Next-Gen Decentralized Workflow Automation in Ore Mining: A System Architecture Perspective

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The **Workflow Automation Engine (WAE)** introduced in this poster offers a transformative solution for automating and optimizing key business processes in the ore mining industry. The WAE integrates several cutting-edge technologies, such as Business Process Management Notation (BPMN), the Camunda Platform, the Elastic stack, Hyperledger Besu, the InterPlanetary File System (IPFS) and Smart Contracts, to automate and visualise workflows, improve task coordination, ensure compliance with regulatory frameworks, highlight bottlenecks with metrics and increase overall operational efficiency. This solution is particularly designed to address inefficiencies in complex **ore mining business operations** that involve multiple stakeholders, including mining companies, external contractors, logistics providers, and regulatory bodies.

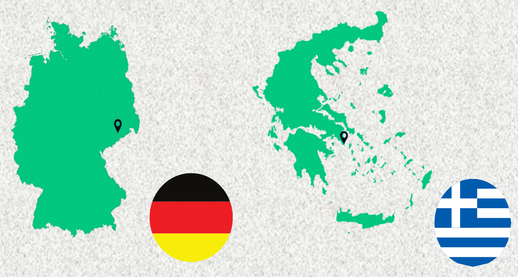
This presentation summarizes the conceptual design, architecture, and intended outcomes of the WAE, while also proposing a validation method for ensuring the effectiveness of the system across diverse mining environments. The solution is expected to be validated in 2026 across three locations: the Research and Education Mine "Reiche Zeche" (Freiberg, Saxony, Germany), the Lavrion Ancient Silver Mines (Attica Region, Greece), and a third site to be determined, all under the auspices of the Horizon Europe **MINE.IO** project *(Grant Agreement No 101091885)*.

Motivation

The ore mining industry grapples with a range of challenges stemming from the intricate nature of its business process management. Key areas such as logistics, regulatory compliance, and stakeholder coordination are particularly complex. Traditionally, these processes have been siloed and heavily reliant on manual, paper-based systems, leading to frequent inefficiencies, delays, and heightened operational expenses. In the absence of digital transformation and in many cases even Internet connectivity, many mining operations still rely on outdated methods for tracking shipments and work orders, managing documentation, and ensuring compliance. This often results in poor visibility across the operational chain, slow response times to regulatory changes, and difficulty in maintaining consistent communication among departments and external partners. The **Workflow Automation Engine** (WAE) aims to tackle these challenges by automating core business functions such as **ore transport scheduling**, process visualisation and, eventually, **optimisation**, automated **work-order placement** when results from **predictive analytics algorithms** become available, **regulatory compliance checks** and **inter-stakeholder communication**.

Pilot sites

The solution will be validated in 2026 across three locations: the Research and Education Mine "Reiche Zeche" (Freiberg, **Germany**), the Lavrion Ancient Silver Mines (Attica Region, **Greece**), and a third site to be determined. Each deployment will include stakeholder feedback and performance logging to assess the adaptability, usability, and operational value of the WAE under real-world mining conditions.



Decentralised Core System Design

The WAE is structured around a distributed and modular architecture designed to ensure scalability, security, and flexibility, with a special tailoring for handling the intricate business processes of the ore mining sector. Supplementarily, the integration with a permissioned blockchain infrastructure ensures the aforementioned business transactions remain transparent and tamper-proof.

At the heart of the system architecture lies the **Zeebe** engine, which orchestrates business workflows through a network of brokers. Zeebe is a part of the **Camunda** platform, a widely used open-source Business Process Management (BPM) solution that supports BPMN (Business Process Model and Notation) for modelling and executing business workflows. Zeebe's architecture enables the efficient execution of business processes, while its distributed nature ensures fault tolerance and scalability for handling large-scale business operations. Each Zeebe broker within the cluster performs task assignment, process orchestration, and monitoring, ensuring that workflows are executed seamlessly across different organisational silos.

As already mentioned, the WAE leverages blockchain technology, specifically the **Hyperledger Besu** framework, to ensure transparent, and immutable record-keeping for all critical business transactions. This integration is central to ensuring trust and accountability across all stakeholders in the mining ecosystem, including mining companies, contractors, and regulatory bodies. Blockchain allows each stakeholder to have access to a tamper-proof ledger of all transactions, including business agreements, work order approvals, task scheduling and completions, as well as compliance checks. By using a permissioned blockchain network, each organisation involved in the mining operations establishes its own node, ensuring consistency of data while maintaining security and privacy. This decentralised approach reduces the risk of fraud and manipulation, especially in low-trust business environments.

