Autonomous and Self-organized Artificial Intelligent Orchestrator for a Greener Industry 4.0

White Paper

TALON's Standardisation Activities

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Table of Contents

List of Figures

List of Tables

Definitions and acronyms

AI	*Artificial Intelligence*
AR	*Augmented Reality*
CNCF	*Cloud Natice Computing Foundation*
CNI	*Computer Network Interface*
CNN	*Convolutional Neural Network*
CPU	*Central Processing Unit*
DT	*Digital Twin*
E2C	*Edge-to-Cloud*
eBPF	*Extended Berkeley Packet Filter*
Eigen-CAM	*Eigen Class Activation Mapping*
GDPR	*General Data Protection Regulation*
GPU	*Graphics Processing Unit*
HIL	*Human in the Loop*
IPFS	*InterPlanetary File System*
LOF	*Local Outlier Factor*
LSTM	*Long Short-Term Memory*
MDE	*Model Driven Engineering*
MTTR	*Mean Time To Repair*
RAM	*Random Access Memory*
REST API	*Representational State Transfer Application Interface*
SDN	*Software-Defined Networking*
SDO	*Standards Development Organisation*
SHAP	*SHapley Additive exPlanations*
SLAM	*Simultaneous Localisation and Mapping*
SysML	*Systems Modelling Language*
TrL	*Trust Level*
TRL	*Technology Readiness Level*
UML	*Unified Modelling Language*
VR	*Virtual Reality*
XAI	*Explainable Articial Intelligence*
XR	*Extended Reality*

Disclaimer

Executive Summary

This white paper outlines the standardization prospects in connection with project TALON—**Autonomous and Self-organized Artificial Intelligent Orchestrator for a Greener Industry 4.0**—under Horizon Europe. As a core component of Work Package 6 (WP6), these efforts aim to ensure that TALON's key technological outcomes are aligned with and contribute to the evolving landscape of international standards. The document provides a comprehensive overview of the project's relevant innovations in Explainable AI (XAI), immersive AR/VR systems, Edge-to-Cloud (E2C) AI orchestration, and blockchain-based AI model governance. It further details the multi-phase strategy adopted to translate these outcomes into actionable contributions to standards development organizations such as IEEE, ISO/IEC, and CEN-CENELEC.

The standardization pathway includes strategic alignment with technical committees, structured engagement methodologies, risk mitigation approaches, and an emphasis on openness, transparency, and sustainability. Result-specific strategies are mapped to existing and emerging standards, ensuring technical compatibility and fostering future interoperability across industrial systems. Ultimately, this white paper aims to serve both as a technical reference and a roadmap to support TALON's broader vision of contributing to the foundations of a sustainable and intelligent Industry 5.0.

1 Introduction

1.1 Objectives of the White Paper

The objective of this white paper is to provide a consolidated view of TALON's contributions to the international standardization landscape, with a specific focus on the technological innovations developed within the project's framework. It aims to:

- Present the standardization potential of TALON's key results, namely the XAI framework, AR/VR systems, AI E2C Orchestrator, and Blockchain.
- Outline the strategic and procedural approach adopted to engage with relevant standard development organizations.
- Identify the alignment of TALON outputs with specific standards bodies, working groups, and ongoing specifications.
- Define the implementation strategy and expected impact of these standardization efforts on industrial automation ecosystems.

By achieving these objectives, the white paper aims to support stakeholders, both within and outside the TALON consortium, in understanding the project's standardization roadmap, its technological maturity, and its role in shaping future industry norms.

1.2 Document Structure

The structure of this document is organized in a clear and concise way, to cover essentially the core points of TALON's standardisation vision.

Therefore, following this introductory section,

- **Section 2** presents an overview of the TALON project, including its architectural approach and overall objectives.
- **Section 3** details the project's relevant technological outputs and their respective standardization strategies. This includes a breakdown of result-specific contributions, alignment with standards bodies, and a five-phase standardization pathway.
- **Section 4** provides the conclusions, summarizing the expected impact of the standardization work.
- Finally, **Section 5** contains references to relevant literature, standards, and supporting documentation.

2 About TALON

2.1 TALON's approach

The diverse range of services, applications, and use cases expected in Industry 5.0 calls for a flexible, programmable, and adaptable AI architecture that optimizes the interplay between edge and cloud AI to boost overall system efficiency. To meet this challenge, TALON presents an AI orchestrator aimed at turning Industry 5.0 into an intelligent, automated platform by capitalizing on edge network advancements and embedding intelligence close to sensors in resource-limited embedded systems with constrained computational, storage, and communication capacities, while incorporating advanced, adaptive sensors and perception.

In this framework, TALON's AI orchestrator enhances both collective and individual user and system performance while respecting each application's design constraints. It achieves this by choosing AI datasets, algorithms, metrics, and models specific to each application. This leads to an innovative system architecture that maximizes efficiency by:

- jointly optimizing edge and cloud resources,
- enabling centralized, distributed, and hybrid intelligence,
- transforming the AI network into a low-power computing system that leverages underutilized commercial and business resources.

Furthermore, by adopting a holistic optimization approach and utilizing blockchain advancements, TALON supports end-to-end personalized and ongoing security and privacy. To address the distinctive features of the TALON architecture, driven by novel components such as the AI orchestrator, blockchain, edge networking, and digital twins, a new experimentally validated theoretical framework will be introduced.

2.2 TALON objectives

Overall, TALON aims at sculpturing the road towards the next industrial revolution by developing a fully-automated AI architecture capable of bringing intelligence near the edge in a flexible, adaptable, explainable, energy and data efficient manner.

TALON's vision is in practice translated in 4 pillars that consolidate the directions described above:

Pillar I: **AI orchestrator for autonomous and dynamic scalability as well as greener AI networks** to enhance resources coordination of infrastructures with different computational and communication resources; thus, significantly reduce the energy consumption.

