

## Output 1.2 Jointly developed solution for skeleton digital architecture with cloud-based brokers and gateway clients

RCO116\_1.1: Jointly developed solutions

### Executive Summary

This document constitutes Output 1.2: Jointly developed solution for skeleton digital architecture with cloud-based brokers and gateway clients, developed under the Arctic Edge project.

It presents the conceptual framework, technical structure, and joint development of the solution.

The Arctic Edge Output 1.2 delivers a jointly developed solution for a skeleton digital architecture enabling real-time, interoperable, and scalable supply chain visibility for SMEs in the Northern Periphery and Arctic region. Although such an architecture provides a solution that can be used throughout the world, it is especially needed in the Northern periphery and the Arctic (NPA), to enhance resilience of supply chains against the challenges encountered in the NPA region

The solution combines a cloud-based broker, gateway clients, and lightweight messaging technologies to connect supply chain actors across multiple tiers. It is designed to address shortcomings of fragmented and manual systems currently used by SMEs, enabling improved coordination, resilience, and data-driven decision-making. The solution outlines a digital architecture developed collaboratively across Arctic Edge partners. It provides a foundational framework for increasing visibility, resilience, and interoperability in regional supply chains, particularly for SMEs in remote or rural areas.

Developed collaboratively across Arctic Edge partners, the architecture provides a transnational, scalable model for digital supply chains and prepares SMEs for future integration into European Data Spaces and advanced AI-driven systems.

The conceptual framework for the digital architecture outlines its structure and technical functionalities focusing on design and integration of cloud-based broker and gateway clients. Partners worked together to identify best in class digital

architecture framework aiming at enhanced supply chain interoperability and resilience.

## 1. Core Technical Team

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## 2. Overview

Supply chains are living networks where even a single disruption can ripple across the entire system. For small and medium-sized enterprises, particularly those in rural or remote NPA regions, the consequences of disruption are magnified. Delays, shortages, and missed updates can significantly impact their ability to deliver products and services on time and remain competitive.

The Arctic Edge project addresses these challenges by strengthening supply chain operations in the Northern Periphery and Arctic region. Jointly developed skeleton architecture focuses on demonstrating how digital tools can provide organisations a clear, real-time view of their supply chains. Rather than relying on emails, phone calls or other manual protocols, SMEs can gain instant visibility of when an order is placed, when production begins, when shipments are dispatched, and when disruptions occur.

This output presents the jointly developed conceptual framework for implementing a cloud-based digital architecture. The planned skeleton architecture is a foundation for Pilot 1, where the digital architecture is integrated into simulated supply chain distributed across three technical partner site.

The framework presented in the Jointly Developed Plan spans three interconnected supply chain levels:

- End Manufacturer (EM)/ Original Equipment Manufacturer (OEM): Receives customer orders and assembles the finished product.
- Tier 1 Supplier: Provides essential sub-components.
- Tier 2 Supplier: Manufactures raw parts for Tier 1.

Importantly, the framework has been developed in alignment with the broader objectives of the Arctic Edge project, ensuring that it reflects both the operational needs and the technological contexts of each partner site. The goal is straightforward yet powerful: to make supply chains transparent, reliable, and resilient through a digital architecture that utilizes intuitive and easy-to-use Internet of Things (IOT) technologies without placing an additional burden on SMEs through complex or costly systems. In the Northern Periphery and Arctic region, supply chains face unique challenges such as geographic remoteness, fragmented systems, and high exposure to disruptions, making resilience critically dependent on visibility, coordination, and adaptability; real-time data enables immediate detection and response to delays or failures, interoperability ensures seamless information flow across diverse partners and systems to support coordinated decision-making, and scalability allows the network to evolve with changing demand and new participants, together creating a supply chain that can anticipate, absorb, and respond effectively to disruptions rather than react too late.

### 3. Solution Definition

The Arctic Edge solution is a jointly developed skeleton digital architecture designed to enable real-time, interoperable, and scalable supply chain visibility for SMEs in the Northern Periphery and Arctic region.

The solution consists of the following core components:

- Cloud-Based Broker: Distributed system of one cloud-based broker for each tier of the supply chain coordinated by end manufacturer to enable standardised data exchange across supply chain actors. Central

coordination layer enabling standardised data exchange across supply chain actors, with a central EM dashboard providing end-to-end visibility of the entire supply chain while tier-specific MQTT brokers maintain distributed control and data exchange at each level.

