-Rail Joint Undertaking

The European railway sector has submitted to the European Commission a proposal for the second phase of the Europe's Rail Joint Undertaking (EU-Rail-2) under the next Multiannual Financial Framework: €18 billion between 2028 and 2034, comprising €3 billion for research and innovation and €15 billion for pre-deployment activities.

This proposal also responds directly to the economic dysfunction documented in ERTMS deployment. The €15 billion pre-deployment allocation represents indeed recognition that system specifications alone do not produce standardisation; coordinated investment to validate, industrialise and deploy standardised solutions at European scale is therefore required.

Within this framework, Control-Command and Signalling (CCS) and Telematics represents a critical priority for pre-deployment investment. The sector should concentrate resources on few but strategically essential pre-deployment projects that address the most urgent standardisation gaps:

1. Standardised full ETCS L2 without line side signalling trackside architectures – moving beyond national interlocking designs and signalling rules to European-standard modular architecture that can be deployed, configured, updated and authorised industrially rather than engineered project-by-project.
2. Traffic management systems with compatible interfaces – establishing common operational concepts and technical interfaces that enable efficient and performant cross-border traffic management without national specificities.
3. FRMCS integration with ETCS solution–that prevents the fragmentation that would result from uncoordinated migration from GSM-R to FRMCS and Baseline 4

The selection criterion of these pre-deployment projects should address components where non-standardisation currently multiplies costs and prevents interoperability. The focus on few pre-deployment projects reflects lessons from the past: too many research initiatives in parallel will not deliver results in time. Concentrated pre-deployment on critical standardisation gaps produces deployment-ready solutions.

We should also underline that the System Pillar should treat operational rule harmonisation not merely as a precondition for technical standardisation, but as one of its most critical deliverables in its own right with dedicated resources, governance and timelines equivalent to those devoted to architectural and technical work. This reflects the reality that, without genuine convergence on operational rules, technical standardisation efforts will continue to be undermined by divergent national operating assumptions, regardless of how well the specifications themselves are written. It also reflects the scale of the transformation involved: national operating rules, training frameworks, maintenance practices, and professional standards are deeply rooted, and changing them is a heavy, costly and lengthy process.

Operational harmonisation must therefore be approached as a major change management exercise, requiring strong governance, clear prioritisation of the most impactful topics and, where sector self-organisation proves insufficient, a degree of external constraint to ensure that the sector moves at the pace that coordinated deployment demands.

The System Pillar's role: from generic integration to pre-deployment coordination

To ensure that pre-deployment investment produces genuinely standardised, deployment-ready specifications, the System Pillar of EU-Rail should assume a reformed role as the body coordinating CCS-focused pre-deployment (cross border) programmes across Europe.

Europe's Rail has established the System Pillar as the "architect of the future EU's railway system." The strategic shift required is moving from this role towards becoming the coordinator that ensures pre-deployment projects deliver specifications ready for immediate deployment. This includes the development of the specifications, understood as the system's technical specifications, the definition of the required interfaces, the harmonized operational rules and the specifications needed to ensure that deployment, upgrade, and commissioning procedures are industrialised and lean.

To this purpose, the System Pillar should fulfil five specific responsibilities for CCS pre-deployment that distinguish it from previous approaches to European railway harmonisation.

1. The System Pillar should focus on the missing standardised system architectures with "mandatory" modular interfaces, operational scenarios, signalling rules and industrialised procedures agreed by the sector. This requires a fundamental departure from current practice: as soon as a standardised solution is made available, Infrastructure Managers should agree to not accommodate any longer "national variations" at the architecture or functional level through national implementation chapters in specifications. Suppliers should develop their products fulfilling the complete standardised European solution and providing lean roadmap evolution of their systems onboard and trackside.

   Furthermore, the rail sector should stop specifying its own proprietary technology where proven, cost-effective solutions already exist in wider markets. Historically, the railway sector has invested heavily in developing bespoke technological solutions (from communication protocols to hardware platforms) even where functionally equivalent products were readily available at a fraction of the cost. This approach inflates development timelines, limits the supplier base to a small number of rail-specific vendors, and disconnects the sector from the innovation cycles and economies of scale that drive cost reduction in other industries. Where technology from broader markets can meet railway functional and safety requirements (whether through direct adoption or through the addition of a rail-specific certification layer) the sector should default to using it. To this purpose the System Pillar specifications should be written in a way that defines functional and performance requirements without prescribing rail-specific technological implementations, thereby opening the door to competitive supply from adjacent industries and accelerating the pace of innovation.

   The principle of modular design based on technology available from other markets/industries serves a specific economic purpose in this context: it enables migration strategies aligned with Infrastructure Managers' asset management realities. While modularity remains essential, the appropriate degree of modularity must be economically justified. It will be for the market and manufacturers to demonstrate if certain components can be deployed more efficiently when delivered together rather than separately (whether in cost, time, or operational continuity). Such evidence-based considerations should be reflected in the outcome of the System Pillar work.