Pillar II: ***Distributed blockchain for high-security, privacy and trust in a heterogeneous application environment*** *to transform I5.0 into intelligent platforms and introduce new service models and use cases.*

Pillar III: **Flexible E2C deployment for "almost-zero latency" and high-computational capabilities near sensors**, by means of personalized caching, task offloading, AI models placements and distributed as well as TL.

Pillar IV: **DTs and HIL to boost AI explainability, trust-worthiness and transparency** by visualizing and involving the human into the decision-making process and decisively reduce the learning latency by combining TL approaches with DTs.

A number of matching individual objectives to be pursued, accompanies the 4 broad pillars, as shown in the table below.

Table 1: TALON's vision and objectives

Vision	**Objective ref.**	**Objective description**
Pillar 1	O-1	To enable zero-touch deployment and operation
	O-2	To reduce the energy footprint of the whole AI network
Pillar 2	O-3	To guarantee high-level security and privacy in heterogeneous application environments
Pillar 3	O-4	To efficiently assess and boost the AI E2C performance
	O-5	To enable reusability of datasets, algorithms, metrics and models
Pillar 4	O-6	To present AI theoretical framework
	O-7	To boost the explainability and transparency of the AI approaches

3 Standardization activities

3.1 Relevant TALON results

3.1.1 R1 – XAI

The TALON project implements an Explainable AI (XAI) framework structured across 4 Trust Levels (TrLs), designed to improve transparency and trustworthiness throughout the entire AI pipeline in edge-based industrial systems, as in Figure 1. This hierarchical approach addresses explainability from raw data validation through adversarial testing of AI decisions, ensuring transparency for industrial applications where understanding AI behavior is critical for operational safety and efficiency.