- Gateway Clients: Local interfaces deployed at SME, EM, and supplier sites to connect existing systems (ERP, MES, sensors).
- Messaging Infrastructure (MQTT): Lightweight, real-time communication protocol ensuring efficient and scalable data exchange.
- Data Orchestration Layer (Node-RED): Handles logic, workflows, and integration between systems.
- Dashboards and Interfaces: Provide SMEs with real-time visibility of orders, production, and logistics.

This solution addresses fragmented and manual supply chains by replacing disconnected communication (emails, spreadsheets) with real-time, event-driven data flows, enabling improved decision-making, resilience, and coordination. As a result of this output, Arctic Edge partners have jointly defined a shared digital architecture framework that can be deployed, tested, and scaled across multiple pilot sites, enabling interoperable and data-driven supply chain operations.

#### 4. Problem Statement and Transnational Value

Many SMEs in the NPA region rely on manual or semi-digital supply chain tools such as spreadsheets, emails, and phone calls. These introduce delays, errors, and blind spots that:

- Disrupt production schedules
- Delay deliveries
- Increase the cost of coordination
- Reduce competitiveness in national and cross-border markets
- Lead to lost customers
- Rely on outdated systems that are costly to maintain and require specialist expertise that many SMEs lack

A more reliable, transparent, and interoperable system is needed, one that enhances situational awareness across multi-tier supply chains and provides early warnings when risks arise.

Main beneficiaries:

- EM/OEM
- SME supplying end manufacturers
- Organisations willing to enhance operational sustainability and trace the origin of the produce across the supply chain
- SMEs who are experiencing shortage of resources, including human and finance
- Organisations dependant on critical components and supplies

The solution delivers strong transnational value, which is central to the NPA programme.

- Supply chain challenges in the NPA region are shared across countries, including:
  - Fragmented systems
  - Limited digitalisation
  - Geographic remoteness
  - Vulnerability to disruptions

The Arctic Edge architecture addresses these challenges by:

- Enabling cross-border data interoperability between supply chain actors
- Supporting multi-country supply chains (e.g., Ireland–Finland–Sweden flows)
- Providing a standardised yet flexible framework adaptable to different regional contexts and industry sectors, including manufacturing, food processing, dairy, and fishing etc
- Facilitating knowledge transfer between regions with varying levels of digital maturity

The solution would not be achievable through a single-region approach, as it relies on cross-border collaboration, shared learning, and interoperability across different national systems.

## 5. Joint Development Process

The skeleton architecture has been jointly developed by Arctic Edge partners through a collaborative, transnational co-creation process.

This process included:

- Cross-partner workshops to define system requirements and supply chain use cases
- Technical collaboration between research institutions (AIM, LTU, NKCCI, CENTRIA, HI) to design architecture components
- Industry input from SMEs (Digital Beacons) to ensure practical applicability and usability
- Iterative refinement of architecture based on partner feedback and pilot planning needs

Each partner contributed domain-specific expertise:

- AIM – system design, orchestration, and use case development
- LTU – technical modelling and validation,
- NKCCI – ERP integration and knowledge transfer
- Digital Beacons (SMEs) – real-world use cases and scenarios
- HI – Dashboarding and Performance Matrix development
- Centria – knowledge transfer and validation
- SCC – long term implication, sustainability

This collaborative approach ensures that the solution is technically robust, practically relevant, and adaptable across multiple regional contexts. The

architecture was refined through multiple cross-partner workshops and technical sessions conducted during WP1.

## 6. Skeleton Digital Architecture Design

The architecture supports a lightweight, cost-effective, and scalable solution stack for digital supply chain visibility. It enables SMEs to retain existing ERP systems while integrating seamlessly via messaging protocols and low-code orchestration.

Why this solution works

SMEs across the Northern Periphery and Arctic region often rely on manual tools such as spreadsheets, email, and phone calls to manage their supply chains. While familiar, these methods create delays, errors, and a lack of visibility. The solution proposed addresses these weaknesses by introducing a lightweight, interoperable digital framework, that is cost-effective, inexpensive for moderately sized operations, and adds minimal monetary overhead, making it highly suitable and accessible for SMEs.

