

D3.2 - M36 - Synthesis Report of the 3 reports: D3.2 – M36 Digital Technologies 4.0 and Green Transition Impacts on Predictive Maintenance, Supply Chain and Alignment of VET Offer and Industry Needs in Advanced Manufacturing in the Basque Country

WP3 – Observatory - D3.2 - M36 – Synthesis Report



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GLOSSARY AND/OR ACRONYMS

AFDET - French Association for the Development of Technical Education
AFM - Asociación de Fabricantes de Máquina Herramienta- Machine Tool Manufacturers Association
AFNOR - French association for standardisation
AI - Artificial Intelligence
AR - Augmented Reality
BC report - Basque Country report
CAGR - Compound Annual Growth Rate
CAM - Computer-Aided Manufacturing
CMMS - Computerized Maintenance Management System
CNC - Computer Numerical Control
CoVE - Centres of Vocational Excellence
EaaS - Equipment-as-a-Service.
EQF - European Qualification Framework
ESCO - European Skills, Competences, Qualifications and Occupations
FCS - Finite Capacity Scheduling
GSCM - Green Supply Chain Management
HVET - Higher Vocational Education and Training
ICS - Infinite Capacity Scheduling
IoT - Internet of Things
IT - Information Technology
IUT - University Institute of Technology
LCAMP - Learner-Centric Advanced Manufacturing Platform
LLM - Large Language Model
MaaS - Maintenance as a Service
MOOC - Massive Open Online Course
MPS - Master Production Schedule
MRP - Material Resource Planning
MV - *Mecanic Vallée*
NLP - **Natural Language Processing**
PdM - Predictive Maintenance
PdMaaS - PdM-as-a-Service
PLC - Programmable Logic Controller
ROI - Return On Investment
SCM - Supply Chain Management
SCOR - Supply Chain Operations Reference
S&OE - Sales and Operational & Execution
S&OP - Sales and Operations Planning
SLMs - Task-Specific Language Models
SME - Small and Medium-sized Enterprises
TKNIKA - Centre for Applied Research in Vocational Training in the Basque Country.
TPM - Total Productive Maintenance
VR - Virtual Reality
XR - Extended Reality



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EXECUTIVE SUMMARY

The LCAMP (Learner-Centric Advanced Manufacturing Platform) project, under the CoVE initiative, aims to strengthen regional skill ecosystems in Advanced Manufacturing through collaboration, resilience, and innovation.

This synthesis report consolidates the key findings and strategic insights from three in-depth studies conducted within the LCAMP project on **Predictive Maintenance (PdM)**, **Supply Chain Management (SCM)**, and the **Alignment of VET Offer with Industrial Needs (BC)**. Developed by the LCAMP Observatory and led by the French cluster *Mecanic Vallée* and the Campus des Métiers et des Qualifications Industrie du Futur, with the support of partners located in Germany, Italy, Slovenia, Basque Country and the participation of Canada, the report aims to provide strategic insights for SMEs, Vocational Training Centres, and policymakers to help align industrial transformation with education and skills development

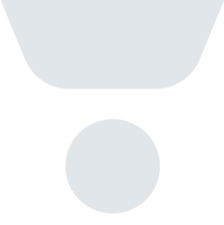
This report provides a key component of the strategic roadmap for enhancing the sustainability and growth of advanced manufacturing in the European Union (EU) and beyond. It synthesises insights from three focused investigations - on **Pdm and Maintenance domain, SCM with a focus on Profit Planning, S&OP, MPS, MRP, FCS/ICS processes (so called SCM 4.0 in this report)**, and the **alignment of Vocational Education and Training (VET) with industrial needs (BC)** - to assess how technological and organisational shifts are reshaping the ecosystem of small and medium-sized enterprises (SMEs) and the VET centres that support them.

The report highlights how digitalisation and green transitions are reshaping industrial processes, bringing both opportunities and challenges. While the digital and green transitions are advancing rapidly across industry, with large enterprises often leading the way in adopting technologies such as AI, digital twins, and advanced analytics, SMEs require more **iterative, modular approaches** due to limited financial and human resources. This presents a challenge for VET institutions tasked with preparing a diverse student body for an increasingly complex labour market. Despite this dichotomy, VET centres are uniquely positioned to respond to the evolving demands of industry through greater **collaboration, innovation, and systemic integration**.

Key findings from this synthesis include:

- **Digital Technology Adoption:** SMEs are making gradual progress in adopting technologies such as cloud-based PdM systems and AI-driven SCM platforms. Yet, implementation is uneven due to a lack of internal expertise, insufficient infrastructure, and financial barriers.
- **Skills Gaps and Workforce Readiness:** There is an urgent need for **technical skills** (e.g. data analysis, Internet of Things (IoT), Artificial Intelligence (AI), cybersecurity) as well as **transversal and soft skills** (e.g. adaptability, collaboration, systems thinking). VET institutions must address these gaps with flexible and hybrid training approaches, calling for closer industry-VET Centres collaboration and the autonomous empowerment of VET centres across Europe.
- **Operational and Organisational Transformation:** Digital and green transitions are reshaping industrial operations, driving cultural shifts toward agility, cross-functional collaboration, and data-informed decision-making. These changes demand corresponding reforms in training approaches and workforce development.
- **Sustainability Contributions:** PdM and SCM technologies directly support the green transition by improving energy efficiency, minimising resource waste, and enabling circular





economy practices. These technologies also enhance industrial resilience and long-term competitiveness.

- **Barriers to Adoption:** Common barriers include high implementation costs, resistance to change, fragmented data systems, and cybersecurity concerns. Tailored strategies and support mechanisms are needed to help SMEs move from experimentation to scaled adoption.
- **Strategic Recommendations:** The report advocates for improved **alignment between industry and academia**, expanded **investment in VET centres**, and coordinated **initiatives that jointly address digitalisation and sustainability goals**. Integration of core technologies into VET curricula and collaborative development with SMEs are also key enablers for future readiness.

Achieving a sustainable, robust, and forward-looking manufacturing sector will depend on the ability to **seamlessly integrate digital and green technologies** into industrial operations, while transforming educational practices to meet the evolving demands of the economy. By aligning emergent industry needs with innovative, learner-centred VET strategies, this report lays out **actionable steps to enhance workforce readiness, promote sustainable practices, and build a resilient industrial ecosystem for Europe and the world**.



1. INTRODUCTION

1.1. PURPOSE OF THE REPORT

The purpose of this report is to contribute to the overall goal of defining a structure and methodology for the observation and analysis of technological trends, skills requirements, and employment trajectories within the advanced manufacturing sector, with a view to supporting the future success of learners in Vocational Education and Training (VET) centres across the European Union.

It builds upon the findings of **three fields of Observation** conducted within the LCAMP project – **PdM and Maintenance domain** (Pichoutou Pascal et al., 2025a), **SCM with a focus on Profit Planning, S&OP, MPS, MRP, FCS/ICS processes (so called SCM 4.0 in this report)** (Pichoutou Pascal et al., 2025b), and the **alignment of Vocational Education and Training (VET) with industrial needs (BC)** (Pablo Marino, 2025) - and synthesises them to provide a unified vision of the key technological, operational, and workforce evolutions reshaping industrial ecosystems.

This report places particular emphasis on two core transformation dynamics of advanced manufacturing:

- The **digital transformation**, encompassing the integration of AI, IoT, data analytics, and automation into production and planning processes, and
- the **green transition**, which drives sustainable practices, resource efficiency, and climate-conscious innovation in operational strategies.

In this context, the report investigates how **small and medium-sized enterprises (SMEs)** are currently responding to these shifts in the fields of Observation. It explores their **practices, challenges, and readiness levels** through field observations, survey analysis, and documentation of **real-life business cases**. These insights aim to provide actionable benchmarks and strategic insights for two key audiences

- For SMEs: It offers **an overview of emerging technologies, concepts and tools applied in the fields of observation, and mainly in PdM and SCM domains**, making it possible to improve the efficiency of business processes.
- For VET Institutions:
 - To provide **strategic recommendations** for the adaptation of VET curricula and institutional strategies accordingly, and
 - To guide **policy and investment decisions** that enhance the capacity of training centres to anticipate and respond to evolving workforce needs.

At the heart of this analysis is a commitment to **learner-centred innovation**: equipping VET centres with the intelligence and tools needed to prepare students not only for current labour market demands, but for the future of work in **resilient, sustainable, and digitally integrated industrial environments**.



1.2. METHODOLOGIES

The methodology underpinning this synthesis report follows the structured framework of the LCAMP Observatory, as defined in the Observatory Process Cycle (D3.1), which aims to identify, analyse, and validate emerging occupational fields in the context of advanced manufacturing. This year's selection of Predictive Maintenance (PdM) and Supply Chain Management (SCM) as observation fields was guided by both cross-sectoral technological relevance and their strong alignment with the digital and green transformations defined in LCAMP's Work Package 7 (WP7).

The overarching approach follows a multi-stage and multi-method design, which enabled the combination of quantitative industrial analysis, qualitative VET engagement, and territorial deep dives:

Methodology for PdM and SCM Reports

The PdM and SCM strands of the research adopted a technology-driven approach combining:

- Cross-country expert discussions with partners from France, Germany, Sweden, Italy, Turkey and Slovenia to define priorities;
- A comprehensive literature review of scientific publications, industry foresight reports, and international case studies;
- Triangulated data collection, including:
 - Surveys targeting SMEs and VET Centres to gather insights on technology adoption, maturity, workforce gaps, training needs and investment barriers;
 - Semi-structured interviews with business leaders and technical experts;
- Both have been examined and validated by experts

These steps enabled robust insight generation on the operational, organisational, and workforce impacts of technology adoption, with validation by all LCAMP partners to ensure methodological coherence.

Methodology for BC Report (Business Change & Education)

In parallel, the BC (Business Change) report employed a field-based, education-centred methodology, aimed at understanding how VET institutions are responding to transformations in industry. This involved:

- An in-depth regional study in the Basque Country, based on the LCAMP 2024 analysis of job evolution in advanced manufacturing;
- Interviews with 21 VET professors, ranging from one-year specialization course instructors to mentors involved in dual training and innovation projects, to map pedagogical adaptation and innovation practices;
- Engagement with 12 industrial stakeholders, including SMEs and tech startups, to explore their talent needs and collaboration models with education;
- Survey input from the Spanish Association of Machine Tool Manufacturers (AFM) and complementary desk research on four selected occupations;
- Alignment with ESCO and other European skills frameworks to ensure consistency in qualification and competence analysis.

This dual-layered methodology - European and regional - enabled a comprehensive, vertically integrated understanding of how digital and green transitions affect the supply of and demand for skills, particularly in VET ecosystems.

By integrating these complementary methodologies, this report offers both a **pan-European strategic perspective** and a **grounded, practice-oriented lens** into the evolving dynamics of advanced manufacturing, ensuring relevance for both policy-makers and training practitioners.



1.3. CONTEXTS & MARKET DYNAMICS

Over the past decade, the accelerated adoption of Industry 4.0 technologies has fundamentally reshaped industrial operations, highlighted in the fields observed, particularly in **Maintenance and Predictive Maintenance, Supply Chain Management (SCM), CNC machining and quality control**. These transformations are not only technological but also organisational and strategic, redefining business models, market dynamics, and workforce expectations across the European advanced manufacturing ecosystem.

According to the **PdM report**, the global PdM market - valued at **USD 10.93 billion in 2024** - is forecast to exceed **USD 70 billion by 2032**, with projections reaching beyond **USD 100 billion by 2033**. Key drivers include the deployment of **AI, IoT, cloud computing**, and **sensor-based analytics**, enabling real-time machine condition monitoring, proactive maintenance strategies, and lifecycle cost optimisation. PdM has become a strategic enabler in sectors such as automotive, aerospace, and industrial manufacturing, with rapid adoption in North America, Europe, and growing momentum in Asia-Pacific.

Nevertheless, the **PdM report** also reveals important gaps. While large firms often lead in deploying predictive technologies, **SMEs face structural constraints** - limited investment capacity, insufficient digital readiness, and a lack of technical expertise- which slow their adoption. The shift from reactive to predictive maintenance demands not only technological capability but also new organisational models and workforce roles.

At the same time, the **SCM report** highlights how recent global shocks - COVID-19, geopolitical tensions, inflation, and climate disruption - have exposed vulnerabilities in global supply chains. In response, firms are investing in **Digital Supply Networks (DSNs)**, local sourcing strategies, and technologies like **blockchain, AI, digital twins**, and **advanced planning systems** to achieve visibility, agility, and resilience. SCM is evolving from a cost-optimisation function into a **strategic pillar of innovation and sustainability**, with particular focus on **Scope 3 emissions**, circularity, and risk anticipation.

Still, **European SMEs struggle to keep pace**. The SCM report identifies persistent barriers such as:

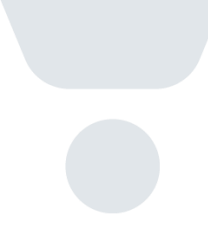
- Fragmented legacy systems and limited technological interoperability;
- Financial constraints and high entry costs for new tools;
- Cybersecurity concerns and data governance challenges;
- Internal resistance to organisational and process transformation.

These challenges directly affect workforce evolution. As roles become more data-centric and interdisciplinary, workers are expected to combine traditional know-how with skills in digital tools, systems thinking, and real-time decision-making.

These European trends are mirrored and reinforced by findings from the **regional case study in the Basque Country**, as presented in the **BC report**. The Basque manufacturing ecosystem, which includes a strong mix of SMEs and innovation-oriented firms, is undergoing similar structural shifts. According to the BC report insights, more than **44,000 new industrial hires** are projected in the region for 2024 alone, with **over 70%** focused on **production, maintenance, quality, and engineering roles**. The AFM Cluster highlights the urgent demand for **CNC operators, maintenance technicians**, and **quality controllers** who are also able to navigate data environments and interconnected systems.