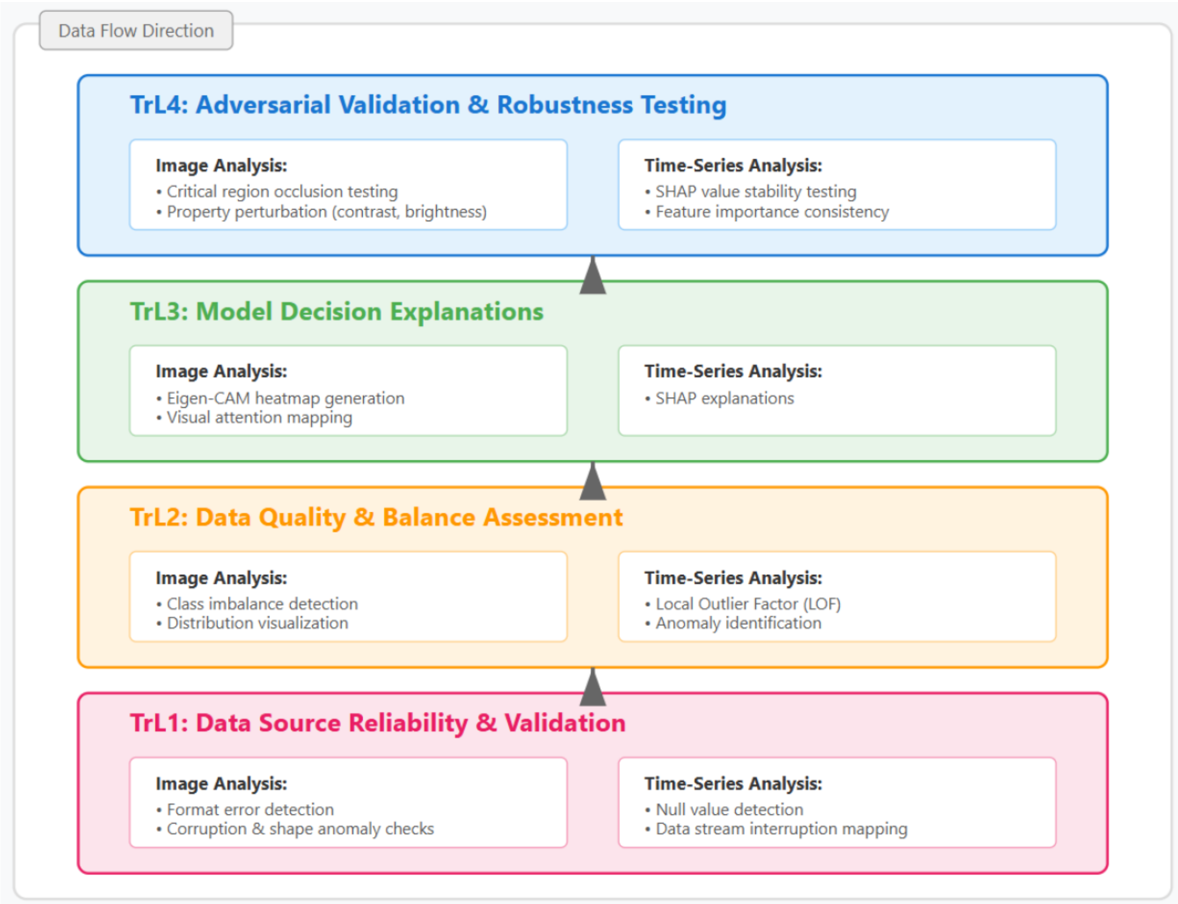

Figure 1: XAI Trust Levels Framework

TrL1 forms the foundation of TALON's XAI framework by analyzing and validating the reliability of data sources. For image data, the system detects inconsistencies including formatting errors, corrupted files and shape anomalies that could compromise dataset integrity. For time-series data, TrL1 identifies null values and interruptions in data streams. The system generates time-series visualisations highlighting missing data points, enabling operators to identify patterns in data loss that might indicate systematic issues. Building upon those data, TrL2 addresses data quality issues that impact AI model performance. For image tasks, the system detects class imbalances that could lead to biased model training. For time-series data, TrL2 employs the Local Outlier Factor (LOF) algorithm to identify anomalous data points. The LOF implementation calculates local reachability density for each data point, comparing it with neighboring points to detect outliers that could distort model training *[1]*. TrL2 outputs include interactive visualizations showing class distributions for images and outlier locations for time-series. TrL3 provides interpretability for AI model decisions across both computer vision and time-series forecasting tasks. For image-based applications, TrL3 implements Eigen-CAM (Eigen Class Activation Mapping), which uses Principal Component Analysis to generate visualization heatmaps highlighting image regions most influential to the model's decisions *[2]*. For time-series analysis, TrL3 employs SHAP (SHapley Additive exPlanations) for highlighting feature importance *[3]*. Finally, TrL4 represents the most advanced trust level, performing adversarial validation to ensure the reliability and consistency of XAI explanations themselves. For image-based explanations, TrL4 systematically occludes critical regions with human-in-the-loop, verifying that model confidence appropriately decreases when important features are hidden—mimicking human visual reasoning. Additionally, TrL4 perturbs image properties including orientation, contrast, and brightness to assess whether explanations remain consistent under minor variations that shouldn't affect fundamental object recognition. For time-series explanations, TrL4 applies similar robustness testing to SHAP values, ensuring that feature importance rankings remain stable.

3.1.2 R2 – AR/VR

The TALON project also investigates the use of immersive technologies, including Virtual Reality (VR) and Augmented Reality (AR), to support intelligent, edge-based automation systems. As part of Task 5.5—focusing on AR/VR applications for training and maintenance—dedicated solutions are being developed to improve workforce preparedness, operational safety, and productivity. These applications utilise Extended Reality (XR) interfaces in conjunction with AI-driven support systems to deliver enhanced functionality.

The VR Training application provides a fully immersive simulation environment specifically designed for industrial training purposes. It allows users to interact with highly realistic virtual representations of factory settings and equipment, facilitating experiential learning in a risk-free environment. The system features intelligent tutoring capabilities, dynamically adjustable difficulty levels, and AI-powered performance analytics that monitor user actions and task execution. These features collectively deliver real-time feedback and in-depth learning insights, thereby accelerating the development of practical skills.

In alignment with Pillar III of the TALON project, which emphasises human-centric edge computing, the VR Training platform offers a safe, repeatable, and scalable training solution, while delegating computational workloads to edge-based AI systems. Its architecture supports compatibility with standard industrial communication protocols and is adaptable to specific use cases, such as robotic programming, emergency response simulations, or quality assurance processes. Crucially, this system also establishes a foundation for defining standardised metrics to assess both VR-based skill proficiency and the fidelity of simulated environments.

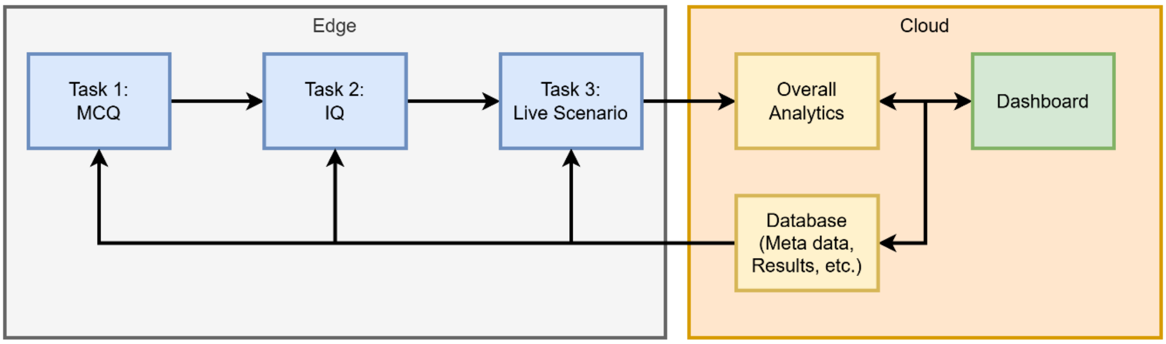

Figure 2: Overview of VR-based Training Application

The innovative strength of the VR Training application lies in its holistic integration of advanced methodologies specifically designed for industrial manufacturing environments. Distinct from traditional VR systems, it offers context-aware scenarios that accurately mirror real-world settings, enabling trainees to more effectively absorb operational procedures and safety protocols. The high-fidelity simulation not only enhances situational awareness but also incorporates adaptive feedback mechanisms that respond in real time to user interactions. A particularly notable innovation is the dynamic scenario adaptation approach, which personalises the training experience by responding to individual performance metrics and behavioural cues. Moreover, the use of natural, gesture-based controls and user-friendly interfaces reduces the learning curve, ensuring the system remains accessible to users with diverse levels of experience. The training is further enriched by an embedded scoring mechanism within interactive tasks, which promotes user engagement and supports continuous self-evaluation through goal-oriented progression and gamification techniques.

The AR Maintenance application, on the other hand, is designed to deliver real-time, on-site support to technicians engaged in maintaining complex industrial machinery. Through the use of head-mounted displays or mobile AR devices, the system overlays context-sensitive digital instructions, AI-driven diagnostics, and safety notifications directly onto the technician's physical workspace. Employing visual Simultaneous Localisation and Mapping (SLAM) in combination with edge-based AI inference, the application identifies machine components, tracks user movements, and dynamically adjusts guidance to match the current maintenance procedure.

In alignment with Pillar II of the TALON project, which focuses on enhancing the reliability and operational availability of edge AI systems, the AR Maintenance tool offers significant value in time-critical and high-risk industrial environments. For example, in the event of equipment failure, the application can propose diagnostic and troubleshooting steps informed by real-time data, such as visual sensor outputs, thereby reducing mean time to repair (MTTR) and supporting adherence to safety protocols.