   Infrastructure Managers will largely continue to replace components of existing systems rather than pursuing wholesale signalling system renewal. This is a reflection of sound,

realistic asset management practice. An appropriate level of modularity, calibrated for economic efficiency, makes it possible to replace or upgrade individual subsystems without disproportionate knock-on effects on the rest of the infrastructure, allowing deployments to keep pace with technological advances while preserving the value of prior investment.

Modularity must also extend beyond physical deployment. The system must be sufficiently modular in terms of data structures and functional allocation so that interventions on the railway network - whether operational, maintenance-related, or capacity-driven - can be easily planned, configured, and executed within the system. This ensures that network evolution decisions translate into manageable, predictable system changes rather than large-scale disruptive transitions.

This modular approach will support intermediate migration targets rather than requiring direct migration to final target architecture. This approach should transform migration from unrealistic "big bang" replacements or very long periods of overlapping technologies into an economically viable asset management strategy, with multiple intermediate migration targets on the path toward final architecture.
For current brownfield projects to be commissioned, Infrastructure Managers should require the approval of specifications that enable meaningful steps toward target architecture while creating preconditions for gradual migration and leaving open all options to integrate future technological progress. Each time Infrastructure Managers decide to replac/e a part of the overall system, the ideal situation is indeed implementing a harmonised product and /or harmonised operation (possibly by using a national adaptor on the legacy side). To this purpose, short-term decisions for current tenders are also paramount: wrong decisions taken now delay overall deployment of target architecture, as system lifecycles of 20-30 years lock in today's choices for decades.

2. The System Pillar should tackle operational rule harmonisation as a precondition for technical standardisation. Technical interfaces cannot be standardised while the operational and engineering rules that underpin them remain fragmented. Where two Infrastructure Managers apply different operational rules to the same railway function - train detection, movement authority, speed supervision - they will inevitably generate different technical requirements, and the supply industry will inevitably produce different solutions. This is not a supplier failure; it is a specification failure that originates with Infrastructure Managers themselves. The System Pillar must therefore treat the harmonisation of operational rules as a first-order deliverable, not a downstream consequence of technical standardisation. For each CCS pre-deployment project, the System Pillar should explicitly map which operational and engineering rules underpin the technical requirements, identify where national divergences exist, and facilitate the sector agreement needed to resolve them before specifications are finalised. Stakeholders must accept that this process will require relinquishing rules that reflect national habit rather than genuine operational necessity. The discipline required is significant, but the logic is inescapable: a common European system cannot be built on divergent national operating assumptions.

3. The System Pillar should coordinate pre-deployment validation under operational conditions. EU-Rail deliverables should be tested on operational networks before any incorporation into TSIs or adoption as sector standards. This testing cannot be limited only to laboratory validation or supplier demonstrations; it should also occur on realistic working environment, where real operational constraints and integration with previous existing systems reveal specification gaps that laboratory testing cannot always detect. Validation must demonstrate interoperability across national boundaries and between suppliers, not merely compatibility within a single national network or with a single supplier's product suite. The experience with DAC and FRMCS shows that testing phase must explicitly include dialogue with ERA on authorisation processes to identify regulatory barriers before deployment begins. When authorisation requirements are discovered during deployment rather than during validation, they may create bottlenecks that delay implementation and force specification changes after products have already been developed.

   The System Pillar must ensure that feedback from the various pre-deployment validation activities is incorporated in the most effective manner into the specifications. This requires that pre-deployments be comparable, that test campaigns be centrally defined by the System Pillar, and that their results remain transparent to all project parties and to the System Pillar itself. Any changes introduced in the standardised specifications must be considered within this process, as findings from one pre-deployment may need to be implemented across the system if approved.

   Ultimately, the role of the System Pillar in pre-deployments is to ensure that each pre-deployment (and its outcomes) serves the deployment of a single, standardised European system, rather than validating divergent solutions tailored to specific cross-border contexts.

   A credible pre-deployment regime also requires an explicit financing and risk-sharing framework. Infrastructure Managers that open their networks to pre-deployment testing face real operational exposure, such as disruption to traffic, additional engineering effort, and financial risk, that must be recognised and compensated.

   The next Multiannual Financial Framework should therefore include a dedicated financing mechanism for pre-deployment network access based on shared cost structures between the EU, the System Pillar programme and the hosting Infrastructure Manager. Without such a mechanism, pre-deployment will continue to depend on the willingness of a small number of Infrastructure Managers to absorb disproportionate cost and risk, which is neither sustainable nor equitable.