Interviews in the Basque region underscore the pressure on **training centres** to respond to hybrid skill demands. Companies report that roles are becoming more fluid, blending previously siloed functions and requiring professionals to adapt quickly across processes. This reinforces the importance of **transversal competencies** - problem-solving, collaboration, adaptability - as well as **technical digital skills**.





These changes are not isolated. They reflect a broader trend across Europe: a convergence of **digital and green transitions** driving new performance standards, organisational models, and workforce requirements. As the BC report shows, **VET centres** must not only follow these changes but anticipate them - through curriculum renewal, partnerships with industry, and flexible learning pathways.

In this context, the **LCAMP Observatory** plays a strategic role in consolidating insights from different territories, validating technological signals, and supporting the alignment of VET systems with emerging market dynamics. By combining macro-level foresight with ground-level data from regions such as the Basque Country, this report provides a comprehensive picture of how **advanced manufacturing is evolving - and how education and training must evolve with it.**



2. EMERGING TECHNOLOGIES

The industry's digital transformation is driven by a series of advanced technologies that are reshaping advanced manufacturing through a constellation of key enabling technologies. These innovations not only improve performance, but also align operations with sustainability goals. Based on the Pdm, SCM and BC reports, this chapter presents an overview of the most important technologies in their fields of observation.

- **Internet of Things (IoT):** IoT plays a foundational role in numerous domains. It connects physical assets to digital systems using sensors and devices, becoming foundational for data acquisition in many fields.
IoT's added value lies in its ability to generate real-time, granular data at low cost. However, challenges include sensor calibration, network integration, cybersecurity risks, and data overload without proper filtering or analytics.
- **Cloud and Edge Computing:** These technologies support data storage, processing, and analytics across distributed environments:
 - Cloud computing enables SMEs to access advanced tools such as predictive analytics platforms, real-time monitoring dashboards, collaborative planning systems, and scalable data storage solution - without the need for significant on - premise infrastructure. Cloud platforms aggregate data, provide AI capabilities, and host dashboards supporting decentralised decision-making.
 - Edge computing allows processing close to the data source, reducing latency and network dependency, critical for real-time responses needs. It also supports local operations in warehouses or manufacturing lines.

Cloud platforms offer scalability and interoperability, while edge ensures autonomy and speed. The main constraints are data security, system integration, and service reliability - especially where infrastructure is fragile.

- **Digital Twins:** A digital twin replicates a physical process or system in a virtual environment, virtually representing physical assets, systems, or processes. They combine sensor data, historical records, and AI-based predictions to simulate real-world behaviour.
Digital twins offer significant added value by bridging real and virtual operations. Their constraints include modelling complexity, high-quality data needs, and integration with legacy systems.
- **Artificial Intelligence (AI):** AI is rapidly becoming the backbone of predictive systems in large domains. It enables systems to learn from data, identify complex patterns, make predictions, and support decision-making. AI supports the transition from rule-based automation to systems capable of learning, adapting, and optimising decisions. AI empowers industries to optimize maintenance cycles, streamline production, and enhance supply chain responsiveness.

The broad field of Artificial Intelligence encompasses a range of advanced methods and architectures. The following overview highlights key categories - Machine Learning and Deep Learning, Neural Networks and Transformers, Generative AI and Data Augmentation, **NLP and Conversational AI**, Explainable AI (XAI) and Interpretable Machine Learning (iML), **Clustering algorithms for optimisation**, and Optimisation Algorithms - each playing a distinct role in enabling predictive, adaptive, and transparent decision-making across industrial contexts.



Machine Learning (ML) and Deep Learning (DL)

ML models - such as Decision Trees, Random Forests, and Support Vector Machines (SVMs) - are extensively applied in many fields. They help forecast equipment degradation, classify component failures, predict demand fluctuations, and optimize inventory and scheduling.

- Decision Trees allow interpretable, rule-based decision-making.
- Random Forests, as ensembles of Decision Trees, improve prediction accuracy by aggregating multiple trees.
- SVMs are used in classification tasks (e.g., inventory segmentation) and regression models (e.g., demand forecasting), effective in high-dimensional datasets.
- Added Value: High accuracy and flexibility in structured environments.
- Constraints: Requires large, high-quality datasets and parameter tuning.

Neural Networks and Transformers

Neural architectures - including Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks - are particularly suited for time-series forecasting and predictive scheduling. These are essential in modeling production demands, maintenance cycles, or procurement trends.

- Transformer models (e.g., BERT, GPT) are being adopted for complex text-based analysis, such as interpreting reports or parsing contracts.
- Added Value: Handle sequential dependencies and unstructured data with high predictive power.
- Constraints: Resource-intensive and difficult to interpret without specific tools.

Generative AI and Data Augmentation

LLMs (Large Language Models) models, such as BERT and GPT, process large datasets and detect real-time scheduling anomalies. They are particularly effective in handling long-range dependencies in data, making them suitable for instance for:

- Dynamic scheduling adjustments
- Synthetic failure data generation, addressing the scarcity of historical breakdown data. This supports robust models even when historical datasets are sparse.
- Enhanced training of AI models by simulating rare but critical events.
- Natural language generation, e.g., summarizing maintenance logs, generating work orders, or producing technician guidance.
- Added Value: Enables AI even in low-data contexts, improves generalization.
- Constraints: Requires robust model training frameworks, validation mechanisms.

NLP and Conversational AI

Natural Language Processing (NLP) enables AI to parse unstructured data like emails, chat logs, or technician notes:

- Chatbots streamline supplier communication.
- Named Entity Recognition (NER) extracts structured data from texts.
- Topic Modeling (LDA) and Sentiment Analysis aid in risk detection and workforce management.
- Added Value: Automates knowledge extraction and communication.
- Constraints: Sensitive to linguistic nuance and data privacy concerns.

Explainable AI (XAI) and Interpretable Machine Learning (iML)

The integration of Artificial Intelligence (AI), the Internet of Things (IoT), and human-machine interfaces connects hardware and software systems to optimize automation business processes. As industries transition towards Industry 5.0, the focus shifts from



machine-centred operations to human-centred AI, where AI technologies augment human decision-making to enhance productivity.

However, its effective deployment depends heavily on the availability of high-quality data, skilled personnel to develop and maintain models, and user confidence in the system's outputs. For many SMEs, these prerequisites remain a barrier - particularly in the absence of external support structures or modular, easy-to-integrate solutions.

To address concerns around trust and usability, new approaches are emerging to make AI more transparent and accessible through Explainability and Interpretability solutions:

- XAI (e.g., SHAP, LIME) enhances user confidence by providing clear explanations of how AI systems reach their conclusions. This helps operators understand the rationale behind AI-generated decisions, fostering trust and facilitating adoption.
- iML uses inherently interpretable models like Decision Trees, Generalized Additive Models (GAMs), and Explainable Boosting Machines (EBMs). iML ensures that decision models used are inherently transparent and interpretable. By enabling users to trace the logic behind predictions or recommendations, iML contributes to more responsible and controllable AI integration in operational contexts
- Added Value: Increases transparency, supports regulatory compliance.
- Constraints: Requires tailoring to specific model architectures.

Clustering algorithms for optimisation

AI leverages clustering techniques to enhance planning, classification, and scheduling:

- K-Means, DBSCAN (Density-Based Spatial Clustering of Applications with Noise) and Gaussian Mixture Models (GMM) are a widely used unsupervised learning algorithm for grouping similar data points together.
- Added Value: Automates classification, enhances process efficiency.
- Constraints: Sensitive to outliers, requires tuning.

Optimisation Algorithms

AI-powered optimization is used to balance complex resource allocation problems:

- Genetic Algorithms (GA): Multi-objective scheduling and resource balancing.
- Ant Colony Optimization (ACO): Dynamic routing and sequencing.
- Particle Swarm Optimization (PSO): Adaptive workload balancing and procurement planning.

In sumup, these methods are critical in production planning, procurement alignment, and logistics.

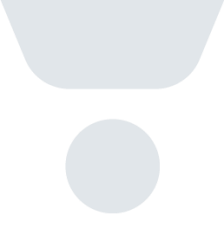
- Added Value: Solves real-time, large-scale allocation problems.
- Constraints: High computational demand and sensitive to parameter settings.

- **Cybersecurity:** Cybersecurity is not only a technical concern but a foundational element of trust in digital systems. As reliance on AI, cloud, and IoT expands, ensuring robust cyber resilience becomes essential - particularly for SMEs that may lack the necessary infrastructure or expertise. These advancements introduce vulnerabilities, making industrial control systems (ICS) and operational technology (OT) infrastructures more susceptible to cyberattacks. The reports highlights three major risks:
 - **Advanced Persistent Threats (APTs)** targeting sensitive supplier or logistics data.
 - **Supply Chain Poisoning**, where malicious components are introduced during upstream processes.
 - **Data Breaches**, causing operational disruption and reputational harm.

To mitigate these risks, initiatives like DETECTA 2.0 focus on integrating cybersecurity measures into PdM, enhancing resilience for small and medium enterprises (SMEs).

- **Blockchain:** Although its adoption is still incipient among SMEs, blockchain is identified as a promising solution for traceability, transparency, data integrity across decentralised





systems and contract management and a strategic enabler for cybersecurity, offering immutable and decentralized records of transactions.

Blockchain's added value is in transparency and trust. However, it remains complex to implement and is not yet widely adopted in SME environments due to technical and cost barriers.



3. DIGITAL AND GREEN TRANSITION TRENDS IMPACTS IN SMES

3.1. TECHNOLOGICAL SHIFTS IN THE FIELD OF OBSERVATION

Building on the advanced technologies described previously, we now turn to their concrete applications within the domains examined in the PdM, SCM, and BC reports.

This suite of advanced technologies are reshaping Predictive Maintenance (PdM) and Supply Chain Management (SCM). While the two domains differ in scope and operational logic,

These digital technologies are not just tools, but catalysts for new industrial practices, with the adoption of these advanced technologies in the fields of predictive maintenance (PdM) and supply chain management (SCM). Although these fields serve different business objectives, they increasingly rely on overlapping technologies and innovation models: they share a growing reliance on Artificial Intelligence (AI), the Internet of Things (IoT), Cloud Computing, and Digital Twins. These technologies do not just support automation - they are redefining how decisions are made, resources are allocated, and performance is optimised.

PdM technologies are primarily used to predict equipment failures, enhance machine uptime, and reduce unplanned interventions. They reshape how companies monitor, maintain, and service equipment. IoT sensors provide real-time condition monitoring. AI enables early detection of degradation and failure risks. Digital twins simulate operational behaviour, and cloud platforms aggregate and analyse data at scale.

SCM technologies, by contrast, are applied to forecasting, planning, scheduling and network orchestration. The shift is evident in the increasing use of AI for demand forecasting and risk analysis, IoT for asset and shipment tracking, and cloud systems for synchronising operations across suppliers and customers. SCM processes – related to the field of observation in planning, execution, and monitoring - are being redesigned to leverage digital capabilities for agility and resilience.

3.1.1. TECHNOLOGICAL NARRATIVES AND STRATEGIC FOCUS

While PdM applications focus on internal performance, system reliability, and cost optimisation, SCM applications are driven by network coordination, flexibility, and sustainability. This reflects distinct narratives:

- PdM prioritises uptime and process excellence, with a goal of zero unplanned downtime and cost-efficiency in maintenance.
- SCM emphasises agility, end-to-end coordination, and resilience, particularly in volatile markets or regulatory contexts.

Both domains are converging towards more autonomous, explainable, and service-based systems. However, their deployment paths differ:

- Large companies lead with integrated AI and digital twin platforms.



- SMEs, while slower to adopt, show potential via modular solutions, cloud-based services, and collaborative ecosystems.

3.1.2. TECHNOLOGIES IN PREDICTIVE MAINTENANCE

Predictive Maintenance is rapidly evolving from traditional time-based and reactive maintenance approaches to data-driven, condition-based models. This shift is largely made possible by the deployment of the digital technologies described above, as described below.

Internet of Things (IoT)

IoT devices gather real-time data from machinery and enable continuous monitoring by tracking key parameters like vibration, temperature, pressure, energy use, and lubrication levels. This data feeds into predictive models to detect anomalies and schedule maintenance proactively.

This data is critical for condition monitoring and feeds directly into AI models and diagnostics platforms.

IoT helps anticipate failures before they impact production and enables remote surveillance.

Cloud and Edge Computing

Cloud platforms support scalable data storage, analytics, and maintenance dashboards - enabling SMEs to implement PdM without building their own IT infrastructure. They support the development of PdM-as-a-Service (PdMaaS).

Edge computing processes data at the equipment level, allowing real-time decisions and reducing latency, which is critical in high-speed production environments.

Digital Twins

Digital twins simulate the dynamic behaviour of assets, supporting what-if analyses and lifecycle predictions.

Used in combination with PdM software, they provide insights into stress factors, energy consumption, and expected time-to-failure.

These simulations help optimise preventive interventions and spare part planning.

Artificial Intelligence (AI)

In maintenance, AI is used to build predictive models that forecast equipment failure, detect anomalies, and recommend optimised maintenance actions.

Different AI approaches are deployed depending on the context:

- Machine Learning (ML): ML algorithms are widely used in PdM for failure prediction, anomaly detection, and trend analysis. These systems improve over time by learning from historical data.
- Deep Learning (DL): A subset of ML, DL is used in PdM to process sensor data and detect subtle patterns for instance in vibrations, temperature changes, or pressure readings.
- Large Machine Learning Models (LMMs): These models integrate vast datasets to offer scalable insights. In PdM, LMMs help interpret complex multi-sensor data.
- Generative AI / Large Language Models (LLMs): In PdM, LLMs offer a new interface for technicians by enabling natural language interaction with diagnostic tools or maintenance instructions. They can summarise historical maintenance logs or answer procedural queries.

