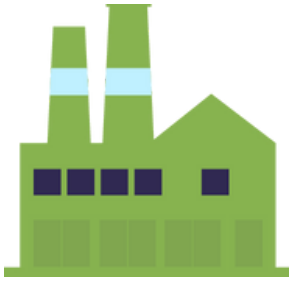
4!ZDM
Zero Defects Manufacturing

POLICY BRIEF

Zero-defect and large-scale manufacturing – human-centric, open and ethical aspects of Factories of the Future / Made in Europe projects

This policy brief discusses novel approaches to zero-defect manufacturing and their role in the transition to Industry 5.0. It presents key aspects identified by ongoing Factories of the Future projects OPTIMAI, I4Q and Penelope for a human-centric, open and ethical European industry. It provides recommendations for policy measures to take into consideration when deciding on priorities for future Made in Europe work programmes.



Key points

- AI methods for zero-defect manufacturing deployed on factory shopfloors
- Human-centric tools for workers
- Digital Twins
- A Legal and Ethical framework
- Sustainable digitalisation & positive social impacts
- Develop technical guidelines to ensure that new manufacturing processes and large parts comply with standards as well as with current norms, while utilising AI techniques
- Technical guidelines to ensure that new manufacturing processes Life-cycle thinking to assess the potential for environmental and cost improvements through LCA/LCC.

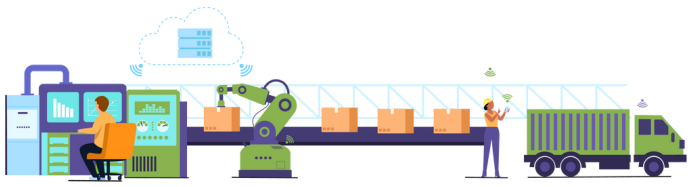
Introduction

Smart manufacturing has traditionally been studied from a technocentric perspective. However, with the gradual shift from Industry 4.0 to Industry 5.0, the technology-driven focus needs to be complemented by a human-centric approach to the manufacturing industry.

Industry 5.0 reflects a shift to a more sustainable, human-centric and resilient European industry allowing for humans and artificial intelligence to work together [1]. Manufacturing operations need to be supportive of smart governance, collaborative, focused on user needs, and ultimately oriented towards the development of well-being for its citizens.

The manufacturing of large-scale parts needs the implementation of a holistic data management and comprehensive automation methodology based on worker-centric tools to achieve the desired levels of precision using modular and more flexible equipment.
In this policy brief, three Horizon 2020 projects representing the Zero-Defect Manufacturing (4ZDM) Cluster share their experiences and lessons learned in areas including openness, end-user involvement and ethics. OPTIMAI, I4Q and PeneloPe reflect on selected success stories and provide recommendations for the Made in Europe Work Programme 2025-27.

As the 2025-27 work programme is being planned and the topics are being drafted, it is important for past and current projects to feed into the policy development to ensure that the needs of the field, the market and the actors involved are reflected in the scope of the new calls.



The experience from the current Factories of the Future projects OPTIMAI, I4Q and PeneloPe provides insights into how practices can be shaped to deliver optimal outcomes. This policy brief presents a few of the success stories that emerge from the projects and that can be applied to other projects and initiatives.

The **OPTIMAI** project has developed new solutions to optimise production, reduce defects and improve training to safeguard European industry for generations to come. Key parts of the OPTIMAI system include:

AI methods for ZDM deployed on factory shopfloors: methods to detect accuracy, meet timing restrictions and record AI actions. OPTIMAI uses near-real time methods, and Reinforcement Learning is used for adjusting machine parameters and preventing upcoming defects. A distributed ledger (blockchain) framework has been deployed to immutably record actuation signals.