4. The System Pillar should deliver implementation-ready specifications to standards bodies and ERA. Specifications emerging from pre-deployment projects should be incorporated into TSI and maintained (following the relevant ERA processes) or recognised as sector standards, ideally without further development or refinement. Rather than assuming that specifications must remain fixed, the systems validated during pre-deployment should be designed to also allow affordable updates, enabling manufacturers to maintain a single product roadmap that can be progressively enhanced and deployed across all European projects. New functionalities will be planned with the objective of ensuring system stability

over reasonable periods, and enhancements will follow a strategic planning process. However, it is unavoidable that systems will require updates due to errors discovered after deployment or due to changes in infrastructure, such as improvements to installations or the construction of new lines adjacent to the network or obsolescence of technology.
This approach will also be beneficial for the supply industry, as manufacturers will be able to develop industrial products based on a unified roadmap - without national variants - rather than repeatedly adapting prototypes to evolving specifications. Industrial production requires predictable evolution paths, established supply chains, and proven manufacturing processes to achieve the cost efficiency and production volume required for European-scale deployment.

For the principle of affordable incremental updates to be genuinely realised, a harmonised technical architecture should ideally be accompanied by a "common procurement model" that explicitly builds in mechanisms for affordable updates and upgrades throughout the lifecycle. Specifications should be conceived and contracted as living standards subject to managed evolution, with procurement frameworks that create the right incentives for suppliers to invest in a single unified product roadmap rather than maintaining multiple legacy product branches in parallel. Without such a commercial framework, the economic rationale for standardisation will continue to be undermined at the implementation stage, regardless of how well the specifications themselves are written.

5. The System Pillar should establish a formal functional system architecture methodology with transparent governance which includes the sector organisations. This methodology will prevent lobbying for fragmenting specifications through demands for optional national parameters or implementation variations. Clear processes for requirements management, change control, economic justification (business case), compatibility assessment and version management will ensure that once specifications enter pre-deployment validation, specifications continue to evolve in a controlled manner, with sufficiently stable periods between new functionalities to safeguard existing, ongoing and future investments.

6. The System Pillar should treat brownfield migration specifications as a first-order deliverable, not as a by-product derived after the target architecture is complete. The reality across Europe is that the vast majority of ETCS implementation takes place on brownfield networks and Infrastructure Managers face a largely common set of challenges regardless of national context: sequencing of subsystem replacement, management of interfaces between new and legacy components, coexistence of old and new technologies during long transition periods and management of cut-over risk.
A common European framework for brownfield migration covering sequencing principles, interface management, coexistence rules and a shared approach to dealing with legacy systems would be among the most practically impactful contributions the System Pillar could make in the near term. This would also directly help Infrastructure Managers that must launch tenders while the full target architecture is still maturing. Brownfield migration specifications must therefore be developed in parallel with the target architecture, not afterwards.

Refocusing the System Pillar": cooperation with Innovation Pillar and covering regional lines

Two further aspects deserve explicit mention. First, the cooperation between the System Pillar and the future Innovation Pillar must be clearly governed within the successor of Europe's Rail. The standardised modular architecture delivered by the System Pillar should be designed from the outset to accommodate future innovation, not to foreclose it. Furthermore, the interface between the two pillars must include transparent mechanisms for bringing validated innovations into the architecture in a controlled manner, without destabilising specifications that are already in deployment.

Second, among others, the affordability challenge should encompass the different rail network characteristics. Not only high-density lines but also regional lines require dedicated attention in both the System Pillar and Innovation Pillar work programmes. In several Member States, regional networks contain hundreds or even thousands of level crossings, and a full CCS replacement based on the target architecture defined for high-density lines is simply not economically viable in those contexts. Specifications, products and business models designed for this segment of the network cannot be an afterthought: they should also be addressed as a specific work stream, with the understanding that a credible European standardisation strategy must be affordable across the whole network, not only on the busiest corridors.

The Failures the reformed System Pillar will address

The proposed reformed System Pillar role has the ultimate objective to address four specific failures visible in ERTMS deployment, each of which imposed billions of euros in additional costs while reducing interoperability benefits.

To prevent uncontrolled specification evolution. When specifications change during deployment, railway undertakings face a choice between operating with obsolete equipment that cannot access newly equipped infrastructure, or retrofitting equipment at costs approaching those of new installation. The reformed System Pillar prevents this failure by ensuring that specifications follow a controlled evolution, with sufficiently long stability periods to protect ongoing investments. Moreover, the System Pillar must ensure that its specifications lead to systems that support future evolution, enabling streamlined and cost-efficient upgrades rather than designs lacking updateability and upgradeability both in functionality and data engineering.