Trust and usability:



- Explainable Artificial Intelligence (XAI): in PdM, XAI techniques such as GradCAM, DIFFI, and ARCANA are used to help operators understand why an AI model flagged a component as faulty. These methods highlight which variables (e.g. vibration, temperature) contributed most to an anomaly or failure prediction. For instance, DIFFI ranks features causing anomaly detection in time-series data, while ARCANA identifies root causes by analysing reconstruction errors in autoencoder-based models. Such tools enhance trust and enable more informed decision-making.
- Interpretable Machine Learning (IML): in PdM, IML focuses on using transparent models like Decision Trees, LionForests, and Explainable Boosting Machines (EBMs) that offer clear logic and rule-based predictions. For example, LionForests generate human-readable IF-THEN rules from Random Forests to explain fault classifications, while EBMs show how each input feature contributes to maintenance outcomes. These methods help operators and engineers trace the reasoning behind predictions, supporting responsible AI integration in industrial settings.

Blockchain:

In PdM, blockchain is rarely used but may support secure logging of maintenance operations or part replacements for warranty and traceability.

Cybersecurity

PdM emphasizes the protection of machine data and continuity of operations.

Case Study Insights

Two cases described in the PdM report the evolution of Predictive Maintenance (PdM) from reactive, time-based models to advanced data-driven systems. It emphasizes how AI, quality integration, and modular automation are reshaping PdM strategies. These two case studies illustrating the deployment of cutting-edge models and their practical benefits across industries.

- Case 1 - Enhanced PdM Using Product Quality Integration
 - Methods Used:
 - Integration of ML and Product Quality for PdM
 - Development of a Three-Step Framework with **91%** of accuracy.
 - Results:
 - The vacuum mixer machine was identified as the most critical element impacting PQ (85% of total waste)
 - The framework demonstrated that predicting maintenance needs based on product quality variations leads to significant cost savings and improved efficiency.
 - Financial Impact:
 - 50% reduction in machine downtime costs.
 - 64% reduction in scrap-related costs.
- Case 2 - Anomaly Detection in Induction Motors Using Real-Time IoT Data
 - Methods Used:
 - The study compared three ML algorithms based on their sensitivity, specificity, and inference time (average performance across validation and test datasets).
 - Results:
 - The study successfully developed a low-cost, real-time predictive maintenance system using IoT sensors and ML algorithms for anomaly detection in induction motors.



3.1.3. TECHNOLOGIES IN SUPPLY CHAIN MANAGEMENT

In SCM, digital transformation is focused on improving agility, visibility, and responsiveness across the value chain. As described below, technologies are deployed at all levels analysed in the field of observation within SCM planning and execution.

Internet of Things (IoT)

IoT sensors support operational execution by enabling:

- Real-time tracking of shipments and containers,
- Warehouse condition monitoring (e.g., temperature-sensitive goods),
- Automation of inventory counts and replenishment triggers.

It supports real-time visibility, alerting, and traceability.

IoT is considered an enabling technology and is already standard in many large companies. For example, pilot results show that IoT-based monitoring in production networks can reduce material waste by 12-20%.

Cloud Computing

Cloud platforms provide the backbone for integrating planning systems and supply chain visibility tools:

- Cloud systems host dashboards, real-time KPIs, and collaborative planning interfaces.
- Used to synchronise data flows across departments and external partners (suppliers, transporters, customers), enabling data sharing across networks and supporting decentralised decision-making.

Edge computing systems can support local operations in warehouses or manufacturing lines.

Digital Twins

While still emerging in SCM, digital twins are used to:

- Simulate supply chain networks and production flows,
- Evaluate capacity changes or supply disruptions,
- Test impact of sustainability measures or lead time variations.

They are often coupled with control towers, providing a “cockpit view” of SCM operations.

Blockchain:

In SCM, blockchain helps track the origin and movement of goods, verify compliance, and automate transactions through smart contracts. It is especially useful in regulated industries or sustainability-certified supply chains. It offers secure and transparent data exchanges for ensuring contract compliance.

Cybersecurity

Identified as both a central pillar in digital strategies and one of companies' main concerns in the SCM Survey, with 100% of medium enterprises and 60% of small ones rating it as “critical”, Cybersecurity in SCM is identified as high risks in complex supplier ecosystems and points to blockchain as a promising solution.

Artificial Intelligence (AI)

AI enables smart forecasting, risk management, and planning synchronisation:

- in SCM, it supports forecasting, inventory optimisation, dynamic inventory control, planning and scheduling. According to the SCM report, AI was mentioned in 9 out of 31 use cases and has led to up to 15% reduction in logistics costs and 35% improvement in inventory



accuracy. Nevertheless, AI adoption remains limited among SMEs, but its strategic potential is widely acknowledged

Different AI approaches are deployed depending on the context:

- Machine Learning (ML): In SCM, ML is used for forecasting, risk assessment, and adaptive planning. These systems improve over time by learning from historical data.
- Deep Learning (DL): A subset of ML, in SCM, DL can support image recognition (e.g., for product quality) and pattern extraction from large datasets.
- Large Machine Learning Models (LMMs): In SCM, they support global demand forecasting and network optimisation.
- Generative AI / Large Language Models (LLMs): In SCM, they may support document automation or customer service chatbots.

To address concerns around trust and usability, new approaches are emerging to make AI more transparent and accessible:

- Explainable Artificial Intelligence (XAI): in SCM, risk management systems increasingly use **XAI methods** like **SHAP**, **LIME**, and **GradCAM** to clarify how AI models make decisions - such as ranking suppliers based on lead times, ESG performance, or cost. These tools help stakeholders understand and trust automated forecasts or assessments, making AI-driven recommendations more transparent and acceptable to decision-makers.
- Interpretable Machine Learning (IML): In forecasting and logistics, **IML models** such as **Decision Trees**, **Explainable Boosting Machines (EBMs)**, and **GAMs** are used to provide clear, traceable logic behind planning recommendations. For example, **DIFFI** and **LionForests** help identify root causes of supply chain anomalies or disruptions, ensuring decisions are explainable and auditable - especially important for regulated industries or collaborative planning processes.

Applied to the SCM levels defined in the field of observation, AI application can be summarised as follows:

- Profit Planning (PP): AI simulates financial outcomes and supports scenario planning.
- Sales & Operations Planning (S&OP): AI optimises demand forecasting, allowing better coordination between sales forecasts and production plans.
- Master Production Scheduling (MPS) & MRP: AI calculates optimal production and procurement quantities under uncertainty.
- Finite/Infinite Capacity Scheduling (FCS/ICS): AI-driven algorithms enhance resource allocation and sequencing.

Performance gains:

Some SCM use cases integrating AI show up to 15% reduction in logistics costs and 35% improvement in inventory levels.

3.1.4. EMERGING OPERATIONAL AND INNOVATION MODELS

Beyond technologies, new operational models are gaining traction:

- Platform-based collaboration between SMEs and service providers (e.g., PdM platforms or SCM integrated logistics control towers).
- Service-oriented architectures that reduce internal infrastructure needs. For example, PdMaaS (Predictive Maintenance as a Service) enables companies, particularly SMEs, to outsource predictive capabilities without owning the infrastructure. It is cost-effective and typically provided through cloud platforms or OEMs (Original Equipment Manufacturer) bundling diagnostics with equipment (Equipment-as-a-Service).
- Testbeds and public-private partnerships, which help SMEs de-risk experimentation.



The BC report offers also concrete examples of SMEs accessing shared digital infrastructure, embedded services, or training modules through regional ecosystems. These models and ecosystems provide shared access to infrastructure, training, and support services, particularly in regions with active industrial clusters, playing a critical role in making high-end technologies accessible to smaller actors.

3.2. GREEN CONTRIBUTIONS TRANSITION

The digital transformation in advance manufacturing and the domains observed in the three reports is closely intertwined with the green transition. The described technologies are not only enablers of operational efficiency but also powerful levers for environmental performance. This chapter summarises how the advanced technologies applied to the observed activities contribute to sustainability goals - by reducing emissions, optimising resources, and supporting circular economy practices - and how they are aligned with broader political and regulatory frameworks.

3.2.1. SUSTAINABILITY: OPPORTUNITY AND OBLIGATION

Both the PdM and SCM reports highlight a dual narrative around sustainability:

- In the PdM context, sustainability is framed as a driver of innovation and efficiency. It improves performance, lowers costs, and enhances competitiveness - making it a “self-funding” improvement.
- In the SCM context, sustainability is also a regulatory imperative. Companies must comply with ESG (Environmental, Social, and Governance) criteria, EU Green Deal targets, and emerging legal frameworks (e.g. due diligence in supply chains, Scope 3 emissions monitoring).
- In the common SME context, the integration of digital transformation with environmental goals remains underdeveloped. Many small and medium-sized enterprises (SMEs) lack the necessary expertise in sustainability management, particularly in applying systems thinking within the circular economy. Although environmental objectives are increasingly being communicated, there is still a significant gap in practical training approaches that embed ecological considerations into business operations and employee development programs.

This creates both a strategic opportunity and a compliance obligation: digital technologies enable companies to anticipate and meet increasingly stringent environmental requirements while positioning themselves as leaders in green innovation.

3.2.2. PDM AS A CATALYST FOR ENVIRONMENTAL EFFICIENCY

The PdM report frames predictive maintenance as a win-win strategy: it improves operational performance while simultaneously advancing sustainability goals. Its environmental contributions are tangible and measurable:

- Reduced energy consumption: By detecting inefficiencies early and maintaining machines under optimal operating conditions, PdM avoids energy waste.
- Lower material waste: Scheduled maintenance based on actual need reduces emergency repairs and premature part replacements, minimising the use of spare parts and raw materials.
- Extended asset lifespan: Early detection and correction of faults help extend the usable life of equipment, aligning with circular economy goals.



- Optimised logistics and transport emissions: Preventing breakdowns means fewer unplanned interventions and urgent spare part deliveries, leading to lower logistics-related emissions.
- Support for the circular economy: PdM facilitates reuse and refurbishment, reducing the need for new equipment and contributing to sustainable asset management.

Overall, PdM supports both CO₂ reduction targets and economic competitiveness, helping SMEs balance environmental goals with profitability. The reports present PdM as a strategic lever that reconciles climate action with industrial efficiency.

3.2.3. SCM 4.0 AND GREEN SUPPLY CHAIN MANAGEMENT

The SCM report goes further by positioning SCM 4.0 as a core enabler of Green Supply Chain Management (GSCM). Through digitalisation, companies gain visibility and control over environmental impacts across the full value chain - from sourcing to production, transport, and end-of-life.

Key contributions include:

- 12–20% reduction in material waste through IoT-enabled monitoring of resource flows.
- 5–10% CO₂ reduction in logistics via AI-based route optimisation and load balancing.
- Blockchain-enabled traceability increases the share of recycled materials used in production by up to 15%, due to improved transparency and supplier accountability
- Circular economy integration, with digital tools enabling closed-loop logistics, remanufacturing, and lifecycle tracking.
- Eco-design support, allowing supply chain stakeholders to collaborate on greener product development from the design phase onward.

Despite these advances, only 27% of surveyed companies have formally aligned their digital and sustainability strategies, pointing to a major opportunity for synergy.

3.3. OPERATIONAL, ORGANISATIONAL AND WORKFORCES IMPACTS

Building on the previous chapters, which outlined how emerging technologies can enhance business activities and highlighted their sustainability contribution, this section focuses on their broader impacts. Emerging technologies not only offer digital solutions to concrete challenges but are also fundamentally reshaping how companies operate, structure themselves, and evolve their workforces. Below, we summarise the key changes identified across the three reports, as they manifest in Maintenance and predictive maintenance (PdM), supply chain management (SCM), **Automation, Quality Control and CNC Operating.**

PdM and SCM are both catalysts for broader changes in workflows and organisational structures, requiring significant adaptation in organisations and workforce roles.

In both domains, new roles are emerging that combine engineering expertise with digital fluency. Maintenance and logistics professionals are increasingly expected to interpret dashboards, interact with AI-driven systems, and collaborate across departments.

In PdM, new models like PdMaaS shift tasks from technicians to data analysts and remote service operators.

In SCM, similar transformations occur. Decision-making becomes more data-driven, requiring coordination across IT, logistics, purchasing, and planning. Workers need to manage integrated



platforms, validate algorithmic suggestions, and collaborate with external stakeholders. These changes highlight the growing importance of transversal skills and digital literacy.

3.3.1. OPERATIONAL IMPACTS

At the operational level, PdM and SCM 4.0 have introduced major shifts in how decisions are made, how workflows are structured, and how resources are managed in real time.

In **Predictive Maintenance**, operations are moving from traditional preventive routines to a more dynamic, **data-driven approach**. In PdM, interventions are based on actual wear patterns or anomalies detected by sensors, which leads to reduced machine downtime and more efficient resource utilisation.

This transition brings several tangible operational improvements:

- **Reduced unplanned downtime** through continuous condition monitoring and real-time alerts.
- **Strategic scheduling** of maintenance tasks during planned downtimes or low-activity periods.
- **Data-informed decision-making**, replacing intuition with sensor-based diagnostics and forecast dashboards.
- **Automation of routine decisions**, such as triggering maintenance orders when thresholds are exceeded.

Similarly, in SCM, digital tools such as AI, IoT, and cloud platforms enhance agility and responsiveness across the supply chain. Planning becomes less reactive and more anticipatory, thanks to real-time data and automated scenario modelling.

Operational changes include:

- **Real-time visibility** of logistics and inventory flows, improving responsiveness to disruptions.
- **Dynamic planning and re-planning**, based on live inputs from IoT devices and digital twins.
- **AI-assisted decision-making**, including automated procurement or delivery route optimisation.
- **End-to-end workflow integration**, breaking down silos between departments like sales, production, and logistics.

These changes are further illustrated by the findings from the Basque Country regional report. The operational impacts of digital transformation are reshaping how professionals perform their daily tasks and interact with technology systems. There is a clear shift toward predictive approaches across all profiles, moving from reactive to predictive and condition-based maintenance and quality control supported by sensor networks, real-time alerts, and advanced monitoring systems.

The redistribution of tasks is evident. For example, machine or line operators are acquiring some of the traditional responsibilities of quality control, making quality a shared responsibility among production teams. Maintenance technicians now face expanded responsibilities that go beyond traditional repair tasks and include contributing to process optimisation and the technological integration of automation systems.