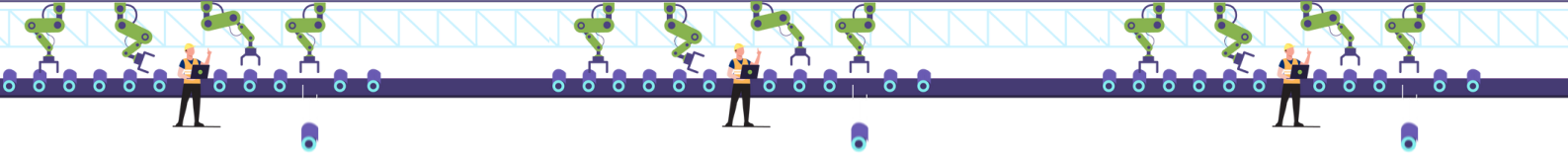
Human-centric tools for workers: tools that enhance workers' abilities and increase overall productivity. In OPTIMAI, a framework for real-time egocentric computer vision has been developed that is used for AR applications to enrich the worker's Field of View. A Decision Support tool has also been developed to provide real-time inspection and prediction results and capture worker's feedback on AI results. With this approach, AI algorithms are retrained to model workers' experience and expert knowledge.

- **Digital Twins**: Developed in OPTIMAI for use in production planning to reduce ramp-up time and reduce scrap rate at early production runs.

- **Legal and Ethical framework**: Ensuring ethical and legal compliance in the use of novel technological tools by workers. OPTIMAI uses Touchpoint [2], a tool designed by Trilateral Research with the purpose of simplifying the process of the ethical, legal and societal risk and impact assessment in research projects. OPTIMAI also has a robust Ethics Board with four external and three internal members with recognised expertise in the field of ethics. They advise the consortium on ethical matters relevant to the project and its aims throughout the lifetime of the project. The Board attends meetings, produces regular ethics screening reports and reviews deliverables.

In addition to the development of sustainable Reliable Industrial Data services to manage the significant amount of data coming from factory devices for supporting smart manufacturing, the use of **i4Q** solutions in the pilot sites leads to the following positive social impact:

Job Creation and Skills Development: Smart Manufacturing initiatives have created new job opportunities in areas such as data analytics, AI programming, and IoT maintenance. It is creating talent attractiveness in industrial sectors. Skilled workers who can operate, maintain, and optimize the advanced systems are attracted to manufacturing companies. I4Q systems support will make the job more interesting for humans and enhance the skill profile of human workers. The process optimisation will also allow human workers to move up the job ladder and acquire new skills and rewarding roles.



- **Safer Work Environments**: IoT devices equipped with sensors can monitor workplace conditions in real time, detecting potential hazards such as temperature extremes, toxic gases, or equipment malfunctions. The i4Q solution set offers an opportunity of relieving stress-points in repetitive human driven processes which today are not possible to automate using traditional industrial solutions.

- **Sustainability and Environmental Impact**: IoT-enabled industrial systems can help optimize resource usage, energy consumption, and waste production. The use of i4Q advanced sensing and data techniques has driven to a full usage of raw materials.

- **Improved Quality of Products**: Smart Manufacturing and IoT technologies enable real-time monitoring and quality control during production processes. This leads to fewer defects and higher-quality products reaching consumers, enhancing customer satisfaction.

- **Local Economic Growth**: The implementation of Smart Manufacturing practices often involves collaboration between companies, technology providers, and local governments. Several partners of i4Q are developing sustainable collaborations in other domains. This collaborative ecosystem can lead to increased investments, job creation, and overall economic growth within a region.

PENELOPE aims to develop an end-to-end Digital Manufacturing solution, enabling a bidirectional dataflow for seamless integration across the entire manufacturing chain. PENELOPE implements a digital manufacturing architecture for a precise, accurate, flexible and responsiveness manufacturing of large-scale parts from the initial product design.

- **Develop technical guidelines** to ensure that new manufacturing processes and manufactured large parts obtained therefrom will comply with quality standards as well as with current norms, regulations and technical standards applicable in the domain of each target component addressed by PENELOPE, helpful towards novel certification schemes, including guidelines to comply with Health, Safety and Environmental (HSE) aspects.

Ensure the alignment of PENELOPE results with current **standardisation activities** (on digital architectures) and its contribution towards its wide adoption.

RINA will develop **technical guidelines** regarding the new production process, encompassing the different production stages based on PENELOPE's digital approach and taking advantage of the application of AI techniques (hot topic in safety assurance).