To prevent fragmented implementation. Pre-deployment coordination ensures all Member States can deploy standardised solutions according to the specifications on reasonably synchronized schedules as much as possible (and if required, adaption of the legacy environment). Economic support for pre-deployment should only go to those projects that comply with the system specifications and procedures for validation agreed following the reformed System Pillar. When deployment occurs simultaneously across borders rather than sequentially within national territories, economies of scale for rolling stock operators improve dramatically, as a locomotive equipped for international operation can be manufactured and authorized once rather than requiring country-specific adaptations. It is to note that this only happens when the cross border includes at least the first relevant node of each of the cross-border countries. In fact, the reformed System Pillar prepares the ground for coordinated deployment plans, which will be handled through the High-Level Deployment Group.

To prevent product unavailability. Supply industry frequently cannot deliver products matching deployment schedules because demand is fragmented across different baselines and national variants, and the business case for industrial production remained uncertain. The reformed System Pillar prevents this failure by providing the supply industry with standardised system specifications and industrialised deployment and authorisation procedures early enough to complete product development, establish manufacturing processes, and build production capacity before deployment schedules require delivery.

To prevent authorisation bottlenecks. deployment repeatedly encountered delays when authorisation bodies (ERA, NSAs, NoBos and AsBos) discover that specifications or products did not meet safety requirements, that testing procedures had not been defined, or that cross-border authorisation procedures had not been established. These discoveries often occurred during last phases of deployment rather than during specification development because authorisation processes were not included in validation. The reformed System Pillar may prevent this failure by defining the future required authorisation processes for the specifications and systems delivered therewith. Focus should be placed on defining streamlined and industrialised procedures for designing, engineering, deploying, validating, authorising and maintaining projects in a standardised manner, enabling a common approach to system deployment and authorisation through processes developed in parallel with the system specifications.

Fundamentally, this requires a shift from project-specific authorisations toward an EU-wide approach based on the authorisation of standardised building blocks with cross-acceptance across Member States[26].

Together, these four preventive functions address the core dysfunction in deployment with the objective to reduce costs. This is not incremental improvement but structural reform of how European railway standardisation functions.

System Pillar to High-Level Deployment Group: Interface with binding commitments

The System Pillar's coordination of pre-deployment will strengthen its existing structural connection with the High-Level Deployment Group. The management of latter should also be reinforced by Europe’s Rail, supported by the European Commission and its role as forum for coordinating pan-European deployment planning be fully endorsed by the sector.

The relationship between these two groups requires clear division of responsibilities to prevent the coordination failures that undermined ERTMS and TMS/CMS. While the System Pillar delivers deployment-ready specifications, the High-Level Deployment Group coordinates deployment of these specifications, ensuring Infrastructure Managers and Railway Undertakings can work - also with the relevant national authorities - to implement aligned deployment plans. Whenever relevant, this coordination prevents the fragmentation that occurs when each Member State deploys independently on different schedules with national variations. The coordination must recognize that migration dates will vary and be project-specific, highly dependent on system lifecycle management, but aligned deployment plans

[26] Where project-specific authorisation remains necessary, digital tooling should be deployed to industrialise and accelerate the process, reducing it to a verification of correct integration of pre-authorised components rather than a full re-assessment of the system at each deployment.

ensure that national variations in timing do not undermine interoperability or fragment specifications.

The System Pillar and High-Level Deployment Group should operate through formal governance mechanisms organised within Europe's Rail, also involving the European Commission, the ERTMS Coordinator and the Agency, and designed explicitly to prevent the coordination failures that undermined ERTMS deployment.

However, these mechanisms cannot rely on voluntary cooperation or informal coordination; they require upfront binding commitments.

The first commitment: develop joint work programmes that - on the basis of the users requirements - establish which specifications will be prioritised when and which deployment milestones depend on these specifications. Joint work programmes create formal dependencies between System Pillar deliverables and Deployment Group milestones, preventing situations where deployment schedules are set independently of specification readiness. The work programme makes explicit which Member State deployment plans depend on which specifications, enabling early identification of conflicts between national schedules and specification delivery timelines.

The second commitment: agree on a synchronized timeline planning that ensures pre-deployment validation completes before deployment begins. Synchronized planning requires that when the System Pillar identifies delays in specification validation, the Deployment Group automatically adjusts pre-deployment schedules accordingly.

The third commitment: active stakeholder representation ensures that stakeholders with implementation responsibility are adequately represented in both System Pillar specification development and Deployment Group coordination. The precise form and intensity of stakeholder involvement should be proportionate to the maturity of the work: for mature products approaching deployment, structured participation of Infrastructure Managers, Railway Undertakings, supply industry, and ERA/NSAs in both forums is essential to close the gap between what specifications promise and what deployment can deliver. For specifications still under development, lighter and more flexible coordination mechanisms should be used to avoid overburdening the process with contractual and project management complexity that would slow rather than accelerate progress. The key principle is that no specification should reach the deployment stage without the operational, industrial, and authorisation perspectives having been adequately tested — but the means of achieving this must remain manageable.