3.3.2. ORGANISATIONAL IMPACTS

Operational improvements are only possible when supported by appropriate **organisational structures and cultural changes**. The implementation of PdM and SCM 4.0 tools challenges traditional hierarchies and promotes more collaborative, agile models.



In both domains, organisations are increasingly adopting **cross-functional teamwork** and **agile working methods**. Rather than long, linear projects, they now rely on short pilot cycles, with iterative feedback loops. This enables faster innovation and better alignment with fast-evolving technological landscapes.

Key organisational evolutions include:

- **From siloed departments to cross-functional collaboration**, involving IT, operations, maintenance, and data teams.
- **Development of agile project models**, based on rapid experimentation and scaling.
- **Increased use of digital platforms**, enabling transparency and coordination across teams.
- **Stronger leadership roles in change management**, with managers acting as enablers of digital adoption.

From the Basque Country case study, the transformation at the organisational level includes the emergence of hybrid roles that bridge functions traditionally separated across maintenance, automation, and quality domains. Automation is no longer isolated but interconnected with broader production and data platforms, requiring employees to navigate human-machine interfaces and communication protocols.

This convergence of roles brings new collaborative dynamics, where professionals must work across traditional boundaries and actively engage with integrated systems. Moreover, the adoption of data-driven decision-making processes has made real-time analytics central to daily operations.

Companies increasingly contract services related to AI, cybersecurity, and predictive maintenance, highlighting the growing need for digitally-aware internal roles. These professionals may not be deep technical experts but possess enough foundational knowledge to ensure smooth communication with external technology providers. Their function is to translate technological innovations into operational practices that align with the internal needs and strategic objectives of the organisation.

One particularly notable shift is the emergence of new business models like Maintenance-as-a-Service (MaaS). Enabled by PdM, this model allows vendors to offer equipment uptime guarantees or performance-based contracts, redefining customer-supplier relationships:

- Maintenance becomes a **value-added service**, not just a cost centre.
- Manufacturers evolve toward **service-oriented models**, with predictive diagnostics integrated remotely.
- This transformation supports **recurring revenue streams** and **closer client partnerships**.

However, these changes do not come without challenges. From the SCM report, several organisational **barriers to transformation** have been identified:

- **Technological integration issues**, especially in SMEs with legacy systems.
- **Cybersecurity concerns**, exacerbated by greater digital exposure.
- **Resistance to change**, particularly among older or more experienced workers.
- **Financial constraints**, limiting SMEs' ability to invest in infrastructure or talent.

Despite these obstacles, successful organisations are those that proactively manage change by building internal capabilities and fostering a **culture of learning, trust in data, and experimentation**.

3.3.3. WORKFORCE IMPACTS

Technological adoption goes hand in hand with a transformation of work. PdM and SCM 4.0 demand **new roles, new skills, and new mindsets**.



In **PdM**, maintenance professionals are moving away from purely mechanical tasks toward **monitoring, analysis, and strategy**. Traditional technicians are increasingly required to interpret sensor data, understand statistical patterns, and work alongside IT systems.

This shift entails:

- **Transformation of roles**, such as the emergence of PdM analysts or digital maintenance strategists.
- **Integration of IT and OT skills**, as technicians must now interact with condition monitoring software and AI tools.
- **Cross-training between departments**, fostering collaboration across maintenance, data, and engineering teams.

In parallel, the Basque Country study revealed a growing demand for hybrid professional profiles that combine traditional technical expertise with digital competencies. For example:

- Quality technicians are now expected to combine inspection skills with digital and data management, using machine vision systems, 3D scanners, and digital verification tools.
- CNC operators increasingly interact with MES and ERP systems, perform program adjustments, and apply data analysis techniques, including predictive maintenance.

In **SCM**, workforce changes mirror these developments. Manual data entry and rule-based planning are increasingly automated. Employees now supervise algorithm outputs, handle complex exceptions, and provide strategic inputs into planning decisions.

The SCM report identifies several major workforce impacts:

- **Emergence of hybrid roles**, such as supply chain analysts with digital and operational expertise.
- **Growing demand for data and systems literacy**, even in traditionally non-technical roles.
- **Increased need for cybersecurity awareness**, given the sensitivity of connected systems.
- **Greater emphasis on learning curves and continuous training**, as technologies evolve faster than existing curricula.

However, many companies – particularly SMEs – face acute challenges:

- **Digital skills gaps and talent shortages** limit their ability to adopt SCM 4.0 tools effectively.
- **Misalignment between training programmes and real-world systems** undermines return on investment.
- **Employee resistance to automation**, often linked to fears about job loss or complexity, creates friction.

To succeed in this new environment, workers must develop both **technical** and **soft skills**:

Key technical and analytical skills include:

- Data analysis and visualisation (e.g. using dashboards)
- Understanding predictive algorithms and fault models
- Familiarity with cloud platforms and diagnostic tools

Critical soft skills include:

- Adaptability and continuous learning
- Teamwork across departments
- Effective communication of technical findings

These findings highlight the urgency for companies to embed **workforce development and change management** into their digital strategies.



3.4. ADOPTION AND MATURITY IN SMES

The adoption of advanced technologies and contributions to the green transition previously described is accelerating in small and medium-sized enterprises (SMEs). However, this process remains uneven and faces a variety of operational, cultural, and strategic barriers. This section presents a synthesis of adoption levels, key constraints, and the related implications for skills development.

The data and figures presented here are drawn from the studies referenced in the three reports, as well as from dedicated surveys conducted among SMEs.

3.4.1. CURRENT ADOPTION LEVELS AND KEY FIGURES

Across the board, SMEs increasingly recognise the strategic value of PdM and SCM 4.0 technologies. Their motivations stem from both internal drivers (such as improved efficiency and cost reduction) and external pressures (compliance requirements, client expectations, and supply chain integration).

3.4.1.1. PDM ADOPTION HIGHLIGHTS:

- The global predictive maintenance market shows robust growth, with manufacturing as a leading sector.
 - While the PdM report notes that 81% of firms were investing in predictive approaches in 2018, with 40% calling it a strategic priority, the most common practices remain time-based or curative maintenance.
 - Search interest in PdM has tripled since 2017, surpassing other maintenance-related searches, indicating its growing importance as a must-have industrial solution.
 - The most widely used PdM method is vibration monitoring (28% of implementations).
- The survey results indicate that while SMEs recognize the importance of Predictive Maintenance (PdM) in enhancing efficiency and competitiveness, its adoption remains at an early stage of exploration for many companies.
- A few frontrunners have implemented pilot PdM systems, particularly on critical assets.

3.4.1.2. SCM ADOPTION HIGHLIGHTS:

- Survey results reveal wide variation in digital maturity, from highly connected logistics networks to manual, Excel-based workflows.
- Only a small percentage of SMEs have adopted integrated digital and green SCM strategies: 3% of SMEs in the EU demonstrate high digital intensity, compared to 98% of large firms.
- 64% of SMEs report difficulties in analysing their own operational data, and 74% feel they are not generating sufficient value from current digital investments.
- The results of the SMEs survey indicate that execution and scheduling functions are the most commonly digitised. However, forecasting, S&OP, and MPS functions show lower integration, especially in smaller firms.
- SCM-specific adoption is concentrated in execution and scheduling, using tools such as AI, IoT, and cloud-based computing.
- Forecasting and S&OP functions are underdeveloped, especially in small enterprises.



3.4.2. BARRIERS AND CONSTRAINTS

While the value proposition of PdM and SCM 4.0 technologies is widely recognised by SMEs, **the nature and intensity of the barriers to adoption differ** slightly between these two domains.

3.4.2.1. FINANCIAL CONSTRAINTS

For **PdM**, financial barriers are often linked to:

- The **high initial cost** of sensors, monitoring equipment, analytics platforms, and integration into existing maintenance infrastructure.
- The need for **specialist services or external consultants**, which adds operational costs in the absence of internal capabilities. Even with cloud or “as-a-service” models, ongoing operational costs remain a concern.
- Limited awareness or access to **targeted funding** for PdM innovation — many SMEs remain unaware of available grants or find them difficult to access.

In the case of **SCM**, financial constraints stem from:

- The **cumulative cost of digitising multiple functions** (e.g. procurement, inventory, logistics), which may require platform overhauls or cloud migration.
- Lack of return on investment visibility due to **underutilised digital tools** - many SMEs invest in ERP extensions or dashboards but fail to fully adopt them.
- Difficulties in justifying investments for **green transition components** such as carbon tracking or circular logistics in the absence of short-term gains.

In both domains:

- The limited investment capacity of SMEs - often operating under tight cash flow conditions - remains a major hurdle. Even pay-as-you-go or “as-a-service” models are sometimes perceived as risky recurring expenses.
- Many SMEs lack access to public funding or private investment, slowing technology adoption.

3.4.2.2. TECHNICAL BARRIERS

In **PdM**, technical challenges are often rooted in:

- **Integration difficulties:** Connecting modern sensors and data systems to older machinery or disparate CMMS tools.
- **Interoperability issues:** Incompatible data formats or machine interfaces hinder seamless monitoring.
- **Cybersecurity risks:** Increased connectivity opens up vulnerabilities, especially in unattended edge devices.

In **SCM**, technical barriers manifest through:

- with legacy systems that do not support real-time collaboration or automation.
- Difficulties in **linking planning systems to operations** - for example, integrating inventory dashboards with actual warehouse or transport data.
- A lack of data quality and governance frameworks, resulting in poor or delayed decision-making.

In both areas:



- the **absence of robust internal IT support structures** exacerbates technical barriers. SMEs frequently depend on generalist staff or third-party support, delaying resolution and innovation.
- Cybersecurity is a cross-cutting concern, with 100% of medium enterprises and 60% of small ones rating it as “critical”, exacerbated by the limited internal expertise
- **Complex and fragmented legacy IT infrastructures** hamper the integration of PdM/SCM solutions

3.4.2.3. ORGANISATIONAL AND STRATEGIC BARRIERS

For **PdM**, organisational barriers include:

- **Lack of a digital maintenance strategy**, leading to fragmented or isolated pilot initiatives.
- **Low visibility of PdM value** at the management level, resulting in low prioritisation.
- Reluctance to change from traditional preventive or reactive approaches, especially among experienced technicians.

In **SCM**, strategic barriers tend to be more cross-functional:

- **No unified digital roadmap** across departments, resulting in piecemeal and uncoordinated adoption.
- Resistance from staff used to Excel or paper-based systems, particularly in logistics and procurement roles.
- A disconnect between green supply chain ambitions and daily operational decisions — often due to **a lack of strategic alignment**
- Many SMEs lack roles like Chief Data Officer, SCM Process Owner, or IT Security Officer, limiting internal innovation capacity.

Across both domains, **cultural resistance to change** and lack of leadership in digital transformation are recurring issues. Digital efforts are often spearheaded by isolated champions without broader organisational support.

3.4.2.4. SKILLS NEEDS

Each of the above constraints underscores the growing need for new skills and capabilities.

These **skills gaps** can be **multi-dimensional**, affecting both frontline workers and management organisations.

Based on the three PdM, SCM, and BC reports, we are consolidating the results in order to share them with Work Package 5, which is responsible for training in LCAMP. By identifying the key competences specific to each field, this work package will be able to draw on the data to support its activities. Collaboration between the different Work Packages is a key aspect of the LCAMP project.

You can find in the entire table available in annex 1:

- **44 entries** describing skills, competences, and attitudes.
- It spans **9 different occupations**.
- The most common categorisation is **"Competence"**, followed by "Skill" and "Attitude".
- **4 distinct skill types** are identified, reflecting the diversity of capabilities needed: AI literacy, Digital, Professional and Transversal.
- The analysis highlight a strong emphasis on **AI-related and cybersecurity skills** across domains.

Here is an extract reflecting the type of information available in Annex 1:



Table 1. Skills needs (extract)

LCAMP Competence Area	Categorisation	Recommended subcategories in the LCAMP framework	Occupation/Origin of the report	Skill / Competence / Attitude
AI Literacy	Competence	Critical Digital Competence	Predictive Maintenance (PdM)	Basic AI or Machine Learning - Basic knowledge of AI/ML models
	Skill	Computer vision	Quality control Technician (BC)	Computer vision and CNNs for defect detection - apply neural networks for automated quality control
Digital	Attitude	Cybersecurity	Supply Chain Management (SCM)	Cyber security awareness - IT security awareness
	Competence	Problem solving	Predictive Maintenance (PdM)	Problem solving (maintenance) - analytical thinking for data-driven decision making
		System Design	Automation-robotics technician (BC)	Industrial robotics integration - connect robots with production line systems
	Skill	Data literacy	Predictive Maintenance (PdM)	Interpretation of sensor data - ability to read and use IoT sensor data
		ICT	Automation-robotics technician (BC)	Communication protocols (OPC-UA, Ethernet) - implement industrial communication standards
			CNC operator (BC)	Digital interfaces and HMIs - operate touchscreen controls on CNC machines.
			Maintenance technician (BC)	Install and configure industrial IoT sensors - set up connected sensors for data collection
		Problem solving	Maintenance technician (BC)	Troubleshoot data connectivity in IoT networks - solve communication problems in connected systems
		Data literacy	Quality control Technician (BC)	Digital inspection systems operation - use automated measurement and testing equipment
			CNC operator (BC)	MES/ERP system integration - connect machining operations with enterprise systems
			Maintenance technician (BC)	Use cloud-based platforms to monitor machine performance - access remote monitoring systems
		Digital Manufacturing	CNC operator (BC)	CAD/CAM software operation - use computer-aided design and manufacturing programs



Transversal	Attitude	Communication	Supply Chain Management (SCM)	Communication and coordination - openness and willingness to embrace digital transformation
		Flexibility/Agility	Predictive Maintenance (PdM)	Adaptability - willingness to adapt to changing roles/technologies
	Competence	Collaboration/Teamwork	Predictive Maintenance (PdM)	Collaboration - cross-departmental collaboration (maintenance, IT operations)
		Critical thinking	Supply Chain Management (SCM)	Strategic thinking - holistic understanding of complex supply chains
	Skill	Collaboration/Teamwork	Transversal skills (BC)	Cross-functional collaboration - work effectively with multidisciplinary teams in digital environments
		Communication	Transversal skills (BC)	Communication and coordination - share information clearly across departments and shifts
		Flexibility/Agility	Transversal skills (BC)	Adapt to emerging technologies - willingness to learn and use new technological tools
		Problem solving	Transversal skills (BC)	Problem-solving and decision-making - analyze situations and make effective technical decisions
		Continuous improvement	Transversal skills (BC)	Continuous improvement mindset - identify optimization opportunities in digital manufacturing processes
Professional	Competence Skill	System Design	Automation-robotics technician (BC)	Industrial robotics integration - connect robots with production line systems
		System Design	Automation-robotics technician (BC)	Vision systems configuration - set up cameras and image processing for robot guidance and automation

Cultivating a culture of learning is essential. SMEs must not only train for tools but also foster environments where curiosity, feedback, and digital experimentation are normalised.