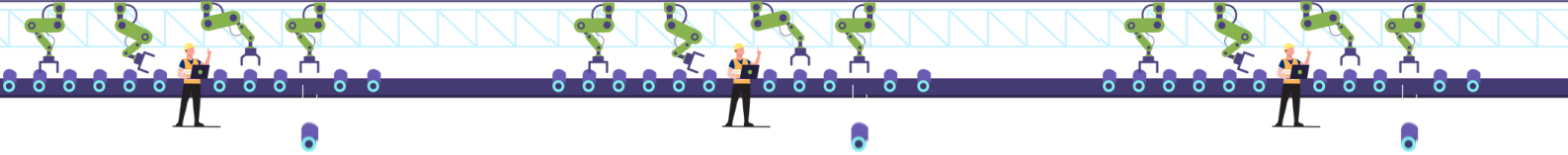
RINA will monitor the execution of the project to align project results with existing **standardisation activities** (CEN and ISO), with special focus on architectures, guidelines and (quasi-standards for production lines concepts (ICT/M2M/Data exchange like AutomationML, OPC UA). Further research will be conducted on existing/developing standards and other standardisation activities relevant to PENELOPE (e.g., CEN/TC 310 or ISO/IEC/JTC 1/SC42)

Life-cycle thinking will be used to assess the potential for environmental and cost improvements through LCA/LCC.

Environmental footprint:

- Penelope is developing a framework, based on a life cycle thinking approach, to analyse the bottom-line impacts against the project objectives of the 3 real-scale pilot lines. This framework will be composed of Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCC), for a thorough assessment of the achieved impacts on terms of production costs, times, waste generated and the global environmental impact. The main goal is the identification of impact hotspots of selected technologies and applications. The proposed benchmarking based on a life-cycle approach enables to monetised environmental and economic externalities to perform systematic analysis of the benefits of potential new projects/investments.

- Technologies developed in PENELOPE are expected to reduce the environmental footprint of the products due to a more efficient production process (less material and energy consumption) and a consequence reduction in cost. Furthermore, it is expected that PENELOPE technologies will increase the performance of the products (i.e., weight reduction in the transport sector, ensuring material recyclability at the end of life) with additional environmental impact reduction during all life cycle.



Conclusions & Policy recommendations

1. Ethical dimension

- In the MiE WP 2025-27, Introduce ethical, legal and societal issues management strategy as mandatory in proposals with a strong focus on AI in the same way as the D&E&C strategy is mandatory.
- Make it mandatory for projects to appoint an ethics advisor/advisory board for projects with an ethics dimension. In the EC's guidance to beneficiaries on how to complete the ethics self-assessment, this is currently only a suggestion, not an obligation.

2. Human-centric approach

- Make it mandatory for future proposals to integrate a human-centric approach to manufacturing, with appropriate SSH contributions. Make proposals address a) the involvement of end-users in the pilots to ensure human-centric approach and maximise acceptance among the European workforces; b) how technologies can improve factory work for humans and how human-robot cooperation can be improved. A strategy for skills development should be included. This requirement is currently included in a limited number of topics and should be integrated into all relevant MiE topics.

3. Dissemination and exploitation

- Encourage more publishers to follow Plan S [3]
- Define an equilibrium between open source and the IPR Protection Strategy
- Develop the use of existing platforms and networks to maximize impact
- Increase the visibility of existing support services such as Enterprise Europe Network (EEN) contact points, facilitate access to European Innovation Council (EIC) funding.

4. Environmental Footprint

- The technologies developed in Penelope could be applied to different sectors, some of which are represented in the case studies. During the project it observed the need to harmonise environmental objectives in different sectors (aeronautics, energy) to have synergies and to push towards circular economy schemes.
- As environmental demands increase, markets will be driven to adopt new, more efficient technologies in terms of materials and energy used. New policies could encourage the adoption and development of new technologies, such as those developed in the PENELOPE project, thus contributing to a more competitive industrial sector.

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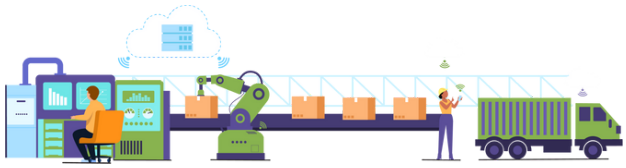

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