AI-PRISM

D1.1 – Technology benchmarking and Project Vision

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Disclaimer

Acronyms and definitions

Acronym	Meaning
AAS	Asset Administration Shell
AASX	Asset Administration Shell Package exchange
AGV	Autonomous Guided Vehicle
AI	Artificial Intelligence
AMR	Autonomous Mobile Robot
AR	Augmented reality
AutomationML	Automation Markup Language
CI/CD	Continuous Integration/Continuous Deployment
CTO	Chief Technology Officer
DIH	Digital Innovation Hubs
ERP	enterprise resource planning
GUI	graphical user interface
HRC	human robot collaboration
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IIoT	Industrial Internet of Things
IIRA	Industrial Internet Architecture Framework
IoT	Internet of things
ISO	International Organization for Standardization
LE	Large Enterprises
LWIR	Long Wavelength Infrared
MES	Manufacturing Execution Systems
MLOps	Machine Learning Operations
MOM	Manufacturing Operations Management
MQTT	Message Queuing Telemetry Transport
MR	Mixed Reality
MWIR	Middle Wavelength Infrared
OPC UA	Open Platform Communication Unified Architecture
OROCOS	Open Robot Control Software
PCL	Point Cloud Library
QDSN	Quick Deployment Sensor Networks
QoS	Quality of Service
ROI	Return of Investments
ROS	Robot Operating System

RTOs	Research and Technology Organisations
SDN	Software-Defined Networking
SME	Small and Medium Enterprises
SSH	Social Sciences and Humanities
TCP/IP	Transmission Control Protocol/Internet Protocol
TSN	Time Sensitive Networking
VPN	Virtual Private Network
WSN	Wireless Sensor Networks

The AI-PRISM project

AI-PRISM will provide industrial users with **human-centred artificial intelligence (AI)-based solutions to create a more efficient, resilient, digital, sustainable and high-quality European manufacturing industry**.

To do so, we will develop an **integrated and scalable environment** with solutions adapted to dynamic and unpredictable manufacturing scenarios that require tasks that are difficult to automate and where speed and versatility are essential to meet users' needs. Furthermore, the solutions will be specific to semi-automated and collaborative manufacturing in flexible production processes and will not require specific robotic programming skills.

Our solutions ecosystem will have four main pillars:

1. **A human-centred collaborative robotic platform** oriented to ease hard-to-automate manufacturing tasks.
2. **A human-robot cooperative environment** powered by trustworthy AI.
3. **Social human-agent-robots teams' collaboration** — AI-based safety monitoring and robot control mechanisms to detect and avoid unsafe situations and ensure social and physical safety.
4. **An open-access network portal** to offer compliant infrastructure.

To evaluate our solutions' performance, transferability, scalability and large-scale deployment, we will perform demonstrations in real operating environments. Specifically, in **four user pilots involving key manufacturing sectors** — furniture, food/beverage, built-in appliances and electronics —, **types of robots and industrial processes that are difficult to automate, plus a generic demonstration facility.**

In addition to seeking quantitative improvements in the manufacturing sector, **AI-PRISM aims to use technological innovation to support a paradigm shift in which AI, robotics and Social Sciences and Humanities (SSH) are integrated into the manufacturing domain for the improvement of flexible production processes**, becoming a viable and widespread alternative for European factories.

During the next three years, **25 partners** from **12 countries** will join forces to make AI-PRISM a reality. From educational institutions to research and technology organisations, robot manufacturers, industries and use case providers; our interdisciplinary consortium brings together all the actors of the human-robot collaboration value chain and involves key experts in SSH, standardisation, exploitation, and dissemination.

Contents

1. Introduction

AI-PRISM project aims to provide industry with human-centred artificial intelligence (AI)-based solutions adaptable to unpredictable manufacturing scenarios including difficult to automate tasks.

The solutions proposed in this project will be oriented towards flexible and collaborative manufacturing between humans and robots. These include a robotic platform oriented to easy or automate difficult or repetitive tasks, a human-robot cooperative environment, AI safety that monitors robot-human relation to avoid unsafe situations and an open access portal to offer the needed infrastructure.

AI-PRISM will provide industrial users with human-centred artificial intelligence (AI)-based solutions to create a more efficient, resilient, digital, sustainable, and high-quality European manufacturing industry and the proposed solutions will be tested in 4 pilots involving 4 industrial companies from very different sectors such as furniture manufacturing, food, household appliances and electronic components manufacturing. D1.1 “Technology benchmarking and project vision” is the main output of tasks 1.1 and 1.2 and its main aim is to serve as a guidance for partners to stay focused on the main goals and objectives of AI-PRISM. It gathers the common vision of the AI-PRISM project agreed among all partners.

In particular, D1.1 provides information about the general positioning and vision of AI-PRISM, the project business and research/technological opportunities, stakeholders, and also use cases. Project innovations and vision enablers for AI-PRISM will also be considered.