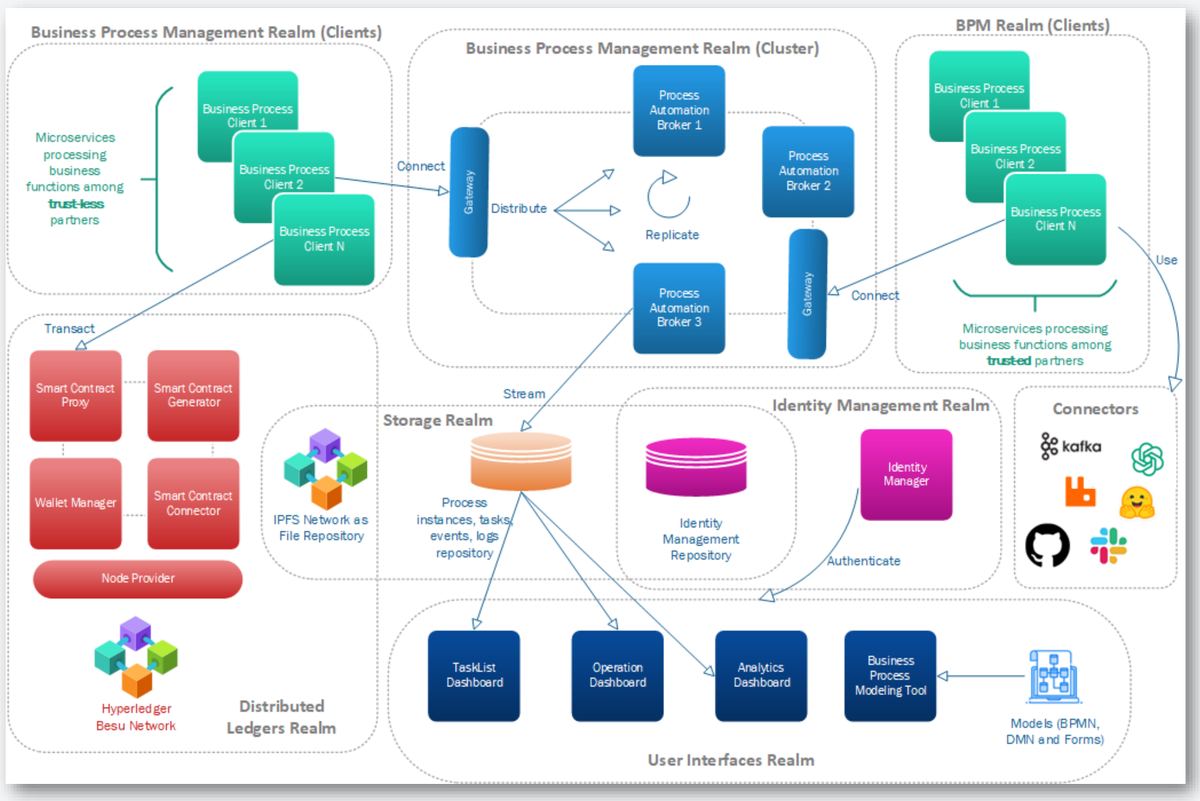
Moreover, the WAE employs Smart Contracts for automating agreements between stakeholders. Its **Smart Contract Manager** architectural layer consists of four main components: the **Smart Contract Connector** (which links the system to the Besu blockchain), the **Smart Contract Generator** (which compiles and deploys contracts), the **Smart Contract Proxy** (which manages interactions with deployed contracts), and the **Wallet Manager** (which handles decentralised identity, i.e. wallet, creation and transaction signing).

Furthermore, the WAE architecture integrates **InterPlanetary File System** (IPFS) for decentralized document storage and exchange, ensuring that critical documents (e.g., contracts, regulatory reports, work orders) are securely stored and shared among authorized stakeholders. This decentralized approach guarantees document availability while maintaining privacy and data integrity.

Real-time Monitoring and Data Analytics

To ensure efficient and effective workflow management, the WAE integrates **Elasticsearch** for real-time data indexing and analytics. Elasticsearch allows the system to index key process data, such as task states, operational metrics, and logs, enabling fast querying and filtering of information. This capability is crucial for managing ongoing operations, as it allows users to track progress, identify bottlenecks, and optimise workflows in real time. Out-of-the-box Connectors, such as those available for Apache Kafka, RabbitMQ, Slack, and other third-party systems, add significant value by integrating Zeebe workflows with external services and systems. For example, a **Kafka connector** can allow workflows to consume or produce messages from services in the same ecosystem (such as the algorithms used for predicting mining machinery downtime), enabling seamless integration with event-driven architectures. The **TaskList and Operations Dashboards** are key tools within the system, designed for different user personas. These are part of the Camunda platform and offer varied perspectives on the process data. While the TaskList is tailored to operational users like field supervisors or equipment operators, the Operations Dashboard provides a high-level overview for process managers. Both dashboards support decision-making by displaying real-time data on resource utilization, task statuses, and any issues that may arise.

MINE.IO Project:



Expected Outcomes & Validation Proposition

The anticipated outcomes of implementing the Workflow Automation Engine (WAE) include reduced manual effort, improved operational efficiency, enhanced compliance, and increased transparency. By automating business processes, mining operations can reduce administrative burdens, improve the speed of decision-making, and ensure that safety and environmental regulations are met. Additionally, the use of blockchain ensures that all actions taken during mining operations are fully traceable and auditable, providing stakeholders with confidence in the integrity of the data. To assess the effectiveness and performance of the WAE, a phased validation approach will be employed. The pilot phase will focus on automating core business processes - namely work order management post predictive-maintenance assessments, transport scheduling, and regulatory compliance checks - within a controlled mining operation. Key Performance Indicators (KPIs) will be used to evaluate the system, including: (1) **Process Completion Time**: Measuring time reduction in completing workflows, with an expected improvement of 30-50% over manual methods. (2) **Task Execution Accuracy**: Targeting an automated task success rate of over 95%. (3) **Compliance Accuracy**: Measuring the percentage of workflows that meet regulatory criteria without manual intervention, with a target of 58%. (4) **Bottleneck Detection Rate**: Evaluating the system's capacity to identify and resolve workflow inefficiencies, aiming to reduce undetected bottlenecks by at least 60%. (5) **User Adoption**: Gauging uptake of the system's TaskList and Operations Dashboard tools, aiming for 80% regular use post-onboarding.

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