### a. Standardisation Across Partners

- Each entity (EM, Tier 1, Tier 2) retains its own systems but communicates through common message formats.
- Orders, production updates, and shipment confirmations with promised delivery dates follow a shared structure, ensuring interoperability across borders and technologies.

### b. Real-Time Visibility

- Instead of waiting for end-of-day reports or phone updates, supply chain events are published instantly.
- SMEs gain live insights into stock availability, production progress, and shipment status.
- Anomalies such as breakdowns or delays are flagged immediately, reducing reaction times.

### c. Predictive Capabilities

- Historical data (orders, lead times, seasonal demand) is stored in SQL databases and enriched with forecasting logic.
- This enables proactive order placement, helping SMEs avoid last-minute shortages or overstock situations.
- Detect and help to prevent amplification of bull whip effect and stock build up
- Promised delivery date vs Actual delivery date. Evaluation mechanism, actual cycle time calculation and prediction

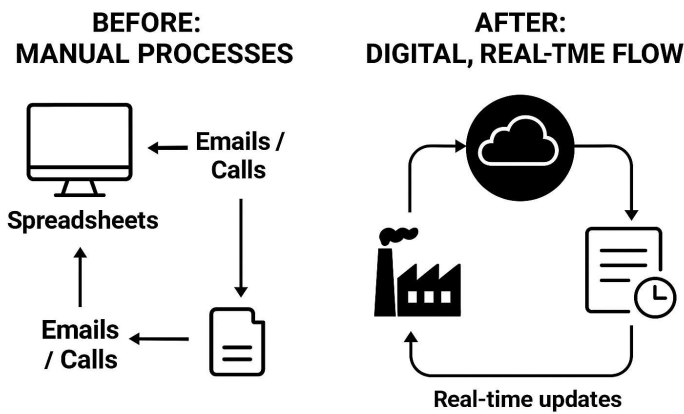
### d. Lightweight and Scalable Architecture

- The framework uses cloud-based tools, Node-RED orchestration, and MQTT messaging technologies that are free and open-source, flexible, and proven in IoT/manufacturing contexts, with no licensing costs for the moderate operational scales typical of NPA SMEs.
- SMEs do not need to replace existing ERPs or databases; instead, the system “sits on top” of what they already have.
- This makes adoption low-risk and scalable as SME operations grow.
- Architectural data structure that can be flexible for future adjustments and refinements (MQTT topics composition, unified tracking number, data flow design, inclusion of data on promised delivery date, scalability with adding data points, broker protocol, basic skeleton for supply chain set up)
- Ability to trigger production in automated factory floor
- Incorporating stock levels to trigger orders

### e. Alignment with Broader Arctic Edge Goals

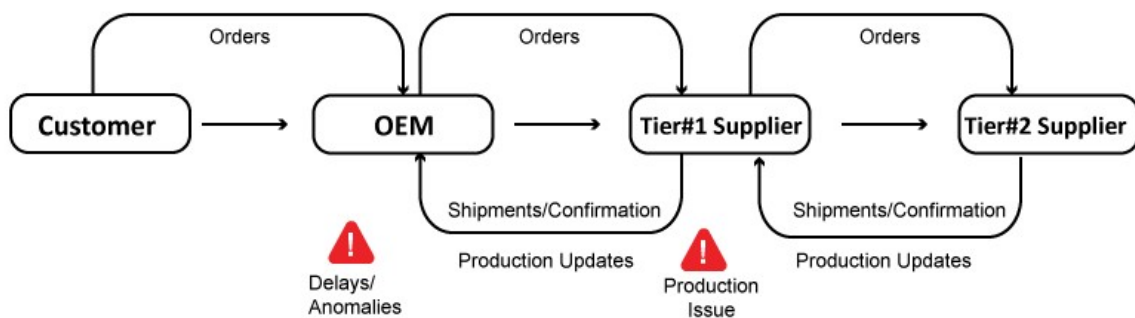
- The approach fits into the project’s mission to promote interoperability, resilience, and sustainability in regional supply chains.
- It also prepares SMEs for future integration into European Data Spaces, ensuring long-term relevance beyond the pilot.