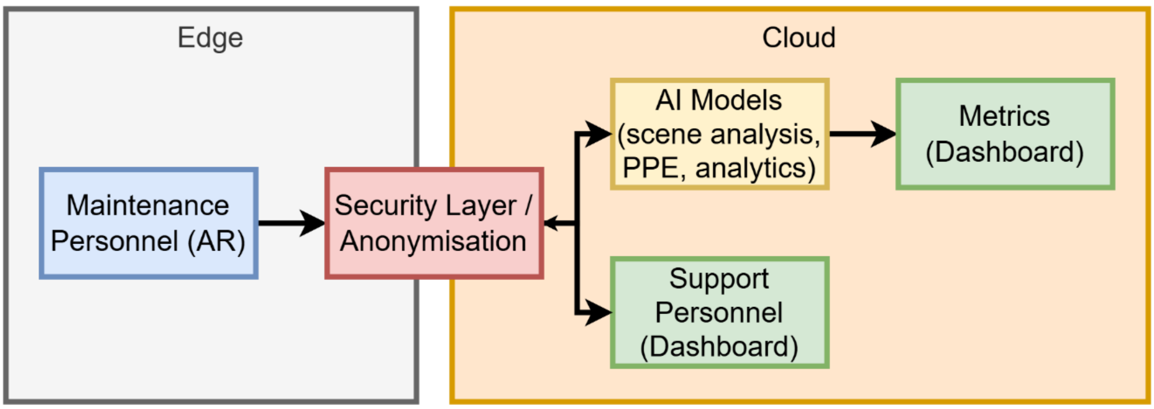

Figure 3: Overview of AR-based Maintenance Application

The distinctive innovation of the AR Maintenance application lies in its integration of advanced artificial intelligence techniques—most notably convolutional neural networks (CNNs)—with extended reality (XR) technologies to facilitate intelligent, context-aware remote maintenance. A core advancement is the implementation of hands-free interaction mechanisms, such as face tracking and target tracking, which enable users to engage with and control AR interfaces without the need for conventional input devices.

Building on this foundation, the system introduces AI-assisted motion control, which mitigates limitations associated with physical input methods and dynamically adjusts interactions to suit individual user preferences and requirements. Further differentiation is achieved through real-time object detection and the contextual overlay of maintenance information, delivering accurate, task-specific guidance as situations evolve.

In addition, the use of gesture-based commands, intelligent sequencing of tasks, and adaptable user interface elements ensures a smooth and efficient user experience. This integration of AI-enhanced interaction, intuitive control schemes, and dynamically delivered content marks a significant step forward compared to traditional AR maintenance solutions—substantially improving accessibility, usability, and operational performance within industrial settings.

3.1.3 R3 – AI E2C Orchestrator to optimise industry efficiency

The AI Edge-to-Cloud (E2C) Orchestrator is conceived as a unified platform that automates deployment, monitoring and optimisation of AI workloads across distributed industrial networks. By integrating zero-touch containerised deployments with a dynamic, policy-driven orchestration engine, the Orchestrator continuously adapts to fluctuations in compute, network and energy conditions without human intervention. Its real-time telemetry pipeline collects metrics on CPU, memory, bandwidth and power utilization, feeding multi-task LSTM-based forecasting models that drive placement, scaling and self-healing decisions. Built-in explainability and digital-twin visualisations ensure transparency of AI-driven actions, while distributed ledger technology secures model integrity and anomaly detection protects against malicious activities. Together, these capabilities reduce manual errors, minimise downtime and lower operational costs, enabling more resilient and energy-efficient industrial networks. See Figure 4 for a high-level architectural overview.

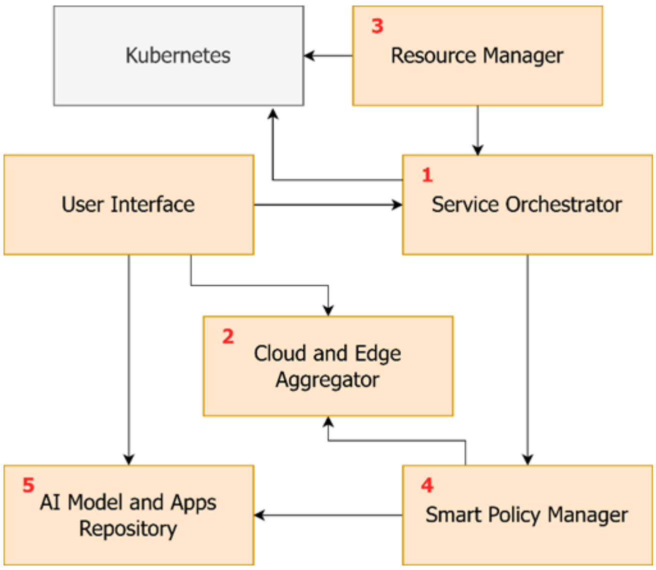

Figure 4: AI E2C high-level architectural overview

The TALON Edge-to-Cloud AI Orchestrator comprises five tightly integrated components that deliver end-to-end automation, telemetry-driven intelligence and energy-aware resource control. The Service Orchestrator(1) handles task lifecycle management, routing latency-sensitive functions to edge devices and offloading compute-intensive jobs to the cloud via Kubernetes' autoscaling and self-healing. Underpinning its decisions, the Cloud and Edge Aggregator (2) unifies metrics from Prometheus, InfluxDB and Kepler, feeding real-time CPU, memory, network and power data into multi-task LSTM-based forecasting models. Exposed through a lightweight REST API, the Resource Manager (3) then translates these predictions into scale-up, scale-down or offload actions. Parallel to this, the Smart Policy Manager (4) normalises accuracy, latency and energy profiles to select the optimal algorithmic implementation for each workload. Finally, the AI Model and Apps Repository(5) maintains versioned, validated artefacts—pre-trained models and application builds—ensuring they are instantly deployable across edge and cloud nodes. Together, these modules enable TALON's Orchestrator to achieve resilient, secure and energy-efficient AI service delivery throughout the edge-to-cloud continuum.