The fourth commitment: establish a clear and simple escalation procedure when national deviations threaten coordinated deployment. The procedure should provide a direct pathway (without unnecessary procedural layers) for resolving conflicts at political level through European Commission intervention when coordination fails at the stakeholder level. The purpose is not to micromanage technical decisions but to enforce the political commitment to coordinated deployment that Member States accept when adopting TEN-T regulations and TSI requirements. The escalation mechanism should be kept lean and workable: overly elaborate governance procedures risk becoming an obstacle in themselves, particularly during the development phase when specifications are still evolving and flexibility is needed.

2nd VISION: Accelerating relevant EULYNX Implementation through Standardisation and Targeted European Support.

The Challenge: Infrastructure Managers at a Critical Juncture

While the reformed System Pillar works toward delivering deployment-ready specifications for the future harmonised CCS+ system, Infrastructure Managers face an immediate operational reality that cannot wait. The mandatory deployment of radio-based ETCS across the TEN-T network, as set out in EU legislation, goes hand in hand with the introduction of digital interlocking technology. Together, these developments represent the most capital-intensive transformation of command, control and signalling systems in European railway history.

Yet they must proceed now, within the very context of non-standardisation that drives costs beyond the net present value of migration.

At the heart of this challenge lies a fundamental question: which specifications should Infrastructure Managers use today for brownfield projects to ensure that their installations are future-proof and aligned with the target architecture that the System Pillar will define? The answer to this question will determine not only the cost-efficiency of the current investment cycle, but also the capacity of the European rail network to converge gradually, through intermediate migration targets, toward the truly harmonised CCS+ architecture that Europe needs.

The Promise and the Gap: Europe's Rail Joint Undertaking's Specifications for CCS+

Europe's Rail Joint Undertaking (ERJU) has been mandated to deliver the specifications for the future harmonised CCS+ system, designed to work in conjunction with harmonised operational rules. The ambition remains valid and necessary. Building on the outcomes from ERJU System Pillar, the measure of success should no longer be the delivery of a complete and exhaustive specification set within a fixed timeframe, but rather the quality, stability, and operational readiness of each specification module as it becomes available, and the ability to apply it step by step in real deployment conditions.

This shift in emphasis matters. Historically, the pressure for comprehensive upfront specifications has contributed to instability, late-stage revisions, and ultimately to the billions of euros in additional costs that have plagued ERTMS deployment. A more effective approach would focus on progressive validation under operational conditions, ensuring that each layer of the CCS+ specification is sufficiently mature before it is used as the basis for procurement, and that the System Pillar retains a central role in validating and endorsing each step of that process.

The Urgency for action and safeguard of IMs investments: focusing on the interfaces between "central equipment" and "field elements"

Despite the absence of a complete and mature set of CCS+ specifications, Infrastructure Managers cannot afford to delay action. Signalling systems across Europe are ageing, and the regulatory obligations stemming from the revised TEN-T Regulation impose clear timelines for ETCS deployment. Infrastructure Managers are therefore compelled to launch calls for tender today, making the best possible choices based on the specifications currently available.

In practice, this means that Infrastructure Managers are largely obliged to fall back on national specifications rooted in legacy systems, a situation that directly perpetuates the fragmented implementation that the reformed System Pillar is designed to overcome. Each procurement based on national specifications risks locking in another 20 to 30 years of non-standardisation, given the high expected lifetime of railway systems and individual products.

In this context, safeguarding the investments made today becomes an absolute priority. Every CCS installation realised in the current period must follow a modular design, so that the harmonised operational rules to be delivered by ERJU can subsequently be integrated through targeted adaptations of the relevant components, rather than through replacement of the system as a whole. This is the principle of modular design applied at its most critical juncture: enabling Infrastructure Managers to proceed with brownfield projects (i.e.: changing only parts of the overall system rather than requiring complete CCS replacement) while ensuring continuity between today's deployments and the technological evolutions to come.

This investment protection imperative places particular emphasis on the interface between "central equipment" and "field elements". The outside CCS installation, together with the CCS field elements, represents the most capital-intensive and long-lived part of a CCS renewal (Mainly because it also requires a lot of work to be done along the tracks in difficult circumstances, like laying cables, creating housings etc., while keeping the current CCS system operational)

It is therefore crucial that the choices made today for these interfaces rest on stable, well-defined boundaries, so that future developments can build upon them without calling current installations into question. Even as the central equipment evolves over time in line with the maturing CCS+ specifications, the outside CCS installation and field elements should remain unchanged, avoiding costly rework and stranded assets. When interfaces are standardised and modular, Infrastructure Managers can replace aging central interlocking equipment without replacing the entire signalling system. Hence, transforming migration from an unrealistic "big bang" replacement into an economically viable asset management strategy with intermediate migration targets on the path toward the final target architecture.