In summary, this solution works because it combines simplicity for SMEs with robustness in design. It addresses the everyday challenges of visibility, communication, and planning, while also laying the foundation for advanced digitalisation in the years ahead. Pic.1 illustrates the shift from manual, disconnected processes (emails, calls, spreadsheets) to a digital, real-time flow of data. By reducing delays and human errors, SMEs gain faster, clearer visibility into their supply chain operations.



Pic. 1. Manual vs Digital

How it works. Technical Stack.



Pic. 2 Data Flow

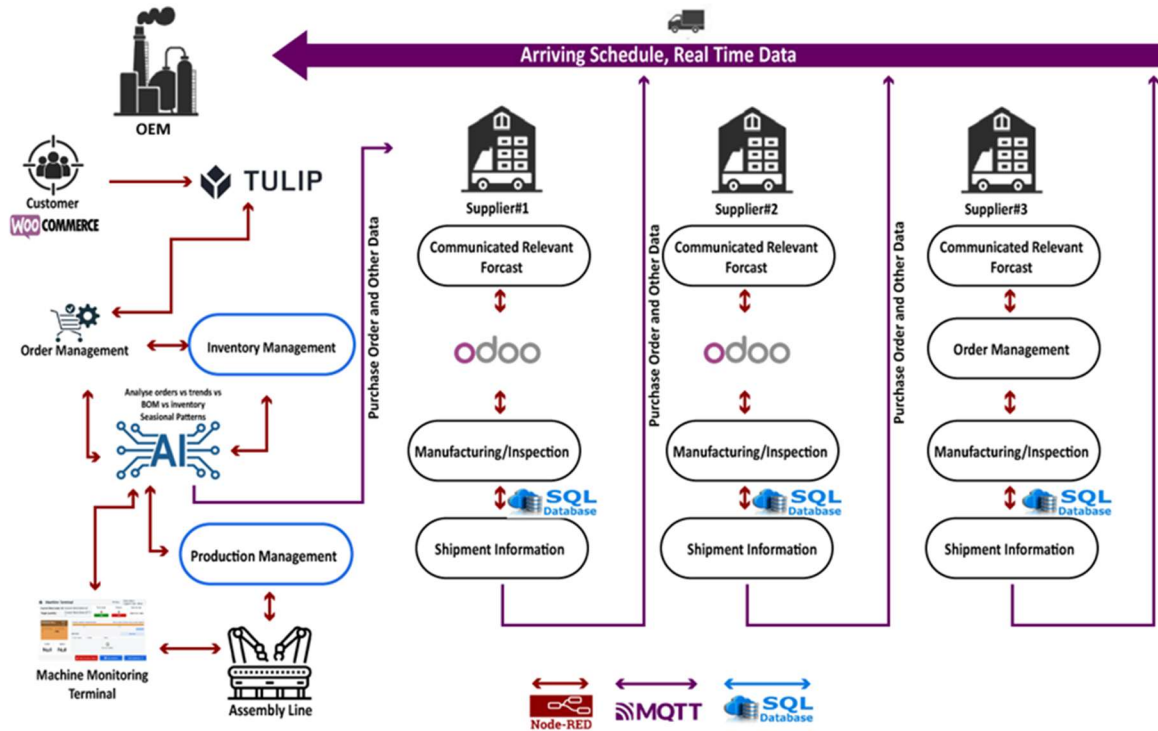
Data flow scheme illustrated in Pic.2 provides a simplified view of how production and supply chain operates. It highlights the flow of information and materials between four key actors:

- Customer – initiates demand by placing an order.
- EM– receives the customer order, assembles the finished product, and coordinates supplier activities.
- Tier 1 Supplier) – delivers sub-assemblies and intermediate components required by the EM.
- Tier 2 Supplier– manufactures and supplies raw parts to Tier 1.

Data and Process Flows:

- Orders: Move downstream from customer → EM → Tier 1 → Tier 2.
- Shipments and Confirmations: Flow upstream as suppliers dispatch goods and confirm deliveries.
- Production Updates: Shared by each supplier, providing visibility of progress across the chain.
- Delays/Anomalies: Any disruption (e.g., production stoppages, late shipments, or customs delays) is flagged, and visualised on the central EM dashboard, ensuring the EM and customer can respond quickly to the accumulated impacts across the entire supply chain.