The AI E2C Orchestrator distinguishes itself through several innovations. First, it departs from static rule-based systems by employing multi-task LSTM networks to forecast resource and energy demands, triggering real-time policy updates that optimise both performance and efficiency. Furthermore, the Orchestrator ensures seamless management across the edge-to-cloud continuum by employing a next-generation SDN controller augmented with eBPF-enhanced CNIs—via Cilium integrated into Kube-OVN—to enforce high-throughput, low-latency connectivity for pods in heterogeneous environments . Energy efficiency is a core concern: real-time power telemetry from the Kepler framework, which uses eBPF probes to extract CPU, GPU and RAM consumption metrics into Prometheus and InfluxDB, is fed directly into scheduling decisions to minimise the platform's carbon footprint . Finally, to underpin trust and regulatory compliance, the Orchestrator embeds a lightweight permissioned Distributed Ledger Technology for federated model governance alongside dedicated XAI modules for decision transparency.

3.1.4 R4 – Blockchain

Blockchain technology is leveraged by TALON project to provide a secure, transparent and verifiable infrastructure to handle sensitive AI model training weights with efficiency (high performance) and without sacrificing excessive energy related resources (ram, cpu, kWh) *[4]*, *[5]*. To support this, a lightweight and modular blockchain explorer was developed based on Hyperledger Fabric networks, with a particular focus on edge deployments and industrial automation scenarios (i.e. TALON's Use Cases). The explorer enables real-time monitoring, querying, and tracing of blockchain activity, such as transactions, blocks and peer statuses by maintaining an off-chain indexed representation of on-chain events and data. As a result, efficient retrieval and visualisation of AI model algorithm weights in due time is possible for organisations inside TALON's network, while simultaneously preserving the authenticity of the ML models.

The explorer includes:

- A block and transaction indexer that listens to TALON's Fabric ledger and stores data in a relational database for fast querying.
- A live network discovery microservice to observe network and peer statuses.
- A client application that interacts with smart contracts.

The system supports various smart contract operations, including storing AI model metadata, execution logs and governance audit trails.

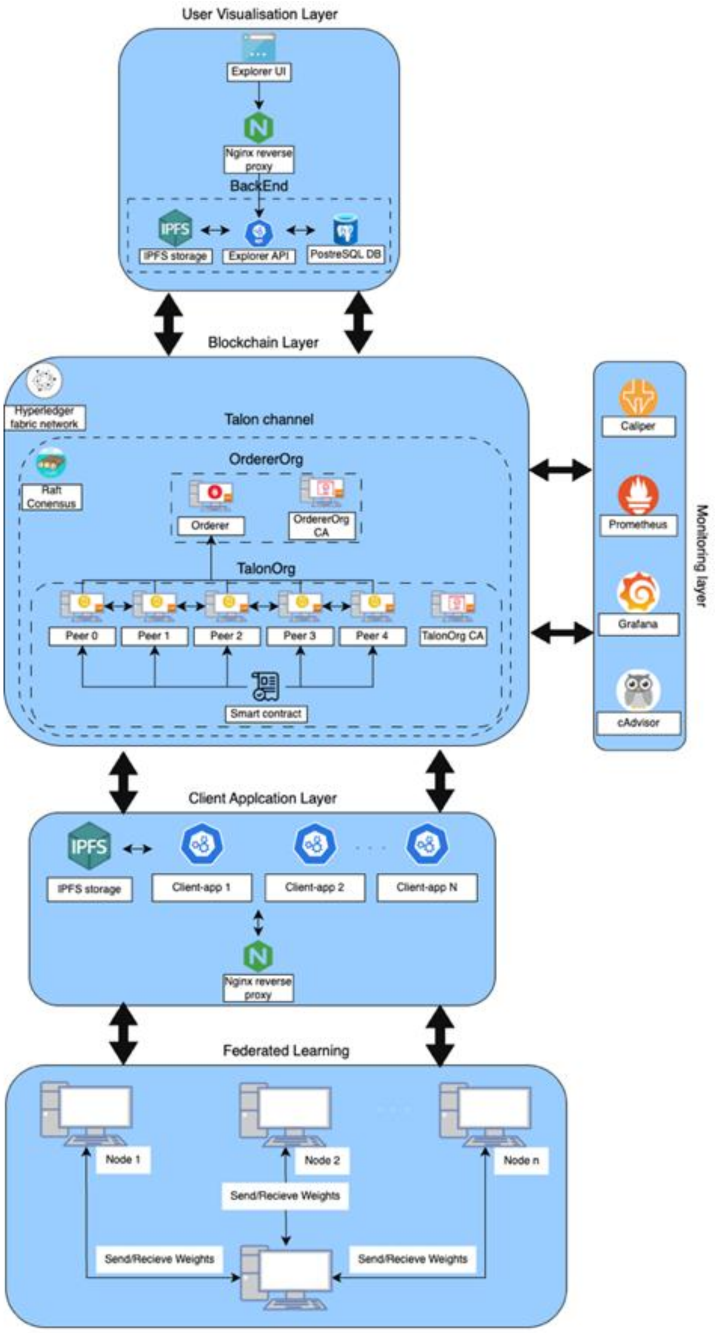

Figure 5: TALON's Blockchain ledger internal architecture

The novelty of this implementation lies in the modular, extensible design of the explorer and its specific tailoring for resource-constrained edge AI systems (a critical use case for TALON). Unlike traditional blockchain explorers that are resource-intensive and primarily built for public networks (e.g. Ethereum), our explorer is optimised for permissioned, enterprise-grade networks. It can use different types of data models and automatically find other systems to connect with. This helps build trust in real-time when multiple AI systems are working together. Moreover, the combination of Fabric-based recod system with decentralised IPFS data storage ensures both integrity and availability of critical model information, a unique feature in the context of federated AI governance.