EULYNX: A Mature Foundation Already in Place

This is precisely where the EULYNX initiative offers a credible and already well-advanced solution. EULYNX has delivered a comprehensive interface specification for the connection between central equipment and field elements, which has also been published by the Europe's Rail Joint Undertaking.

Critically, this interface specification is not a first draft or a theoretical exercise. It is the result of several Plan-Do-Check-Act (PDCA) cycles: the specifications have evolved over time to address problems encountered during pilot implementations and early deployment on operational networks. This iterative process of refinement (precisely the kind of pre-deployment validation under operational conditions that the reformed System Pillar envisions as standard practice) means that the EULYNX interface specifications can be considered quite mature and stable.

If the European rail sector wants to move ahead with harmonised deployment while waiting for the full EU-Rail CCS+ specification package, the EULYNX interface specification is the

natural and logical choice, as the most readily available building block for the modular, standardised architecture that the sector needs.

The remaining obstacles: why full standardisation is not yet achieved

However, the current state of EULYNX implementation reveals a number of persistent obstacles that mirror, at the interface level, the broader failures visible in ERTMS deployment:

1. National variants remain prevalent replicating the fragmented implementation. Despite the existence of a harmonised core specification, national flavours continue to exist within EULYNX implementations. Individual projects are still deviating from the harmonised part of the specifications to accommodate national requirements or preferences or adapting the harmonised specification to the non-harmonised legacy environment. This is the main complaint from the supply industry, which rightly observes that there is no such thing as a truly harmonised standard as long as national variants persist. National variants block the ability to harmonise products, to demonstrate full product compliance with the specifications and to achieve genuine product interchangeability between different suppliers. This fragmentation reproduces, at the level of field element interfaces, exactly the dysfunction of non-standardisation that has driven ERTMS costs to €74–111 billion for an outcome that delivers less interoperability than a truly standardised system would provide.
2. Interchangeability is not yet demonstrated limiting industrial production. Although first attempts have been made within EULYNX to manage variability through a limited number of configurable parameters, full interchangeability between products from different EULYNX-compliant suppliers has not yet been achieved or demonstrated in practice. Without demonstrated interchangeability, the supply industry cannot move from engineering project-by-project prototypes to industrial production at the scale and cost efficiency required for European-wide deployment.
3. Availability of fully compliant products is not ensured perpetuating product unavailability. The supply chain has not yet reached the point where fully EULYNX-compliant products are readily and reliably available commercially of the shelf on the market. This echoes the broader model in ERTMS deployment where the supply industry frequently cannot deliver products matching deployment schedules because demand is fragmented with national variants.
4. The standard is not yet managed as a true open standard lacking transparent governance. For EULYNX to fulfil its role as a European sector reference, it must be openly and freely available to all market participants, including non-members. The further evolution of the specification must follow a transparent Change Control Management (CCM) process, open to broader stakeholder participation and guided by criteria that reflect the needs of the entire sector. This transparent governance is essential: without it, the risk persists that lobbying fragments specifications through demands for optional national parameters or implementation variations.

The EIM way forward: a two-step path towards full standardisation

EIM proposes a structured and inclusive approach to overcome these obstacles and accelerate the transition of EULYNX from a collaborative initiative to a recognised and effective European standard.

This approach is complementary to and consistent with the reformed System Pillar process: while the System Pillar drives the development of the full CCS+ target architecture, the EULYNX standardisation path secures the investments being made today and ensures that current brownfield installations are already aligned with the principles of modular, standardised design.

Step 1: Joint analysis of national variants

EIM calls on Europe's Rail, Infrastructure Managers and the EULYNX community to cooperate in a thorough and transparent analysis of the reasons behind the existing national variants that currently prevent full standardisation.

The analysis should be conducted with a clear methodological distinction between two categories of variants: on the one hand, variants that reflect genuine operational or maintenance needs, including differences in operating concepts, maintenance regimes and infrastructure characteristics that are rooted in real-world constraints, which may need to be integrated into the harmonised specification through tightly governed configurable parameters and, on the other hand, variants that merely preserve national habits without a demonstrable operational justification, which should be phased out.

This distinction is essential for the credibility of the exercise. It allows the sector to remain both ambitious in its pursuit of genuine standardisation and realistic about the constraints under which Infrastructure Managers actually operate.