3.4.3. REAL-WORLD VARIATIONS: BC EXAMPLES

The BC report confirms significant variation in adoption across regions and sectors:

- In digitally advanced ecosystems, SMEs engage with shared platforms, regional hubs, and service providers for PdM and SCM capabilities.
- In others, adoption is fragmented or superficial, driven more by external requirements than internal strategy.

These differences highlight the importance of territorial innovation systems, which help SMEs overcome structural constraints through collaborative experimentation and learning.



3.5. FUTURE TRENDS & STRATEGIC RECOMMENDATIONS

The digital and green transitions continue to reshape the industrial landscape for SMEs. Future trends and recommendations emerging from the three reports highlight technological advances, new organisational models, and strategic directions that SMEs and ecosystem actors should embrace. While the observed domains share common directions, their specific trajectories differ based on operational logic and technological application.

3.5.1. FUTURE DIRECTIONS IN PREDICTIVE MAINTENANCE (PDM)

The PdM report emphasises the importance of building scalable, people-centered, and performance-driven strategies to make predictive maintenance more accessible and impactful across SMEs.

- **Expanding Access to Financial Support and Technology Adoption:**
Many SMEs remain reluctant to adopt PdM due to cost, risk, or complexity. The report recommends concrete actions to lower financial and technical barriers:
 - Facilitating financial incentives and access to affordable PdM technologies, particularly through public-private partnerships or EU-level programmes.
 - Promoting scalable, cloud-based PdM-as-a-Service models to reduce capital expenditure and lower the adoption threshold.
 - Encouraging collaborative demonstration platforms where SMEs can observe and test real-world applications of PdM solutions.
- **Investing in Workforce Training and Digital Skills Development:**
Human capital remains a critical success factor for PdM. The report highlights the need to align training with the evolution of maintenance practices:
 - Expanding digital skills and maintenance analytics training, particularly among technicians and operators.
 - Working with vocational education and training (VET) centres to embed PdM-specific modules into curricula.
 - Encouraging lifelong learning and cross-skilling approaches to align maintenance teams with evolving tools (e.g., AI-assisted diagnostics, remote monitoring).
- **Optimising PdM Strategies for Long-Term Competitiveness:**
To generate long-term value, PdM must move beyond isolated use cases and become a pillar of strategic asset management:
 - Shift from isolated PdM use cases to strategic, enterprise-level maintenance transformation plans.
 - Incorporate data governance and cybersecurity protocols into PdM system design.
 - Track and optimise PdM KPIs to demonstrate business value and sustainability impact over time.

3.5.2. FUTURE PERSPECTIVES AND RECOMMENDATIONS FOR SCM 4.0

The SCM report presents a holistic vision for supply chain digitalisation that emphasises transparency, partnership, and strategic alignment with customer and environmental expectations

- **Building Trust, Transparency, and Information Sharing:**
As supply chains become more digital and decentralised, the SCM report highlights the foundational role of trust:



- Digitalisation (e.g., Supplier Relationship Management platforms) should be used not only for automation, but to enable open, traceable communication across partners.
- Trust-building mechanisms such as collaborative tools, shared dashboards, and co-innovation platforms should be fostered.
- SMEs should be supported in balancing technological efficiency with personalised human interaction, to sustain long-term loyalty and cooperation.
- Strategic Recommendations (10 Key Actions):
To navigate digital transformation and global complexity, the report proposes a structured framework with ten actionable levers:
 - Digitise Procurement and Supplier Relationship Management – Implement collaborative platforms and modular tools like EaaS to boost transparency and responsiveness.
 - Leverage Digital Tools to Foster Transparency – Create regional SCM 4.0 demonstrators and use blockchain or AI for open information flows.
 - Strengthen Data Governance and Information Security – Ensure secure, compliant data exchange across supply chain partners.
 - Align Supplier Services with Customer Expectations – Use digital feedback loops to adapt to evolving client needs.
 - Balance Digital Efficiency with Human Engagement – Prioritise emotional intelligence, negotiation, and trust in digitally mediated interactions.
 - Promote a Collaborative Partnership Culture – Move from transactional to partnership models, emphasising shared value and co-innovation.
 - Invest in Workforce Upskilling and Relational Capabilities – Provide digital logistics, planning, and relational skill training via VET partners and hybrid learning.
 - Strengthen Change Management Support – Offer diagnostics, advisory services, and change facilitation to support SMEs through transformation.
 - Embed Digital Within Green Strategies – Integrate sustainability KPIs into digital projects (e.g., Scope 3 emissions, circular logistics).
 - Conduct Regular Trust and Relationship Audits – Assess collaboration maturity and address emerging risks in supplier relations.

3.5.3. DIGITAL TRANSFORMATION STRATEGIES FOR ADVANCED MANUFACTURING: INSIGHTS FROM THE BASQUE COUNTRY

The Basque Country report provides valuable insights into the practical realities of digital transformation in advanced manufacturing, highlighting both challenges and opportunities for SME development. The analysis reveals that human resistance to change remains the primary barrier to digital transformation, surpassing even technological complexity and financial constraints. Companies are evolving toward hybrid workforce profiles that demand both traditional technical expertise and digital competencies. This shift is especially evident in occupations such as Maintenance Technician, Automation Technician, CNC Operator, and Quality Technician, where digital skills are increasingly essential for job performance and career development.

Based on these findings, several key strategies emerge for companies navigating their digital transformation journey:

- Implement people-cantered change management strategies addressing cultural adaptation alongside technical training.
- Develop internal roles for digitally-aware employees, coming from VET programmes, who can bridge traditional operations with emerging technologies and serve as effective intermediaries with external technology providers like AI specialists, and predictive maintenance experts.
- Adopt gradual technology adoption approaches using public funding and collaborative projects to explore emerging technologies in low-risk environments



- Recognize the strategic value of Basque Country VET centres in driving digital transformation by actively contributing to applied innovation projects and providing key support for the upskilling and reskilling of the workforce.

3.5.4. SHARED PRIORITIES FOR LONG-TERM SME TRANSFORMATION

Despite the domain-specific approaches, several cross-cutting priorities emerge from the three reports:

- Financial accessibility is essential: whether for sensors, software, or consulting, SMEs need easier entry points through subsidies, leasing, or shared services.
- Workforce transformation is critical: digital and soft skills must be developed in parallel. In SCM, this includes systems thinking, trust management, and AI literacy. In PdM, this means condition monitoring, diagnostics, and predictive analytics.
- Integration of digital and green goals: future strategies must embed environmental considerations, such as energy efficiency, waste reduction, or carbon tracking.
- The human factor remains central: whether in maintenance or supply chain relations, transformation depends on leadership, collaboration, and user adoption.



4. DIGITAL AND GREEN TRANSITION TRENDS IMPACTS IN VET CENTRES

This chapter presents a synthesis of the main findings on the impact of the green and digital transition on training centres, as outlined in the three reports produced (PdM, SCM, and Basque Country). The analysis is based on a literature review, as well as on the results of the surveys and interviews conducted within the framework of these reports.

4.1. CHALLENGES AND OPPORTUNITIES FOR VET CENTRES

4.1.1. INTRODUCTION

The green and digital transition is driving a profound transformation in industry, requiring training centres to adapt their programmes and strategies. Given the rapid pace of change, it is essential for these centres to stay up to date in order to provide learners with the skills demanded by the labour market. The following section outlines the main opportunities and challenges brought about by this transition.

4.1.2. STRENGTHENING COLLABORATIONS WITH INDUSTRIAL PARTNERS

In response to the need to stay aligned with the demands of the productive sector, training centres are increasingly seeking direct collaboration with industry. Many institutions already have networks of business partners that support the integration of practical experiences into their programmes, such as dual training, internships, and joint projects.

This trend was confirmed by the surveys conducted: in the fields of PdM and SCM, the majority of training centres surveyed prioritise partnerships with companies over collaborations with other training centres, aiming to align their programmes with real and current industry needs.

The alignment of VET centres with industrial partners through increased collaboration remains essential for making training programmes match actual workplace requirements. Joint development of learning pathways and integration of emerging technologies into curricula and better responses to evolving skill needs become possible through closer collaboration. Bringing VET students and industry partners together leads to a better mutual understanding, enhances innovation capabilities, and prepares students to actively participate in a company's digital and industrial transformation.

4.1.3. TRAININGS FOR TRAINERS

One of the most significant findings of the SCM survey was the identification of the main obstacles to integrating emerging digital technologies 4.0 in training centres. Most respondents pointed to the lack of training for trainers as the primary barrier, followed the high costs associated with the transition



This issue is not unique to a single country but affects industrial sectors across Europe. The report "Tensions on Workforce and Skills in Industry and Associated Training Schemes" already highlights this gap in France, where there is a recognised and urgent need to strengthen teacher training. Similarly, a training centre in Turkey, surveyed in the SCM study, stated: "The Ministry should mandate teacher training in digital and green transition across all vocational education institutions."

The Basque Country has implemented training programmes for VET trainers to maintain teaching staff knowledge about modern industrial developments and educational methods and technological advancements. The programmes focus on teaching both technical competencies and modern educational methods which include project-based and hybrid learning approaches. The current initiatives need expansion and systematisation and increased accessibility to achieve full readiness of educators for smart and connected industrial environments.

4.1.4. AUTONOMY OF TRAINING CENTRES

Another major challenge for training centres is adapting to new trends despite having limited autonomy. In many European countries, these centres must follow guidelines set by higher authorities, such as ministries of education, which restrict their ability to make independent decisions regarding programmes and teaching methods.

According to the PdM survey, 44% of training centres reported having limited autonomy, and 36% described their autonomy as controlled. Similarly, the SCM survey showed that only 29% of centres had full autonomy.

4.1.5. HYBRID TRAININGS

Digital transformation has enabled greater flexibility and accessibility in training pathways, with the rise of hybrid models combining online and in-person learning. This model not only facilitates the transmission of technical skills but also promotes networking and professional integration.

Moreover, hybrid training is especially convenient for workers, as it allows them to continue their education and obtain a formal qualification while remaining employed. This flexibility makes hybrid models a key strategy to support lifelong learning, upskilling, and the continuous adaptation of the workforce to the evolving demands of smart and connected industrial environments.

4.1.6. GROWING DEMAND

Training institutions are facing growing demand for specialised learning and increased enrolment, creating an opportunity to modernise and diversify their programmes. In Spain, the launch of a master's degree in supply chain management in 2024, although EQF level 7 is not the focus of this report, serves as a clear example of this trend.

VET centres must therefore reinforce transversal skills and foster adaptability among students. While Basque VET centres are already applying collaborative, project-based learning methodologies aimed at developing both technical and transversal competences, the importance of transversal skills is especially critical in today's evolving industrial landscape. Skills such as problem-solving, communication, teamwork, learning autonomy, and creativity are increasingly valued by companies, particularly in the context of digital transformation and continuous change. These competences not only support professional versatility but also enable graduates to adapt quickly to new technologies, workflows, and organisational models.

4.1.7. FINANCIAL CHALLENGES AND FINANCIAL SOLUTIONS

A key challenge for training centres is investing in new technologies, often limited by financial constraints. To address this, many rely on alternative funding sources. According to the PdM



survey, centres mostly benefit from public funding, industry partnerships, and, to a lesser extent, collaboration with other VET centres. In the SCM survey, public and industry funding remain the main sources, while internal funding is limited. Notably, no centres in the SCM survey reported collaboration with other VET centres. Some also mentioned sponsorships and EU projects like LCAMP as valuable support mechanisms.

4.1.8. NEW TECHNOLOGIES ON PEDAGOGICAL STRATEGIES

The emerging technologies mentioned in this report have not only influenced the content of training programmes but are also beginning to impact pedagogical strategies and resources. Below is a brief overview of some possible applications of these technologies in the pedagogical field:

- **Artificial Intelligence - Personalised learning:** AI can adapt training to each learner's pace and needs, offering targeted resources based on their performance.
- **Virtual and Augmented Reality - Safe immersion:** VR and AR can provide simulated environments for hands-on practice, ideal for training in technical fields without real-world risks.
- **Online Platforms and MOOCs - Flexibility and access:** These tools can facilitate distance learning at one's own pace, broadening access to education regardless of location or time.
- **Big Data and Performance Analysis - Continuous improvement:** Big Data can be used to analyse learner data, helping to refine teaching methods and continuously improve training outcomes.
- **In the specific case of the PdM sector:**
 - **MAAS in Training - Access to PdM technologies via collaborative cloud platforms:** Cloud-based solutions can allow students to work with real data and predictive maintenance tools, thereby developing practical skills in the use of these technologies.
 - **MAAS in Training - Use of simulations and real-world case studies:** Simulations and digital twins can allow students to safely practise predictive maintenance techniques, enhancing their skills before working with real machinery.

4.1.9. EUROPEAN INITIATIVES

The desk research revealed multiple EU-funded initiatives which concentrate on technological trends and skills development in advanced manufacturing. The projects have generated important training materials which cover different areas of expertise. The following table shows a selection of resources which provide educational content and good practices at the European level that VET centres and other key stakeholders can use for inspiration and support.