This general framework emphasizes real-time communication, transparency, and anomaly detection. By connecting each tier of the supply chain, SMEs gain the ability to track orders, monitor production status, identify risks before they escalate and make adjustments. The ultimate goal is to make supply chains more reliable and predictable, without overwhelming SMEs with complex systems.



Pic.3 Conceptual Framework

The conceptual framework illustrated above represents the digital architecture for managing interconnected production and supply chain activities across two tier suppliers. This model outlines how data flows between the EM site and its key suppliers using a combination of cloud-based communication protocols, ERP systems, manufacturing simulation, and data analytics tools.

At the core of the EM operation is a Tulip MES system, integrated with customer-facing platforms like WooCommerce. This MES system handles order management, inventory tracking, and production planning. Incoming customer orders are processed through Node-red, which then triggers inventory checks and generates purchase orders to be sent to relevant suppliers.

The inventory management system is supported by Tulip tables, where historical data, BOMs (Bills of Materials), and real-time stock levels are analysed using embedded AI tools. This supports forecasting and decision-making, such as detecting order trends or seasonal inventory fluctuations.

The production management module leverages real assembly line, assembled the final product using raw materials purchased from suppliers. Real-time equipment status is visualized through a Machine Monitoring Terminal, which feeds into the production logic to identify equipment availability, bottlenecks, and utilization. This helps optimize scheduling and production efficiency.

For all three suppliers, the purchase order and relevant forecasts are shared from EM. Each supplier operates its own internal ERP system—Odoo for both Supplier #1 and Supplier#2, and a simplified order and inventory structure for Supplier #3. These systems manage their respective manufacturing and inspection activities, also simulated using Visual Components.

All suppliers maintain their own SQL-based databases to store production and shipment information. The shipment details and real-time delivery schedules are communicated back to the EM site, allowing for continuous tracking and synchronization of incoming materials.

Communication between systems is enabled by Node-RED, which manages the logic and integration between services. Real-time data exchange is handled using MQTT, a lightweight publish-subscribe protocol suitable for IoT and manufacturing environments. This setup ensures scalable and flexible integration among the various ERP systems and technical platforms.

Overall, this framework promotes interoperability, real-time visibility, and data-driven decision-making. It allows each partner site to operate independently while remaining connected to the central production and logistics plan at AIM Centre. This forms the basis for a smart, distributed manufacturing ecosystem, aligned with the broader goals of the Arctic Edge project.

#### ERP / CRM Systems

- |                        |          |                                       |
|------------------------|----------|---------------------------------------|
| • Tulip Cloud Database | EM       | Order management, inventory, planning |
| • Odoo                 | Tier 1   | ERP for production and delivery       |
| • Odoo                 | Tier 2   | Enterprise ERP platform               |
| • Custom Lite          | Internal | Simplified local order tracking       |

#### Database & Forecasting

- Cloud databases across partner sites
- Forecasting algorithms using historical and live data
- BOM analysis to enable pre-emptive restocking

#### Data Orchestration & Messaging

- Node-RED: Manages orchestration flows across services
- MQTT: Lightweight publish-subscribe protocol for real-time messaging
- REST APIs: For integration with external tools or dashboards

#### Simulation & Monitoring

- Visual Components: Simulates production line processes
- Machine Monitoring Terminals: Real-time visibility on line status

#### Dashboards & Interfaces

- Web dashboards for SMEs (Node-red UI)
- Customer portals (e.g. WooCommerce integration) for delivery updates

#### Cloud Infrastructure

- Distributed hosting (regional and central)
- Docker-based services for scalable deployment