3.2 Pathway to standardization

TALON's approach to standardization follows a systematic, multi-phase strategy that leverages the project's four key technological results to contribute meaningfully to existing and emerging standards. The pathway is designed to ensure that TALON's innovations not only advance the state-of-the-art but also provide practical, implementable frameworks that can be adopted across the broader Industry 4.0 ecosystem.

3.2.1 Strategic Alignment with Standards Bodies

TALON's standardization activities are strategically aligned with multiple international standards organizations to maximize impact and adoption:

- IEEE Standards Association: The project's XAI framework (R1) and AR/VR applications (R2) align directly with IEEE P2976 for XAI principles and IEEE 2048 AR/VR Working Group standards, respectively. TALON partners will contribute reference implementations and validation methodologies through IEEE working groups.
- ISO/IEC JTC 1: The AI E2C Orchestrator (R3) and blockchain explorer (R4) map to several ISO/IEC standards including ISO/IEC 23053 for ML system frameworks and ISO/TC 307 for blockchain technologies, accordingly. TALON partners will provide technical specifications and interoperability guidelines to these committees.
- CEN-CENELEC: The project's AI and AR/VR components align with CEN-CENELEC JTC 21 on Artificial Intelligence, particularly for object detection and decision explainability standards.

3.2.2 Multi-Phase Standardization Approach

TALON's standardization methodology embraces an all-encompassing five-phase procedure that adopts the principles of contemporary standardization frameworks and strives to translate them into a well-documented evaluation process. These frameworks include the ISO/IEC Directives, which were largely written by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), and the Institute of Electrical and Electronics Engineers (IEEE) Standards Development Lifecycle. In general, these well-known standardization frameworks tend to work quite well and produce agreeable governance results. However, there are cases, even well-known cases, where steering committees have failed to deliver useful standards after years of effort. So, what makes something work better than another? What tends to make some standardization committees succeed and others fail? Can we understand why certain technologies become standards while others fall by the wayside? Can we apply these to our situation and come up with a better standardization result?

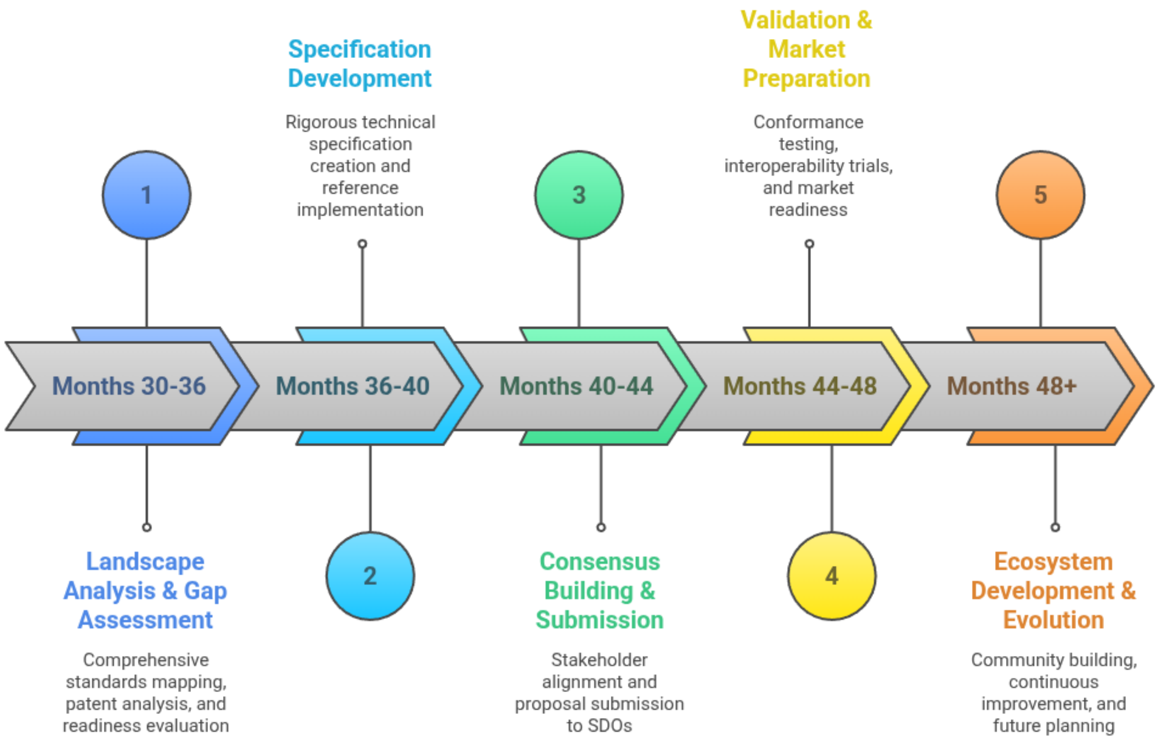

Figure 6: TALON's pathway to standardization

Phase 1: Standards Landscape Analysis and Gap Assessment (Months 30-36)

This preliminary phase uses the systematic methodologies of standards mapping and gap analysis to achieve a comprehensive understanding of the standardization ecosystem. TALON will accomplish this through several different but complementary activities. Initially, a detailed patent landscape analysis is conducted using advanced patent search methodologies to identify potential IP conflicts and opportunities for patent pooling arrangements.

The gap assessment uses the technology readiness assessment framework along with the technology readiness level (TRL) evaluation to determine the maturity of each technological component. For standardization, TALON will assess the potential economic and technical impact of proposed standards by incorporating market analysis, an evaluation of the competitive landscape, and technical feasibility studies.