Table 2. Examples of European Projects in technological trends and skills development in advanced manufacturing

PROJECT	DESCRIPTION
OPTIMAI	Improves industrial quality and efficiency using AI-based defect detection, digital twins, and AR; provides Industry 4.0/5.0 training.
I4MS	European initiative helping manufacturing SMEs adopt digital technologies.
DATA.ZERO	EU project promoting Zero Defect Manufacturing with data-driven solutions and training in AI, IoT, and machine learning.
PreMETS	Erasmus+ project enhancing Predictive Maintenance education with toolkits, micro-credentials, and free Moodle courses.



DRIVES	Erasmus+ project supporting automotive skills through a MOOC on maintenance, cybersecurity, AI, and robotics.
4CHANGE	Tackles metalworker skills gaps via digital, entrepreneurial training and work-based learning.

4.2. IMPACT ON TRAINING AND SKILLS TRAINED

4.2.1. SKILLS TRAINED IN PDM FIELD

New technologies are increasingly being incorporated into training programmes to different extents. The following table highlights examples of programmes linked to the PdM, which have integrated emerging technologies and fields.

Table 3. New technologies and fields into trainings related to PdM

TECHNOLOGY	TRAINING / COURSES
Sustainability	- Baccalaureate in Sciences and Technologies of Industry and Sustainable Development (EQF 4) (France) - Higher Technician Certificate in Sciences and Technologies of Industry and Sustainable Development (EQF 5) (France)
Cybersecurity	Vocational Baccalaureate and Higher Technician Certificate in Cybersecurity, Computer Science, and Electronic Networks (EQF 4) (EQF 5) (France)
IoT	University Bachelor of Technology in Mechanical and Production Engineering, specialising in Innovation for Industry (EQF 6) (France)
IoT and IA	Higher Technician Certificate in Industrial Maintenance
IoT, IA, Cybersecurity	- Vocational Degree in Biomedical Equipment Maintenance (EQF 6) (France) - Vocational Degree in Maintenance of the Industry 4.0 (EQF 6) (France)
IoT, AI, Cybersecurity, Sustainability, Cloud	- Vocational Baccalaureate in Mechanical Product Manufacturing Technician, specialising in Production Execution and Monitoring (EQF 4) (France) - Higher Technician Certificate in Conception of the Product Development Process (EQF 5) (France) - Higher Technician Certificate in Design and Production of Automated Systems (EQF 5) (France) - Vocational Degree in Design and Production of Electronic Systems (EQF 6) (France) - Vocational Degree in Design and Improvement of Industrial Processes and Procedures (EQF 6) (France) - Higher Technician Certificate in Design of Industrial Products (EQF 5) (France)
Examples of Courses in the fields: IoT, AI, Cybersecurity, Sustainability, Cloud	For France: Robotics module. For Slovenia: Digital teaching; Sustainability; User Interface; Efficient use of tools; Ethical Hacking - Practical Training; Cybersecurity; Artificial Intelligence in Information Technology - Practical Training; Artificial Intelligence; Server Systems; Advanced Computer Networks; IoT Smart Electrical Installations; Sustainability; Efficient use and renewable energy sources; Cybersecurity, Security and protection; Cybersecurity, Information Systems Protection; Cybersecurity, Information Systems Protection. Italy: Systems and Networks; Technologies and Design of Information and Telecommunication Systems; Computer Science; Telecommunications; Project Management, Business Organisation.



4.2.2. SKILLS TRAINED IN SCM FIELD

In the field of Supply Chain Management (SCM), the integration of new technologies is also becoming increasingly evident. Below is a detailed table outlining the training programmes and skills related to this area.

Table 4. New technologies and fields into trainings related to SCM

TECHNOLOGIES	TRAININGS	SKILLS
Sustainability	• Bachelor of Technology Management in Logistics and Transport: Mobility and Sustainable Supply Chain • Sustainability in Supply Chain Management	• Manage the logistics and transport chain with a focus on sustainability • Optimise resource use • Implement sustainable development strategies • Integrate responsible practices in logistics and mobility • Conduct sustainable logistics audits • Develop innovative solutions with environmental criteria • Apply Corporate Social Responsibility (CSR) strategies in the logistics field • Achieve socially, ecologically, and economically sustainable supply and production chains • Interpret and apply regulations such as the Supply Chain Due Diligence Act and upcoming EU directives, using tools to assess and optimise sustainability performance • Integrate sustainability into strategic planning and operational management, addressing the balance between economy, ecology, and social aspects • Understand of the legal framework and strategies to achieve long-term sustainability in the supply chain
Cybersecurity	• Quality, Industrial Logistics, and Organisation, specialising in Organisation and Supply Chain • Logistics and Transportation Management, specialising in Mobility and Sustainable Supply Chains • Professional Bachelor's degree in Logistics and Flow Management • IT Infrastructure and Security Technician	• Ensure IT security and the protection of systems • Use of digital tools and the application of cybersecurity rules to acquire, process, produce, and disseminate information • Implement security policies for the protection of data stored in a cloud infrastructure • Apply preventive measures against intrusions, fraud, data breaches, or leaks through the configuration of the information system • Ensure the proper functioning of the company's computer networks and telecommunications • Protect logistics-related data • Secure cloud infrastructure • Apply cybersecurity strategies • Mitigate cyber risks
IA	• Bachelor's degree in Science and Engineering, specialising in Maintenance of Intelligent and Connected Systems • Bachelor's degree in Science and Engineering - Information Systems (EQF 6) • Bachelor's degree in Science and Engineering - Computer Science and Digital Systems (EQF 6) • IT Project Coordinator (cloud infrastructures, applications, or data) (EQF 6) • Logistics and Artificial Intelligence (IA)	• Optimise predictive maintenance, robotics, mechatronics, and computer-aided maintenance management • Process and analyse data to extract strategic information and communicate it to their colleagues to facilitate decision-making. • Data processing and synthesis • Develop and manage databases • Integrate AI into application development • Design and optimise artificial intelligence solutions for industry • Organise and manage AI projects • Develop artificial intelligence tools • Perform predictive data analysis using artificial intelligence • Automate logistics processes with robotics and RPA • Manage data using Big Data • Apply predictive analytics to anticipate demand • Optimise delivery routes using advanced algorithms, and implement cybersecurity strategies in automated systems • Apply ethical principles when using AI



		Maximise operational efficiency and ensure return on investment, with a vision towards Logistics 4.0 and the future of automation in the sector
Cloud Computing	IT Project Coordinator (cloud infrastructures, applications, or data)	- Orchestrate cloud infrastructure - Manage information security - Deploy and maintain cloud computing services - Implement security policies to protect data stored in a cloud infrastructure
Blockchain	Blockchain Solutions Project Manager (EQF 6)	- Design, code, and improve blockchain-specific systems using appropriate programming languages such as Solidity, C++, or JavaScript - Develop web applications and frameworks - Analyse client needs and implement robust and secure blockchain architectures - Apply advanced knowledge in blockchain and cryptography - Create innovative solutions across various sectors, such as finance, logistics, and healthcare - Manage blockchain projects, ensuring effective coordination to meet objectives and address client needs - Provide technically reliable and scalable solutions
IoT	IoT Solutions Designer and Integrator	- Implement connected device architectures, enabling them to send, receive, and process signals, information, or instructions. - Address the specific challenges of businesses, based on their business, managerial, or operational needs - Facilitate the automation of activities, optimise business processes, and strengthen managerial decision-making

In the following table, you will find a more detailed overview of training programmes in Supply Chain Management (SCM) or related fields, along with the main skills taught.

Table 5. Trainings related to SCM and its main skills trained

COUNTRY	TRAINING	SKILLS
France	University Diploma in Logistics and Transport Management (EQF 6)	Logistics, transport, eco-responsibility, sustainability, digital transition, flow management
	Professional Qualification Certificate: Technicien Logistique Industrielle (EQF 6)	Information flow management, industrial consistency, supply and distribution supervision, computerised systems
	Bachelor's Degree in Technology: Management de la logistique et des transports, spécialité Mobilité et supply chain durables (EQF 6)	IT security, sustainability, innovative logistics and transport strategies
	Bachelor's Degree in Technology: Logistics and Transport Management, Sustainable Mobility and Supply Chain Specialisation (EQF 6)	Innovative technologies, digital solutions in logistics and transport
	Bachelor's Degree in Science and Engineering, Intelligent and Connected Systems Maintenance Specialisation (EQF 6)	Digital and energy transition, AI, mechatronics, predictive maintenance, CMMS (Computerised Maintenance Management Systems)



	Professional Bachelor's Degree in Logistics and Flow Management (EQF 6)	Warehouse automation, sustainable logistics, cybersecurity, CSR (Corporate Social Responsibility), flow management
	Bachelor's Degree in Technology: Quality, Industrial Logistics, and Organisation, Supply Chain & Organisation Specialisation (EQF 6)	Digital tools, IT security, information flow management, supply chain, process optimisation
	Bachelor's Degree in Science and Engineering - Information Systems (EQF 6)	Eco-responsibility, circular economy, data management and analysis, AI, digitisation
	Bachelor's Degree in Science and Engineering - Computer Science and Digital Systems (EQF 6)	AI, Deep Learning, Computer Vision, NLP, databases, digital transformation
	AI and Data Science Developer (EQF 6)	AI development, Data Science, process optimisation, predictive maintenance, digital marketing
	IT Project Coordinator (cloud infrastructures, applications, or data) (EQF 6)	Information security, cloud computing, automation, AI, cybersecurity, data protection
	Data Science Developer and Designer (EQF 6)	Predictive analysis, AI, big data, machine learning, data processing
	Project Manager in Blockchain Solutions (EQF 6)	Blockchain, cryptography, Solidity, blockchain application development, smart contracts
	Designer Integrator of Internet of Things (IoT) Solutions (EQF 6)	IoT, automation, connected device networks, data processing, process optimisation
	IT Infrastructure and Security Technician (EQF 5)	Networks, cybersecurity, cloud, infrastructure supervision, IT incident management
	Diploma of Scientific and Technical University Studies: Webmaster et internet-related professions (EQF 5)	Web development, connected objects, virtual reality, augmented reality, digital content creation
	Vocational Degree in Design and Improvement of Industrial Processes (EQF 6)	Digital transition, production line, maintenance, robotics, digital tools, cybersecurity, ethics, environmental responsibility.
	Vocational Baccalaureate in Logistics (EQF 4)	Reception, storage, order preparation, shipment, forklift operation, road transport, safety, quality, environmental regulations, logistics companies, distribution platforms, corporate logistics services.
	Operational Supply Chain Manager Certification (EQF 6)	Logistics management, negotiation, supply chain, transportation, storage, supply, planning, dispatcher, shipping manager
Slovenia	Mechatronics Technician (EQF 4)	Mechanical engineering, electrical engineering, computer science, automation and robotics
	Logistics Technician (EQF 4)	Logistics, warehousing, and supply chain management
	Logistics Engineer (EQF 5)	Logistics, supply chain management, and process optimization



	Mechatronics Engineer (EQF 5)	Automation, robotics, and the integration of advanced technologies into production processes.
Turkey	Bachelor's Degree in Logistics (EQF 6)	Supply chain management, inventory control, distribution, logistics information systems
	Associate Degree in Logistics (EQF 5)	Storage, transportation, customs procedures, inventory management
	Vocational High School Programme in Logistics	Shipment, warehousing, storage, logistics software, internships, warehouse supervisor, shipment staff
Germany	Supply Chain Management	Supply chain management, cost optimisation, customer satisfaction, SCOR modelling
	Sustainability in Supply Chain Management	Regulations, social and ecological sustainability, sustainable optimisation strategies
	Strategic Supply Chain Management (EQF 6)	Planning and managing logistics networks, cost reduction, simulation and strategic planning
	Certified Supply Chain Manager (EQF 6)	Value chain optimisation, cost reduction, logistics project management
	Certified Supply Chain Manager course (EQF 6)	Optimisation of value chains, cost reduction, customer-oriented processes, supply chain management fundamentals, project management, practical tools.
	Certified SAP User in Production Planning (EQF 4 to 6)	SAP system navigation, master data management, production orders, material movements, inventory management, integration with SAP modules (materials management, sales), reporting tools, capacity/resource management
	Effective work preparation – planning and control of the production process (EQF 4 to 6)	Order scheduling optimisation, production control, material management, ERP/MES systems, capacity planning, lot sizing, IT planning tools, delivery service improvement.
Italy	Supply Chain, logistics and operations (EQF 6)	Supply Chain skills, Logistics flow optimisation, Inventory management, ERP, Blockchain, RFID, IoT, Automation, Robotics, AI, Machine Learning, Data analysis, Strategic decision-making, Risk management
	Supply Chain Management (EQF 5)	Procurement management, collaborative practices, order-to-delivery, demand-to-supply processes, business partner integration, efficiency, effectiveness, and responsiveness
	Supply Chain Management	Material procurement, production management, product distribution, end-to-end supply chain management, corporate governance models

4.2.3. SPECIALISATION PROGRAMMES IN BASQUE COUNTRY

The Basque Country has developed a comprehensive range of one-year specialisation programmes (EQF5), delivered in dual format, combining classroom learning with practical company-based training. These courses are designed for students who have completed a two-year higher VET qualification and seek to acquire advanced competences aligned with the needs of advanced manufacturing and digital transformation. These programmes reflect a forward-looking strategy within the Basque VET system to align training with the real and future needs of industry. For more details, consult the official website of the Basque Institute of VET Knowledge.