This analysis should also distinguish between two categories:

- Must-have requirements. Where a national variant reflects a functionality that is genuinely indispensable for safe and efficient operations but is not currently foreseen in the EULYNX specifications, the question must be asked: why is it not there? Such functionalities should be examined with a view to incorporating them into the harmonised specification, where appropriate, through the use of configurable parameters that can accommodate legitimate operational diversity without breaking the standard. The principle is clear: Infrastructure Managers should commit to not accommodating national variations at the interface level through optional parameters or national implementation chapters.
- Nice-to-have requirements. Where a national variant reflects a functionality that is desirable but not strictly essential, a rigorous assessment of the business case at European level must be conducted. Is there a sound justification for adding this functionality in a harmonised way in the same interface specification, or is it more logical to write possible national needs in a separate specification that will lead to other end-to-end components? An honest debate on goals and means of any national variant is necessary, distinguishing between what genuinely adds value at system level and what merely preserves national habits. The experience with ERTMS demonstrates that accommodating national preferences without rigorous justification is precisely the mechanism through which non-standardisation multiplies costs and prevents interoperability.

Step 2: Structured process within the system pillar towards a recognised standard

Building on the conclusions of the first step, EIM envisages the following process:

1. Endorsement by the System Pillar Steering Group. The recommendations resulting from the joint analysis should be formally endorsed by the SP Steering Group, providing a clear mandate for the next phase and ensuring alignment with the broader CCS+ architecture under development.
2. Mandate to EULYNX. On this basis, EULYNX receives a mandate from the sector, through the System Pillar of Europe's Rail, to complete and/or review the specifications within an agreed timeframe, addressing the identified gaps and eliminating unjustified national variants. This mandate must come with stable requirements: specifications evolve during this review phase, but once the review completes, specifications should remain essentially frozen to allow the supply industry sufficient lead time to develop industrial products.
3. Approval of the deliverable. The resulting specifications are submitted for approval by the System Pillar Steering Group, ensuring sector-wide endorsement and legitimacy.
4. Determination of the type of standard. A decision must be taken on the nature of the standard, i.e.: mandatory or voluntary, based on the assumption that the EULYNX specifications can be applied by every Infrastructure Manager and that the assessment has been conducted across all relevant interfaces.
5. Publication under EU-Rail. The specifications will be published under the name of Europe's Rail and should include legal provisions specifying that users cannot claim compliance with these specifications if they have been modified nationally. In other words: the right to apply the standard is granted, but not the right to change it. This approach serves a dual purpose: it protects the integrity of the standard while avoiding the need to mandate the compulsory use of EULYNX, instead relying on the intrinsic value and market logic of a truly harmonised specification. This principle directly addresses the issue whereby national deviations fragment deployment: when claiming compliance requires full adherence to the specification, the economic incentive shifts decisively toward genuine standardisation.
6. Manufacturer compliance. Manufacturers will be required to ensure that the specifications have been fully implemented. One practical mechanism for this could be a self-declaration of conformity, providing transparency to procuring Infrastructure Managers while keeping the compliance process proportionate. This mechanism should be coordinated with ERA to ensure coherence with broader authorisation pathways and to prevent the authorisation bottlenecks that have repeatedly delayed ERTMS deployment.

Ensuring transparency, inclusiveness, and sector coordination

This entire approach must be underpinned by a transparent and inclusive process, consistent with the governance principles established for the reformed System Pillar and the High-Level Deployment Group.

EIM commits to:

1. Engaging with the High-Level Deployment Group on a dedicated discussion on how to foster the adoption of the revised EULYNX standards as a concrete lever for cost reduction. The logic is compelling: the required realisation of radio-based ETCS on the TEN-T network goes hand in hand with digital interlocking, and the standardisation of the interface between central equipment and field elements is the single most impactful step that Infrastructure Managers can take today to reduce lifecycle costs and protect

investments, while the broader pre-deployment coordination under the System Pillar matures.

2. Coordinating with other relevant associations within the System Pillar Steering Group and the High-Level Deployment Group, to ensure that the positions of Infrastructure Managers are aligned. Active stakeholder representation is also essential to narrowing the gap between what specifications promise and what deployment can deliver.
3. Establishing escalation clarity. When national deviations from the EULYNX standard threaten to undermine harmonisation, the same escalation procedures envisaged for the broader System Pillar–Deployment Group interface should apply. This includes European Commission intervention when coordination fails at the stakeholder level, ensuring that the political commitment to standardisation is upheld.

Other outstanding considerations

A number of additional elements require further analysis and discussion to ensure the robustness and completeness of this approach:

- Change Control Management (CCM) process for the remaining variability. While the vast majority of the EULYNX specification can be considered harmonised, a targeted CCM process must be established for the remaining portion (estimated at around 10%) where variability persists. This CCM process must follow the principles of formal functional system architecture methodology: clear processes for requirements management, change control and version management, with defined criteria for who can request specification changes and under what circumstances.
- Preventing unilateral national modifications. The processes governing the use of the standard must be reviewed to identify mechanisms (including, if necessary, certification-based approaches) that make it effectively impossible for companies to unilaterally modify the specifications while still claiming compliance with the standard. This is the interface-level expression of the broader principle that Infrastructure Managers should commit to not accommodating national variations at the architecture level.