## 7. Performance Metrics

Metric	Definition	Why It Matters for SMEs
On-Time Delivery %	Share of orders delivered on or before the expected delivery date (EDD). Based on comparing actual delivery date (DD) with EDD.	Shows reliability to customers or EM. Missed deliveries signal supply chain weakness.
Actual Cycle Time (aCT)	Total elapsed time from order origination (placement) to final delivery, encompassing production, processing, and	Provides visibility into end-to-end order fulfilment time, helping SMEs identify delays across the entire supply chain,

	logistics across all supply chain tiers	improve delivery reliability, and enhance customer satisfaction.
Late Orders (Count)	Number of orders where delivery date (DD) exceeds expected delivery date (EDD).	Simple visibility on how often commitments are missed.
Lateness (Days)	Average difference between promised delivery date (EDD) and actual delivery (DD).	Quantifies the scale of delays, not just their frequency.
Delay Alerts (Real-Time)	System-generated anomaly reports (e.g. machine downtime, shipment delay, customs hold).	Ensures SMEs can react quickly, reducing knock-on effects.
Standard Lead Time (sLT)	Expected duration between placing an order and receiving the goods under normal operating conditions, based on historical supplier performance.	Helps SMEs plan production and inventory more effectively, reducing the risk of delays, stock shortages, and reactive decision-making
Expected Delivery Date (EDD)	Agreed date by which an order is planned to be delivered to the customer, based on order confirmation and standard lead times.	Enables SMEs to monitor delivery performance, manage customer expectations, and quickly identify delays that may impact production or customer satisfaction

## 8. Use Cases

### Use Case 1: Real-Time Order Tracking

- A customer places an order with the EM in Ireland

- The system automatically checks stock and places an order with the Tier 1 supplier in Finland.
- The Tier 1 supplier confirms with an expected delivery date.

SMEs see the entire process instantly on their dashboard, without waiting for emails.

#### Use Case 2: Production Line Anomaly

- Tier 1 supplier promises delivery on 15th October 2025.
- But one of its production lines stops for a full day.
- The system detects the stoppage and immediately updates the EM.

The EM knows right away that the delivery will be delayed by one day and can adjust its own schedule instead of being surprised at the last minute.

#### Use Case 3: Shipment Delay

- Tier 2 supplier (Sweden) sends a shipment of pen tips to Tier 1.
- The shipment gets stuck in customs for 48 hours.
- The shipment status automatically updates to “Delayed – Customs”.

Tier 1 including EM both see the issue live and can inform their customers before complaints arise.

Note that Tier 1 suppliers may serve customers beyond the EM. All orders originating from the EM are tracked using unique order IDs to maintain traceability within the system.

#### Use Case 4: Stock Shortage Alert

- EM’s system forecasts a shortage of ink refills within two weeks.
- Based on historical order trends and supplier lead times, the system automatically alerts Tier 1 and proposes an early replenishment order.

SMEs avoid “last-minute firefighting” and ensure smoother production planning.

#### Use case 5: Bullwhip effect

- A small increase in customer demand is detected at the EM level.

- Instead of each supplier independently increasing production, the system shares real-time demand data and forecasts across all tiers.
- The broker identifies potential demand amplification and provides coordinated recommendations to Tier 1 and Tier 2 suppliers.
- As a result, suppliers align their production with actual demand rather than overreacting, reducing excess inventory, costs, and supply chain instability.

## 9. Innovation Beyond Existing Practice

The proposed solution goes beyond current SME practices and existing supply chain systems in several key ways:

- **Broker-Based Architecture for SMEs**  
Introduces a distributed yet flexible broker model enabling structured data exchange without requiring full system replacement.
- **Lightweight Integration Approach**  
SMEs can retain existing ERP/MES systems while connecting through low-cost gateways and messaging protocols.
- **Real-Time Multi-Tier Visibility**  
Enables visibility across EM, Tier 1, and Tier 2 suppliers simultaneously, rather than isolated data silos.
- **Event-Driven Supply Chain Management**  
Replaces static reporting with real-time updates and anomaly detection.
- **Scalable Digital Foundation**  
Prepares SMEs for future integration with AI, advanced analytics, and European Data Spaces.

This represents a practical and accessible innovation, tailored specifically to the constraints and needs of rural SMEs.

## 10. Contribution to Programme Objectives

The solution directly contributes to the programme objective of:

- Enhancing research and innovation capacities and the uptake of advanced technologies
- Specifically, it supports:
  - Digital Transformation of SMEs  
Enables adoption of modern digital infrastructure without high complexity or cost
  - Supply Chain Interoperability  
Establishes standardised communication across systems and organisations
  - Resilience and Risk Reduction  
Provides early detection of disruptions and improved response capabilities
  - Data-Driven Decision Making  
Enables use of real-time and historical data for forecasting and optimisation
  - Alignment with EU Digital Strategy  
Prepares SMEs for participation in European Data Spaces and AI-driven ecosystems

## 11. Adoption Approach, Scalability, Replication and SME Benefits

- Low-barrier entry using lightweight gateways and existing systems
- Incremental integration, starting with visibility and expanding to forecasting
- Support through pilot demonstrations and toolkits
- No requirement for full system replacement

This ensures that SMEs can adopt the solution gradually, affordably, and with minimal disruption.