The following specialisation courses are currently on offer, including those related to smart and digital industry:



Table 6. Specialisation programmes in the Basque Country

PROJECT	GENERAL SKILL
Intelligent Manufacturing	To develop and manage projects that adapt production processes by identifying production objectives, applying key performance indicators (KPIs), and using advanced technologies for production control, while ensuring quality and safety requirements.
Digitalisation of Industrial Maintenance	To implement and manage digitalisation projects for maintenance in industrial environments, applying state-of-the-art technologies and complying with quality, safety, and environmental standards.
Collaborative Robotics	To develop collaborative robotics projects involving both robotic arms and autonomous mobile robots, and to carry out their assembly, commissioning, and maintenance.
Cybersecurity in Information Technology (IT)	To define and implement security strategies in information systems, by conducting cybersecurity diagnostics, identifying vulnerabilities, and applying mitigation measures in line with current regulations and sector standards, while meeting quality, occupational safety, and environmental protection protocols.
Cybersecurity in Operational Technology (OT)	To define and implement cybersecurity strategies in industrial organisations and infrastructures, through diagnostics, identification of vulnerabilities, and the application of mitigation measures in accordance with existing regulations and industry standards, ensuring compliance with quality, occupational safety, and environmental protocols.
Metrological Quality Control	To carry out quality control of products, production systems, and measurement systems, ensuring the validity of measurements in tests and verifications according to applicable quality standards, and issuing the appropriate documentation while complying with safety and environmental regulations.
Artificial Intelligence and Big Data	To design and apply intelligent systems that optimise information management and big data exploitation, ensuring secure data access and compliance with established accessibility, usability, and quality standards, as well as ethical and legal principles.

4.2.4. PRIORITIES AND LACKS OF SKILLS

According to the PdM report, training centres identified artificial intelligence (AI) and sustainability as the top priority areas among emerging technologies. In the field of supply chain management (SCM), the focus shifts towards IoT, sustainability, and cybersecurity. Nearly 70% of centres highlighted key skill gaps in IoT systems, AI tools, and data analysis. Cloud computing was cited by 40%, while only 14% mentioned collaborative work, suggesting this soft skill is already well covered. Country-specific findings show that:

- France lacks skills in AI and data analysis,
- Italy in IoT systems,
- Turkey in cloud computing and data analysis, and
- Slovenia in IoT and AI tools.

A French training centre representative highlighted the importance of focusing on skills development over theoretical knowledge. They also stressed the value of integrating initial and vocational training, and the potential of AI and XR not only as training tools but as supports for the overall learning process.



4.3. STRATEGIC ROLE OF VETS

Vocational Education and Training (VET) centres are emerging today as dynamic and strategic actors, capable of acting as catalysts for the digital and green transitions. In the face of rapidly evolving technologies and shifting labour market demands, these centres play a key role in adapting skills and supporting transforming industrial sectors.

As highlighted throughout this chapter, and despite existing challenges, new technologies are already being progressively integrated into training programmes and the skills being taught.

Aware of these challenges, training centres have strengthened their strategic partnerships with industry, and to a lesser extent, with other VET centres. These collaborations not only foster knowledge exchange but also provide access to additional funding sources, which are crucial to addressing one of the main barriers to transition: its financial cost.

In this context, training centres have also turned to sponsorship and to participation in EU-funded projects, particularly those supported under the Erasmus+ programme.

Furthermore, centres have seized this opportunity to expand their training offer, making it increasingly specific and specialised, while actively integrating new technologies as part of their teaching strategies. This has enabled them to deliver more modern, interactive and industry-relevant learning approaches, better aligned with the realities of today's professional environment.

VET centres function as essential drivers of industry transformation because they enable innovation and talent development while enhancing regional competitiveness. VET centres now perform beyond basic training functions, actively participating in solution co-creation with businesses, developing specialised programs, and conducting applied research and innovation projects within advanced manufacturing and digitalisation environments.

4.4. CONCLUSIONS AND RECOMMENDATIONS

AND

4.4.1. CONCLUSIONS

The strategic role of Vocational Education and Training (VET) centres as dynamic actors in the digital and green transition is clearly reaffirmed. These institutions are steadily progressing in the integration of emerging technologies and fields such as artificial intelligence (AI), sustainability, the Internet of Things (IoT), cybersecurity, blockchain, cloud computing, virtual and augmented reality, deep learning, and robotics.

According to surveys conducted with training centres, AI and sustainability have been identified as the top priorities within the field of Predictive Maintenance (PdM). In the area of Supply Chain Management (SCM), the focus shifts towards IoT, sustainability, and cybersecurity.

The context of the green and digital transition has provided VET centres with several opportunities, including:

- The increase in demand for training, which has allowed for the expansion of educational offerings.
- The possibility to achieve greater diversification and specialisation in training programmes, which now incorporate not only technical skills but also interdisciplinary competences. A clear example is the initiative carried out in the Basque Country, where one-year specialisation programmes in dual format have been developed, focusing on advanced



skills in smart manufacturing, digitalisation, collaborative robotics, cybersecurity, and quality control.

- Closer collaboration with the industrial sector.
- The growing use of new technologies as pedagogical tools.
- Enhanced accessibility and flexibility of training through hybrid learning models, which combine online and face-to-face instruction. These formats are especially beneficial for working individuals.
- The boost from European initiatives that promote the modernisation of VET.
- Access to funding through EU programmes.
- Diversification of funding sources thanks to collaborations with other training centres and industry.
- In the Basque Country, although barriers such as the lack of digital culture in companies persist, VET centres can play a key role as agents of transformation by training professionals equipped to face the challenges of industrial digitalisation

However, the integration of new technologies has also brought significant challenges, including:

- Limited institutional autonomy, which hinders the ability to respond effectively to constant change.
- The rising costs associated with the adoption of new technologies.
- The lack of specialised training for educators, which limits effective implementation.
- Existing skill gaps have been identified in key areas within the field of Supply Chain Management (SCM). Country-specific findings highlight the following deficiencies: France faces shortages in AI and data analysis skills; Italy in the integration of IoT systems; Turkey in cloud computing and data analysis; and Slovenia in both IoT and AI tools.
- For Basque VET centres still do not fully consider VET graduates as a real option for driving their digital transformation. Although many centres offer advanced programmes in automation and digitalisation (EQF5), these qualifications are not widely recognised or demanded by industry. As a result, students often find limited opportunities in high-tech roles, and the potential of VET to contribute to industrial innovation remains underused.

4.4.2. RECOMMENDATIONS

- Promote hybrid learning models: Expand flexible learning pathways that combine online and in-person formats to support diverse learner profiles, particularly professionals, and foster lifelong learning.
- Diversify the training offer and increase the number of specialised programmes.
- Address critical skills gaps.
- Strengthen training for trainers.
- Reinforce collaboration with companies and other training centres.
- Diversify funding sources: Encourage VET centres to mobilise public funding, industry sponsorships, European projects, and collaborative financing mechanisms to overcome financial limitations.
- Leverage European initiatives: Maximise the use of tools and resources made available by the European Union to support the green and digital transitions as well as education in general.
- Develop country-specific training initiatives to close key skill gaps in SCM: AI and data analysis in France, IoT systems in Italy, cloud computing and data analysis in Turkey, and IoT and AI tools in Slovenia.
- Prioritise skills development over theoretical knowledge by integrating initial and vocational training, and by using AI and XR not only as educational tools but as supports throughout the learning process.



5. CONCLUSION AND OUTLOOK

In order to support the continued growth, resilience, and sustainability of the advanced manufacturing sector across the European Union and beyond, it is essential to anticipate evolving workforce needs, enhance education and training systems, and strengthen alignment between industry and vocational education and training (VET) providers. This report – a synthesis of three complementary investigations into Predictive Maintenance (PdM), Supply Chain Management (SCM), and the regional insights from the Basque Country (BC) – offers an integrated perspective on how digital and green transitions are reshaping both the industrial landscape and the educational ecosystems that feed into it.

Drawing on in-depth fieldwork, multi-country surveys, institutional case studies, and direct engagement with SMEs, large manufacturers, VET institutions, and educators, this work captures a dynamic and nuanced picture of transformation in action. By focusing on two high-impact domains within advanced manufacturing, PdM and SCM, the report examines not only the technologies driving change but also the operational, organisational, and human shifts required for successful adaptation.

Through six key thematic areas – technological and operational shifts, green and digital integration, SME-specific barriers, evolving skills and workforce expectations, strategic innovation models, and the transformation of VET systems – the findings converge on a shared objective: building a future-ready manufacturing ecosystem anchored in agile education, inclusive upskilling, and strong intersectoral collaboration. As such, this concluding section distils strategic lessons, outlines cross-cutting recommendations, and offers a forward-looking vision for how Europe can lead the way in aligning industrial innovation with human-centred development.

5.1. SUMMARY OF KEY FINDINGS

Advanced manufacturing is undergoing rapid transformation, shaped by digitalisation, sustainability imperatives, and evolving workforce dynamics. The insights drawn from Predictive Maintenance (PdM), Supply Chain Management (SCM), and regional fieldwork in the Basque Country (BC) highlight common trends, structural challenges, and actionable opportunities for both SMEs and the VET ecosystem. These findings are organised across six key thematic areas:

5.1.1. TECHNOLOGICAL AND OPERATIONAL SHIFTS

The emergence of AI, IoT, digital twins, edge computing, and cloud-based solutions is revolutionising operational processes in PdM and SCM. PdM enhances asset reliability, reduces downtime, and optimises lifecycle costs, while SCM is transitioning toward resilience and agility through Digital Supply Networks (DSNs). Despite differing application environments, both domains are converging on autonomous, service-based, and explainable systems that demand restructured workflows, cross-functional collaboration, and data-enabled decision-making. New models such as platform-based ecosystems, service-oriented architectures, and testbeds support experimentation, de-risking, and scalable innovation across stakeholders.

5.1.2. DIGITAL AND GREEN TRANSITION IMPACT

Technologies in PdM and SCM are not only performance enhancers but also enablers of sustainability. PdM supports green objectives by extending equipment life, reducing energy consumption, limiting transport-related emissions, and contributing to circularity. SCM aligns with



green practices through emissions tracking, reduced material waste, circular supply strategies, and collaborative design. Digital tools increasingly underpin firms' ability to anticipate and meet environmental obligations, aligning operational optimisation with ecological goals.

5.1.3. BARRIERS AND SME-SPECIFIC CHALLENGES

Both PdM and SCM are constrained by shared structural barriers. Financial constraints remain dominant, with SMEs struggling to access funding for technology upgrades, particularly for modular or interoperable systems. Technical challenges include legacy infrastructure, lack of interoperability, and cybersecurity risks. Organisationally, SMEs often face low digital maturity, limited internal IT support, resistance to change, and a lack of clear strategic vision. PdM implementation also suffers from insufficient access to consultants and unclear ROI, while SCM transformation is slowed by fragmented planning systems, underutilised tools, and data governance gaps.

5.1.4. EVOLVING SKILLS AND WORKFORCE NEEDS

The shift to digital and green operations is reshaping the industrial skills landscape. Roles are becoming hybrid, requiring combinations of traditional know-how, systems thinking, and fluency in digital platforms. Skills in AI, diagnostics, cybersecurity, cloud interfaces, and data interpretation are increasingly vital. Workers are expected to engage in continuous learning, adapt quickly, and collaborate across domains. Transversal and soft skills – like communication, problem-solving, and adaptability – are also growing in demand, particularly as workflows evolve and automation expands.

Yet, digital skills gaps, employee resistance, and the misalignment between training programmes and industrial systems persist as significant obstacles. Addressing these challenges requires the implementation of people-centered change management strategies that address cultural adaptation alongside technical training. Such an approach not only enhances workforce readiness but also ensures sustainable integration of new technologies within organisational processes.

5.1.5. STRATEGIC OUTLOOK AND INNOVATION MODELS

Looking ahead, advancing both digital and green transformation within the European manufacturing ecosystem will require integrated, forward-looking strategies that align technological development with workforce evolution and organisational adaptability. This report draws on cross-European analyses (PdM and SCM reports) and the in-depth regional exploration provided by the Basque Country (BC) report to identify strategic innovation models, emerging best practices, and actionable insights. The BC report in particular highlights the role of regional VET centres as key enablers of industrial innovation, providing real-world examples of collaborative upskilling efforts and low-risk experimentation frameworks.

In **Predictive Maintenance (PdM)**, long-term competitiveness will rely on widening access to funding, investing in workforce training and digital literacy, and optimising data-centric strategies. In **Supply Chain Management (SCM)**, future success hinges on fostering transparency, building trust among partners, aligning digital and green goals, and strengthening data governance.

To support these outcomes, a range of innovation models and enablers are already emerging:

- **Modular and collaborative transformation strategies:** SMEs are adopting phased approaches that balance innovation with affordability. These are often built around shared infrastructures, consortium-led development projects, and cross-stakeholder platforms that facilitate distributed risk-taking and mutual benefit.
- **Service-oriented architectures** - such as **PdMaaS (Predictive Maintenance as a Service)** - provide a viable pathway for SMEs to access predictive capabilities without



investing in costly infrastructure. These solutions, often delivered via OEMs or cloud platforms, shift responsibilities from internal technicians to data analysts and external service providers, increasing flexibility while preserving operational reliability.

- **Testbeds and public-private partnerships** continue to gain momentum as mechanisms to de-risk experimentation, enable applied R&D, and stimulate VET–industry collaboration. The BC report reinforces this with evidence of local VET centres co-leading innovation pilots with SMEs and industrial clusters.
- **Gradual adoption strategies** backed by **public funding and collaborative EU projects** (e.g. LCAMP) allow SMEs to explore emerging technologies in controlled, lower-risk environments - a particularly valuable approach for firms with limited internal capabilities.
- **VET centres as catalysts**: The BC report and broader EU research converge on the strategic role of VET institutions. These centres act as bridges between industrial needs and training provision, while also supporting applied innovation. Their ability to adapt curricula, foster hybrid learning, and train staff in modern pedagogy positions them as key players in sectoral transformation.
- **Digitally fluent intermediary roles** are becoming essential in both PdM and SCM contexts. These new workforce profiles - often shaped by VET training - connect traditional shopfloor expertise with advanced digital tools. They also liaise effectively with external AI providers, predictive maintenance specialists, or software integrators.