In this phase, TALON will set up formal relationships with existing standard development organizations via SDO engagement. This requires participating in relevant working groups as observers, submitting liaison statements, and setting up formal communication channels. The phase ends with the creation of a comprehensive standardization roadmap that aligns with timelines for tech evolution and forecasts of market adoption.

Phase 2: Specification Development and Technical Foundation (Months 36-40)

The strict technical specification development methodology established by ISO/IEC and IEEE guides the specification development phase. TALON will use a model-driven engineering (MDE) approach to ensure that technical specifications are consistent, complete, and interoperable. MDE utilizes formal modelling languages such as the unified modelling language (UML) and systems modelling language (SysML) to create precise and unambiguous technical descriptions.

TALON components' architectures—reference or otherwise—cannot be established in a vacuum. They must cohere with an architectural vision, an architectural style, the rule set that governs the formation and interaction of components within the larger system to ensure that system meets desired quality attributes (e.g., performance, reliability, security) and that the components themselves behave in an optimal manner. In keeping with best practices in systems engineering, we have developed a set of guiding principles (the "what" and "how" of our architectural vision) that we wish our architectural styles (the means to realize our vision) to meet. We have also used these guiding principles to develop the reference architecture and the construction of its constituent components.

Phase 3: Consensus Building and Standardization Submission (Months 40-44)

This phase uses the advanced consensus-building techniques of the Delphi method and the nominal group technique, ensuring stakeholder alignment. TALON will apply a multi-stakeholder engagement framework to glean comprehensive representation across important sectors. The phase involves systematic stakeholder mapping and many analyses to identify key individuals and groups that make, or influence, decisions within target SDOs.

TALON will optimize its standards proposal methodology, which entails strategic timing of our proposals to coincide with the decision-making processes at our target organizations; competitive positioning of our proposals to ensure they stand out from any alternatives; and assessment of the political landscape in our target standards organizations so we can influence its direction, in a pro-TALON way.

This phase employs an international standards harmonization method to ensure alignment across the different SDOs and to prevent them from developing conflicting standards. Using this method, we steer the work through complex organizational relationships to build the support needed to get our proposed standards through to approval. Among other things, this requires writing detailed position papers and preparing our technical leads to give technical presentations and to use demonstration materials effectively at meetings.

Phase 4: Validation, Interoperability Testing, and Market Preparation (Months 44-48)

The validation phase uses in-depth conformance testing methods grounded in the ISO/IEC 9646 testing framework and the ITU-T Z.500 series recommendations. TALON will create tests to ensure our standards function across diverse, real-world technology environments. TALON will utilize the standards impact measurement framework to quantify the effectiveness of proposed standards and the barriers to their adoption. The project will implement systematic feedback collection mechanisms using structured methodologies (e.g., technology acceptance model evaluations and user experience assessments).

Phase 5: Ecosystem Development and Continuous Evolution (Months 48+)

The last phase emphasizes sustainable ecosystem development, using methods like innovation ecosystem framework and technology diffusion theory. TALON will set up a community of practice to maintain, nourish, and further an ongoing coordination collaboration among implementers, researchers, and standards developers. TALON will set up formal mechanisms to collect feedback from implementations of standards, to watch for monitoring trends in technology, and to coordinate updates to the standards themselves. The project will take advantage of an impact assessment and review methodology to evaluate, on a continuous basis, the effectiveness of the standards contributed.

Finally, this phase entails starting formal liaisons with industry consortiums, initiating training and certification programs, and developing necessary tools and resources. The project will use the standards success metrics to monitor somewhat continuously the contributed standards' adoption rates, implementation quality, and market impact.

3.2.3 Result-Specific Standardization Strategies

XAI Framework (R1)

The four-level trust architecture of R1 creates a comprehensive explainability pipeline that addresses industrial AI systems' unique requirements. Each level communicates through standardized APIs enabling seamless integration within TALON's broader edge-to-cloud orchestration framework. The structured approach could align with emerging standards including IEEE P2976 for XAI principles *[6]*, ISO/IEC TR 24028:2020 for AI trustworthiness *[7]*, and ISO/IEC 23053 for ML system frameworks *[8]*.

Research within TALON has also produced enhancements such as Fusion Grad-CAM, a methodology for generating unified attention maps in ensemble learning systems *[9]*. This technique addresses the growing use of ensemble methods in edge AI by providing consolidated visualizations of collective decision-making, further enriching the explanatory capabilities available within the TrL framework.

Looking forward, TALON's hierarchical TrL approach could offer significant standardization potential. The systematic progression from data validation through adversarial testing provides a template for industrial XAI standards. Key contributions include standardized metrics for each trust level, reference implementations for industrial use cases, and guidelines for integrating multi-level explanations into human-machine interfaces.

AR/VR Applications (R2)

The immersive technology components offer significant potential for standards contribution:

- CEN-CENELEC JTC 21 – Artificial Intelligence – Standards for Object Detection and Decision Explainability. CEN-CENELEC Joint Technical Committee 21 on Artificial Intelligence
- IEEE 2048 AR/VR Working Group – Standards for Virtual and Augmented Reality and Human Interaction. IEEE 2048 AR/VR Working Group (VRARWG)
- ISO/IEC 23488:2022 – Information technology — Computer graphics, image processing and environmental data representation — Object/environmental representation for image-based rendering in virtual/mixed and augmented reality (VR/MAR). ISO/IEC JTC 1/SC 24, 2022.
- ISO/IEC 18039:2019 – Information Technology – Mixed and Augmented Reality (MAR) Reference Model. ISO/IEC JTC 1/SC 24, 2019.
- ISO/IEC 5927:2024 – Information Technology – Guidance on Safe Immersion, Set-up and Use of AR/VR Technologies. ISO/IEC JTC 1/SC 24, 2024.
- *3GPP TR 26.928:2022 – Extended Reality (XR) in 5G Systems; Study on Media Distribution Architecture. 3GPP SA4, 2022.*