The architecture is designed to be scalable and transferable across regions and sectors.

#### Scalability

- Modular design allows adding new suppliers, sites, and systems
- Cloud-based infrastructure supports expansion without major redesign
- Compatible with multiple ERP/MES systems

#### Replication

- Applicable to other manufacturing sectors beyond initial pilots
- Transferable to other NPA regions and EU territories
- Can be adapted to different supply chain structures

#### Long-Term Potential

- Integration with European Data Spaces
- Extension to AI-driven optimisation
- Use in circular economy and sustainability tracking

#### SME Benefits

- Clarity: The EM gains full end-to-end visibility of the supply chain, while each supplier tier has visibility of its immediate upstream and downstream partners. This tiered visibility model ensures the right information reaches the right actor at the right time, reducing miscommunication and eliminating manual chasing.
- Fewer Surprises: Anomalies such as machine breakdowns, late shipments, or customs delays are reported instantly, giving SMEs time to adjust schedules and inform customers proactively.

- Better Planning: Built-in forecasting tools analyse historical data, lead times, and seasonal demand, helping SMEs place orders at the right time and avoid costly shortages or excess stock.
- Customer Trust: SMEs can provide accurate and timely delivery updates, even in the face of disruptions, strengthening relationships and competitiveness.
- Scalability: The framework works across regions and borders and can be scaled up to include more suppliers, products, or even entirely new value chains as SMEs grow.
- Resilience: By detecting risks early and sharing information transparently, SMEs build more resilient supply chains that can withstand disruptions.
- Digital Readiness: Pilot 1 acts as a low-barrier entry point for SMEs into digital supply chain practices, preparing them for future integration with European data spaces and advanced AI-driven systems.

Through this structure, SMEs will be able to:

- Track orders from the moment they are created.
- Monitor production steps as they progress across suppliers.
- Access live information on the exact status of shipments.
- Detect problems, such as machine downtime or shipment delays, as soon as they occur.
- Predict future demand and order needs by analysing historical data, supplier lead times, and order patterns, enabling smarter and more proactive order placement.
- Visualisation, tracing order status
- Dashboarding, decision making (bull whip, problems with supplier, etc)

## 12. Next Steps

This general architecture will be validated and refined through:

- Pilot Demonstrations (Output 1.4) across 5 sites (Pilot 1: three sites supply chain simulation, Pilot 2 & Pilot 3 -Digital Beacon real life examples on two partner sites)
- Case Study Documentation on SME integration
- SME Toolkit Development (Output 1.5) including templates, lessons learned, and step-by-step adoption guidance

Pilot 1 will run demonstrations across Ireland, Finland, and Sweden, showcasing how SMEs can adopt and benefit from the framework in real-world conditions. Results will be captured in case studies that highlight both the successes achieved and the challenges faced during implementation. The findings from Pilot 1 will feed into ToolKit for SMEs, designed to provide practical step by step guidance on adopting digital supply chain solution.

This ensures that SMEs not only see the benefits in Pilot 1 but also have the resources and knowledge to implement these solutions in the conditions of limited support in their own operational environment.

### 13. Appendix A: System Components Overview

Component	Role
Tulip MES	EM order and inventory management
Odoo	ERP at Tier 1 & Tier 2 sites
Node-RED	Data orchestration & logic flows
MQTT	Messaging across all tiers
SQL Databases	Production data storage & forecasting
WooCommerce	Customer portal integration
Visual Components	Simulated production processes



## Appendix B: Glossary of Terms

OEM:	Original Equipment Manufacturer
EM:	End Manufacturer
ERP:	Enterprise Resource Planning system
MES:	Manufacturing Execution System
MQTT:	Lightweight messaging protocol for IoT
Node-RED:	Low-code orchestration tool
SQL:	Structured Query Language, used for databases
BOM:	Bill of Materials