Lastly, **SCM innovation models stress the critical role of trust-based collaboration**. While digital tools enable transparency, real-time communication, and traceability, the human dimension of **trust remains fundamental** to long-term supply chain partnerships. Building trust - through cultural alignment, relational continuity, and shared goals - is increasingly recognised as essential to industrial resilience and innovation.

5.1.6. VET SYSTEMS AND EDUCATION TRANSFORMATION

Vocational Education and Training (VET) centres are increasingly recognised as strategic enablers of digital and green transitions within advanced manufacturing. Across Europe - and notably mentioned in the Basque Country - these centres are evolving from purely educational institutions into dynamic hubs of applied innovation, workforce development, and industrial partnership.

Findings show that **training providers are deepening their collaboration with industry**, co-developing curricula that integrate core technologies such as AI, IoT, cloud computing, and cybersecurity. They are also experimenting with **hybrid pedagogical models**, combining in-person and online learning to enhance flexibility and accessibility. These innovations are critical to addressing rapidly changing skill needs and preparing learners - whether new entrants or upskilling workers - for the complexities of modern industrial environments.

Yet challenges remain. **VET centres often face structural barriers** including limited autonomy in shaping programmes, insufficient training for trainers (especially in digital tools and new teaching methodologies), outdated curriculum structures, and constrained funding for upgrading equipment and infrastructure. As a result, many centres struggle to match the pace of industrial transformation.

To address these gaps, VET institutions are beginning to explore new formats such as **micro-credentials**, **modular training pathways**, and **cross-centre collaboration** to better respond to increased enrolment and employer demand for highly specialised qualifications.

The **Basque Country report** offers concrete examples of how these challenges are being met through **gradual technology adoption strategies**, supported by **public funding and collaborative projects**. These initiatives provide safe, low-risk environments for experimenting with emerging technologies and fostering innovation. Furthermore, **Basque VET centres are actively participating in applied innovation projects**, positioning themselves as crucial actors in regional industrial strategies. Their contributions to **workforce upskilling and reskilling**



highlight the pivotal role VET centres can play in supporting local ecosystems and driving transformation on the ground.

Finally, **EU-level initiatives such as LCAMP** offer a critical layer of coordination and support, aligning local experimentation with continental strategic goals. By linking industry, policy, and education, these programmes enhance the capacity of VET centres to act as **catalysts of innovation, sustainability, and inclusion** in the future of advanced manufacturing.

5.2. STRATEGIC LESSONS

The transformation of advanced manufacturing through digital and green technologies reveals six strategic lessons critical to aligning industrial evolution with workforce development and educational renewal:

- **Technology is not neutral - adoption is contextual and unequal.** Large enterprises typically lead innovation, benefiting from robust internal infrastructures and investment capacity. In contrast, SMEs adopt technologies more incrementally, constrained by financial, organisational, and technical limitations. Therefore, successful transformation strategies must accommodate these divergent starting points and prioritise modular, scalable, and service-oriented solutions.
- **The green and digital transitions are converging and mutually reinforcing.** Sustainability goals are no longer separate from technological agendas. PdM reduces energy use, material waste, and emissions through proactive maintenance. SCM digitalisation enables circular economy models and emissions traceability. Green goals are increasingly pursued through digital tools - creating synergies that must be embraced jointly.
- **In both PdM and SCM, expectations of technical expertise and digital fluency, data interpretation acumen and facility with AI interaction, are increasingly appearing in job descriptions, along with the ability to collaborate outside fields of study.** These emerging expectations illustrate the growing demand for hybrid profiles combining deep domain knowledge with cross-functional, digital, and interpersonal skills.
- **VET systems are becoming strategic actors in innovation ecosystems.**
The role of VET centres extends far beyond training delivery. As shown notably in the Basque Country, they are becoming facilitators of industrial innovation, testbeds for applied technologies, and agents of local economic resilience. Strengthening their autonomy, technical capacity, and links to industry is critical to ensuring inclusive transition pathways.
- **Skills are the currency of transformation - and they are evolving.**
- **Technical proficiency in AI, cloud computing, and IoT is increasingly essential.** However, equally important are transversal competences: adaptability, critical thinking, collaboration, and learning autonomy. As hybrid roles emerge and work environments become data-rich, workers must combine operational fluency with analytical capability and soft skill resilience.
- **Change management is the linchpin of transformation.**
- **Technology adoption is as much cultural as technical.** Successful industrial and educational transitions depend on leadership, communication, and trust. From resistance to automation to outdated pedagogical models, progress depends on preparing both people and institutions for continuous reinvention.



5.3. RECOMMENDATIONS

In response to these strategic lessons, the following cross-cutting recommendations are proposed for stakeholders across the advanced manufacturing ecosystem:

For Policy Makers and Funding Authorities

- Ensure sustained investment in digital and green transformation by supporting SME adoption through public-private partnerships, innovation vouchers, and de-risked experimentation platforms.
- Recognise VET centres as strategic transformation agents and support their autonomy, infrastructure upgrades, and capacity to engage in innovation ecosystems.
- Promote alignment between national qualification frameworks and emergent occupational profiles, ensuring that evolving job roles and hybrid skill sets are recognised and transferable across Europe.

For SMEs and Industrial Stakeholders

- Adopt modular, scalable technologies - such as PdM-as-a-Service and cloud-based SCM platforms - to reduce investment risk and increase agility.
- Invest in workforce upskilling through micro-credentials and lifelong learning, for example in AI, data interpretation, and sustainable operations.
- Foster a culture of collaboration by joining platform ecosystems, participating in regional innovation networks, and building trust across supply chains.

For VET Centres and Training Providers

- Develop and integrate hybrid training models that blend online and in-person learning, enabling flexibility for both students and professionals.
- Collaborate with companies on curriculum co-design and real-world application of skills, particularly through testbeds, case studies, and innovation projects.
- Strengthen the training of trainers, equipping them with both digital expertise and modern pedagogical approaches.

For EU-Level Coordination

- Continue initiatives like LCAMP that create structured methodologies for observing technological trends, skill needs, and training innovations.
- Facilitate the harmonisation of digital and green transition strategies across Member States, enabling VET centres and SMEs to operate in a coherent framework of goals and support.

By embracing these recommendations, Europe can ensure that its advanced manufacturing sector remains globally competitive, environmentally sustainable, and socially inclusive - anchored by a VET ecosystem ready to meet the challenges of tomorrow.



5.4. OUTLOOK

The green and digital transitions currently reshaping the advanced manufacturing sector are not just technological challenges - they are human and systemic opportunities. As we look ahead, it becomes clear that successful transformation requires more than access to new tools; it demands the ability to integrate these innovations into everyday operations, workforce expectations, and educational systems.

Across both Predictive Maintenance (PdM) and Supply Chain Management (SCM), the outlook is defined by convergence. Green and digital goals are increasingly linked, not just in terms of sustainability metrics but in shared strategies for efficiency, circularity, transparency, and resilience. In both fields, SMEs and large companies alike are experimenting with hybrid solutions: combining local expertise with cloud-based infrastructure, traditional roles with AI-enhanced systems, and modular adoption strategies with broader value chain alignment.

VET centres are key enablers of this transition. The outlook for vocational education is no longer limited to technical instruction or sector-specific certification; it is expanding toward integrated capability development. Centres must prepare learners to think across systems, work collaboratively across domains, and continually adapt to the evolving demands of digitally-enabled and sustainability-oriented industries. This means promoting flexible learning pathways, strengthening industry partnerships, and ensuring that teachers are empowered with the skills - and institutional freedom - to experiment, evolve, and lead.

At the same time, emerging forms of cooperation and experimentation will shape the next phase of transformation. Whether through testbeds, public-private partnerships, cross-centre initiatives, or experimental funding models, VET centres and industry must co-design both learning experiences and technological roadmaps. Working with multiple VET Centres and dozens of industry partners has provided this work package with valuable insights into the common ground between academic instruction, practical preparation, vocational training, and workforce readiness. Direct access to learning and teaching activities and aspirations, as well as SME and large industry perceptions and protocols, has resulted in a careful analysis of two key areas in the manufacturing landscape. What has become clear is the established value of VET centre training, the imperative of educational and industrial collaboration, and the shared commitment we all have to student success in their learning and employee satisfaction in their work world. Through the lens of predictive maintenance and supply chain management, we have seen that digital and green transformation shares a common future supported by a common commitment.

To that end, the outlook for collaborative integration of these two outcomes - and the two institutions supporting those goals - is both positive and possible. We have it in our power, as individual institutions and as a collective educational sector, to work with manufacturing companies of all sizes in the transformation of learning, teaching, training, and employment. Through recommendations both practical and aspirational, learner-centric and industry-expansive, local and regional and trans-national, we have an opportunity to reimagine the future of vocational and educational training in advanced manufacturing throughout the European Union, and around the world.

These reports, and the insights they carry, would not exist without the collective intelligence, energy, and dedication of all the partners engaged in this work. Across borders, time zones, and institutions, each contributor has brought their expertise and shared commitment to excellence. From the heart of the European Union to its neighbouring regions, this spirit of cooperation reflects the very best of the Erasmus+ mission - collaborative, human-centred, and future-focused. It is a privilege, to witness and be part of such a vibrant example of the European spirit in action.



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8. ANNEX

8.1. ANNEX 1 - SKILLS NEEDS

Table 7. Skills needs (from PdM, SCM and Basque Country reports)

LCAMP Competence Area	Categorisation	Recommended subcategories in the LCAMP framework	Occupation/Origin of the report	Skills needs
AI Literacy	Competence	Critical Digital Competence	Predictive Maintenance (PdM)	Basic AI or Machine Learning - Basic knowledge of AI/ML models
	Skill	Computer vision	Quality control technician (BC)	Computer vision and CNNs for defect detection - apply neural networks for automated quality control
		Machine Learning	Quality control technician (BC)	AI-based inspection tools - use artificial intelligence for defect detection
Digital	Attitude	Cybersecurity	Predictive Maintenance (PdM)	Cyber security awareness - IT security awareness
			Supply Chain Management (SCM)	Cyber security awareness - IT security awareness
		ICT	CNC operator /Quality control Technician/Automation-robotics technician (BC)	Cybersecurity in OT environments - understand security risks in production systems
	Competence	ICT	Supply Chain Management (SCM)	Cloud platform - ability to use cloud tools Problem solving skills - ability to use cloud tools
		Problem solving	Predictive Maintenance (PdM)	Problem solving (maintenance) - analytical thinking for data-driven decision making
		System Design	Predictive Maintenance (PdM)	Predictive model management (failure pattern analysis, risk thresholds)
			Automation-robotics technician (BC)	Industrial robotics integration - connect robots with production line systems



	Skill	Data literacy	Predictive Maintenance (PdM)	Interpretation of sensor data - ability to read and use IoT sensor data
				Data diagnostic skills (maintenance) - data analysis for fault diagnosis
			Supply Chain Management (SCM)	Data literacy - General data literacy in SCM
		ICT	Supply Chain Management (SCM)	Hybrid profiles (supply chain + digital skills) - e.g. supply chain analysts with digital skills
				ERP and SCM system literacy - Routine use of ERP/SCM software
			Automation-robotics technician (BC)	Communication protocols (OPC-UA, Ethernet) - implement industrial communication standards
			CNC operator (BC)	Digital interfaces and HMI's - operate touchscreen controls on CNC machines.
			Automation-robotics technician/Maintenance technician (BC)	Apply basic cybersecurity protocols in OT environments - implement security procedures and access controls in production systems
			Maintenance technician (BC)	Install and configure industrial IoT sensors - set up connected sensors for data collection
				Use Computerised Maintenance Management Systems (CMMS) - manage maintenance workflows digitally
		ICT	Predictive Maintenance (PdM)	Use of PdM platforms - use of PdM dashboards, CMMS tools, etc.
		Problem solving	Predictive Maintenance (PdM)	Data interpretation (maintenance) - data analysis for fault diagnosis



			Maintenance technician (BC)	Troubleshoot data connectivity in IoT networks - solve communication problems in connected systems
		Data literacy	Quality control technician (BC)	Digital inspection systems operation - use automated measurement and testing equipment
				Digital documentation and traceability - maintain electronic records of quality data
				Vision systems configuration - set up cameras and image processing for quality control
			CNC operator (BC)	MES/ERP system integration - connect machining operations with enterprise systems
				Data acquisition and interpretation - collect and analyze production data for optimization
			Maintenance technician (BC)	Monitor sensor data (IoT) - analyze real-time data from connected industrial sensors
				Use cloud-based platforms to monitor machine performance - access remote monitoring systems
		Computer vision	Quality control technician (BC)	Machine vision systems - operate camera-based quality inspection systems
		Digital Manufacturing	CNC operator (BC)	CAD/CAM software operation - use computer-aided design and manufacturing programs
Transversal	Attitude	Communication	Supply Chain Management (SCM)	Communication and coordination - openness and willingness to embrace digital transformation



		Flexibility/Agility	Predictive Maintenance (PdM)	Adaptability - willingness to adapt to changing roles/technologies
	Competence	Collaboration/Teamwork	Predictive Maintenance (PdM)	Collaboration - cross-departmental collaboration (maintenance, IT operations)
		Critical thinking	Supply Chain Management (SCM)	Strategic thinking - holistic understanding of complex supply chains
	Skill	Collaboration/Teamwork	Transversal skills (BC)	Work effectively in teams - collaborate successfully in multidisciplinary work groups Cross-functional collaboration - work effectively with multidisciplinary teams in digital environments
		Communication	Transversal skills (BC)	Communication and coordination - share information clearly across departments and shifts
		Flexibility/Agility	Transversal skills (BC)	Adapt to emerging technologies - willingness to learn and use new technological tools
		Problem solving	Transversal skills (BC)	Problem-solving and decision-making - analyze situations and make effective technical decisions
		Continuous improvement	Transversal skills (BC)	Continuous improvement mindset - identify optimization opportunities in digital manufacturing processes
Professional	Competence	System Design	Automation-robotics technician (BC)	Industrial robotics integration - connect robots with production line systems
	Skill	System Design	Automation-robotics technician (BC)	Vision systems configuration - set up cameras and image processing for robot guidance and automation





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