AI E2C Orchestrator (R3)

The architecture aligns with multiple established standards to facilitate broad interoperability and adoption. Relevant standards" in this context are the formal specifications and protocols that underpin each of the Orchestrator's key technologies, ensuring they interoperate safely, efficiently and in a vendor-neutral way:

- Telemetry and Energy-Aware Scheduling: Real-time CPU, memory, network and power metrics are captured through Prometheus, InfluxDB and Kepler as stated in D3.3. Kepler is a CNCF project that probes performance counters and tracepoints via eBPF to export energy metrics for containers, aligning with the CNCF's observability standards and the Green Software Foundation's guidelines for carbon-aware computing.

- Distributed-Ledger Model Governance: As stated in D3.2, the permissioned blockchain component uses Hyperledger Fabric, which adheres to ISO/IEC 19941 for distributed-ledger security and governance. Fabric's smart-contract and consensus protocols ensure immutable, auditable model-weight storage while meeting GDPR-style data protection requirements.
- Explainable AI (XAI): Decision transparency is delivered via XAI modules whose design could follow the IEEE P7001 standard on model transparency and the ISO/IEC JTC 1/SC 42 working group's emerging best practices. These standards prescribe how to expose rationale, provenance and fairness metrics to stakeholders.

By mapping each functional block to its governing standard, the TALON Orchestrator guarantees that its software stack is not only innovative but also aligns with mature industry frameworks for networking, monitoring, security and AI ethics.

Blockchain Explorer (R4)

The explorer aligns with several ongoing and emerging standards in blockchain and decentralized systems:

- IEEE P3217 – Standard for Blockchain Interoperability Architecture (under development), which relates to ensuring interoperability and data exchange among permissioned networks.
- ISO/TC 307 – Blockchain and Distributed Ledger Technologies, particularly in aspects of governance, smart contract standards and data provenance.
- IEEE P7001 – Transparency of Autonomous Systems, relevant for audit trails and accountability in AI-driven decisions.
- W3C DID (Decentralised Identifiers) – for identity management, applicable if extended with self-sovereign identity modules in future iterations.

Within TALON, SIDROCO plans to contribute to standardisation efforts by:

- Documenting Explorer's architecture and methodology as a reference design for lightweight blockchain indexing in edge networks.
- Providing open-source implementations and use case validations across TALON's pilot deployments.
- Exploring interoperability mappings with other decentralised identity or trust systems relevant to AI governance.

By making the blockchain infrastructure explainable, auditable, and developer-friendly, the explorer significantly advances the vision of trustworthy and accountable AI within the TALON architecture.

3.2.4 Implementation Strategy

Standards Body Engagement

TALON will establish formal relationships with key standards organizations through active membership in relevant technical committees, with TALON partners seeking technical editor positions in key standards and coordination with industry partners to ensure practical applicability through industry liaison activities.

Open Source Strategy

TALON's commitment to open innovation includes release of standardized components as open-source projects through reference implementations, building developer communities around TALON standards through community development initiatives, and providing comprehensive documentation and training materials for standards adoption.

3.2.5 Expected Outcomes and Impact

The standardization pathway is expected to deliver several key outcomes. Technical contributions will include at least four technical specifications submitted to relevant standards bodies, covering XAI trust levels, AR/VR industrial applications, edge-to-cloud orchestration, and lightweight blockchain governance. Industry adoption will be demonstrated through adoption of TALON standards by at least three external organizations through pilot implementations and validation studies. The project will also establish a comprehensive interoperability framework that enables seamless integration of TALON components with existing industrial systems, while developing certification programs that validate implementation compliance with TALON-contributed standards.

3.2.6 Risk Mitigation and Contingency Planning

TALON recognizes potential challenges in the standardization process and has developed mitigation strategies. Standards evolution risk will be addressed through regular monitoring of standards landscape changes with adaptive contribution strategies. Technology maturity risk is mitigated through a phased approach allowing for technology refinement based on standards feedback. Industry acceptance risk is managed through early engagement with industrial partners to ensure practical relevance, while resource allocation risk is addressed through dedicated standardization budget and personnel allocation across partner organizations.

Through this comprehensive pathway to standardization, TALON aims to ensure that its technological innovations become integral components of the next generation of Industry 4.0 standards, facilitating widespread adoption and maximizing the project's long-term impact on sustainable industrial automation.

4 Conclusions

The TALON project's standardization efforts represent a comprehensive and forward-looking approach to embedding its technological innovations within established and emerging international standards frameworks. By aligning with organizations such as IEEE, ISO/IEC, and CEN-CENELEC, and by following a structured, multi-phase strategy, TALON ensures that its contributions are both technically robust and practically relevant for the Industry 5.0 landscape.

Through its four key results—XAI, AR/VR, the AI E2C Orchestrator, and the Blockchain Explorer—TALON addresses critical gaps in trustworthiness, human-centric interaction, energy-efficient orchestration, and verifiable AI governance. Each of these components has been mapped to appropriate standardization pathways, with reference implementations and technical specifications in preparation to support community adoption and integration.

The standardization pathway also incorporates robust risk mitigation strategies, proactive engagement with stakeholders, and a strong open-source orientation, ensuring that TALON's outputs remain adaptable to evolving technological and regulatory contexts. The project's emphasis on ecosystem development, interoperability testing, and continuous evolution further reinforces its commitment to long-term sustainability and relevance.

In sum, TALON not only advances the state-of-the-art in edge AI, immersive technologies, and federated governance but also paves the way for these innovations to become standardized, trusted components of the industrial systems of tomorrow.

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