The building blocks for the EULYNX path are already in place: mature specifications, operational experience, and sector-wide recognition of the interface between central equipment and field elements as the decisive point for investment protection. What is needed now is the collective will to take the next step to analyse the reasons behind national variants, to decide on the path to a recognised standard, and to act together with the determination that the scale of the challenge demands.

V. CONCLUSIONS: TIME TO ACT

The evidence assembled in this strategy paper points to a single, inescapable conclusion: the economic burden of non-standardisation in European railways is not a legacy problem that time will gradually resolve. It is an active, compounding cost that grows with every procurement cycle conducted under fragmented national specifications with lack of industrialisation. Every ‘black box integrated’ signalling system tendered today without standardised interfaces locks in 20 to 30 years of vendor dependency, limited competition, and foreclosed migration options. The longer the sector delays, the higher the cumulative cost of eventual convergence.

The diagnosis is now well established and widely shared. The Copenhagen High-Level Event confirmed that the consensus extends from Infrastructure Managers and Railway Undertakings to the European Commission, ERA, and the supply industry: the status quo is unsustainable. Rising costs, technical fragmentation and slow deployment have created a negative spiral that undermines rail's competitiveness and jeopardises the return on billions of euros already invested. Yet diagnosis without action is merely documentation of decline.

In EIM view, the proposal of reformed System Pillar and EULYNX standardisation represent two complementary responses to the same fundamental problem: the economic burden of non-standardisation and industrialisation in European railways.

EIM therefore calls for decisive and coordinated movement on both fronts of its vision.

On the System Pillar, the sector and the European Commission must seize the opportunity of the next Multiannual Financial Framework to establish a reformed EU-Rail Joint Undertaking that concentrates pre-deployment investment on the few strategically essential CCS projects where non-standardisation currently multiplies costs. The System Pillar must evolve from generic system integration to become the “Coordinator” that delivers stable, operationally validated, implementation-ready specifications, with mandatory open interfaces between system components as the essential precondition for breaking the vendor lock-in that remains the primary structural driver of unaffordable lifecycle costs. Furthermore, the interface with the High-Level Deployment Group must be underpinned by binding commitments, not voluntary coordination. The failures that have plagued ERTMS deployment: customer specific specification add-ons, fragmented implementation, product unavailability, authorisation bottlenecks, and persistent vendor lock-in are not inevitable; they are the predictable consequences of a process that lacked the structural safeguards this paper proposes: stable specifications before deployment, open interfaces preventing proprietary capture, industrialised authorisation and binding coordination between specification and deployment planning.

On EULYNX, the sector cannot afford to treat the standardisation of field element interfaces as a long-term aspiration. It is an immediate necessity. The building blocks are already in place: mature specifications refined through multiple PDCA cycles, operational experience from pilot deployments and sector-wide recognition that the interface between central equipment and field elements is the decisive point for investment protection. What is missing is the collective commitment to close the last mile, i.e.: to analyse and resolve the national variants that fragment implementation, to publish the specifications as a genuine European standard under EU-RAIL with protections against unilateral national modification and to create the conditions for the supply industry to deliver fully compliant, interchangeable products at industrial scale.

These two streams are complementary and mutually reinforcing. The System Pillar defines the target architecture and ensures that future specifications are deployment-ready; the EULYNX path ensures that Infrastructure Managers investing today are already aligned with the upcoming principles of modular, standardised design, protecting their assets against obsolescence and preparing the ground for gradual migration toward the full CCS+ system. Together, they offer the European rail sector a credible and realistic path out of the non-standardisation trap.

EIM calls on all stakeholders: Infrastructure Managers, Railway Undertakings, the supply industry, ERA, the European Commission, and Member States, to move from shared diagnosis to shared action. The governance mechanisms proposed in this paper, such as binding commitments, escalation procedures, transparent specification management and compliance enforcement are not bureaucratic additions; they are the structural conditions without which European railway standardisation will continue to produce fragmented results at inflated costs.

Finally, this call to action must be accompanied by an explicit commitment to those who have already moved. Member States, Infrastructure Managers and Railway Undertakings that have invested early and at scale in ERTMS should not bear disproportionate costs for having acted in good faith on earlier specifications. Every harmonisation step proposed in this paper - the reformed System Pillar, the accelerated completion of EULYNX, the governance of specification evolution, the design of pre-deployment and the shape of the next MFF funding instruments, must be tested against a simple question: does it protect, rather than penalise, the substantial investments already made? Harmonisation and investment protection are not competing objectives. They are two sides of the same commitment to a coherent, industrial, and financially sustainable European railway system.

The time for analysis is over. The time to act is now.