D1.1 “Technology benchmarking and project vision” has been set as Public in the Grant Agreement, meaning that the document will be made available to the general public. However, due to its contents, its main audience will be the project partners. Also, D1.1 can be useful for the wider scientific and industrial community, including other EU funded projects which may be interested in collaboration activities.

2. High Level AI-PRISM Vision

2.1. Context (in general)

2.1.1. Challenge

The concept of AI-PRISM can be simplified to the human-centred enhancement of collaborative features of robotic solutions using Artificial Intelligence (AI). Collaborative robotics is a rapidly evolving field that is reshaping manufacturing and logistics. Collaborative robots (cobots) are designed to work alongside human workers, taking over repetitive, monotonous tasks, while leaving the more complex (and value-adding) tasks to humans. Europe has been at the forefront of the development of collaborative robotics, with several research initiatives that have resulted in the development of advanced collaborative robotics applications that can operate in complex and dynamic environments. AI-PRISM is one of such research initiatives, focusing on the concepts of AI-enhancement, and applying human centred design to better reduce the main adoption barriers. In this sense, the concept of AI-enhancement is not innovative per se. Robotic solution providers make an extensive use of AI to enhance the capabilities of their products. The vision is to think of humans and robots as agents that collaborate to achieve common goals, and the challenge is how AI can enhance this collaboration to overcome the main barriers hindering the adoption of collaborative robotics. Based on this collaboration paradigm, AI is a technological enabler that enhances the perception and reasoning capabilities of collaborative robots, i.e., their ability to analyse the environment (product, process, equipment status) and take optimal decisions to support humans in achieving their objectives in a collaborative ambient.

AI-PRISM stands for AI-Powered human-centred Robot Interactions for Smart Manufacturing. The paragraph above describes what AI Powered Robot Interactions for Smart Manufacturing means, but the human-centred aspect is missing, which is crucial to properly identify and reduce the stop barriers for the adoption of collaborative robotics, and where the innovative aspects of AI-PRISM are found. Often, economic cost is considered the main barrier for the adoption of robotics, and also often, it is assumed that the Return of Investments (ROI) of robotics comes at the expense of lowering personnel costs, that is, replacing humans in the workplace. AI-PRISM adopts a more holistic approach and identifies all the concerns of the stakeholders involved, not only the economic viability concern (which is obviously considered as well), but also several human-centred concerns (Figure 1):

- Usability concerns: Ensure that the solutions are easy to use, that improve significantly the work ergonomics, that they require minimal learning, and that they can be configured without highly skilled personnel. This is crucial because companies are nowadays facing a shortcoming of qualified personnel.

- Safety concern: Ensure that the collaboration between humans and robotic agents (e.g. AMRs or robot manipulators) is safe after eliminating the physical barriers between humans and robots.

- Trustworthiness concerns: Ensure that the AI systems are lawful, ethical, and technically robust, so that the introduction of AI and robotics is not perceived as a threat, and that all agents trust the collaboration with robotic solutions. Trustworthiness implies that the solutions comply with training data requirements, explainability requirements, cybersecurity requirements, cyber resilience requirements, fairness, and bias removal requirements, among other requirements.

- Feasibility concerns: Ensure that the solutions envisioned can be delivered with the resources available, considering the project timeline, and the technical resources and skills available.

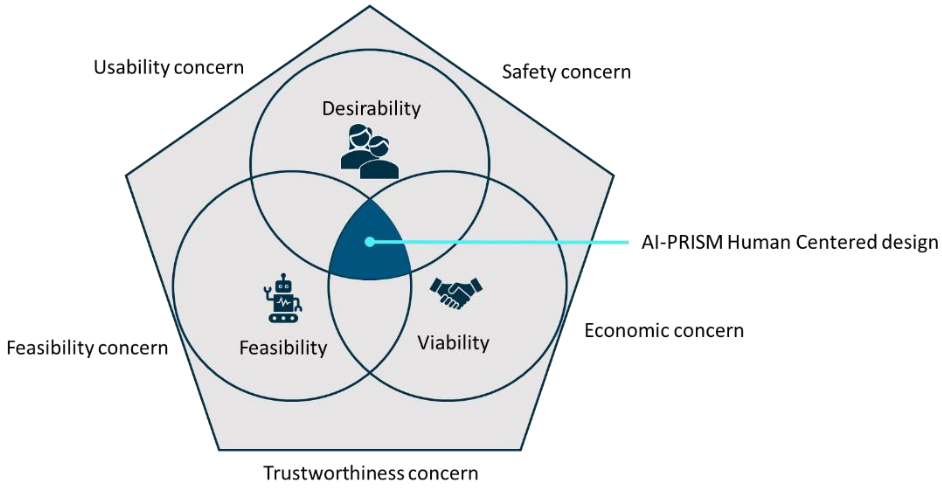


Figure 1 Human-centred design in AI-PRISM

2.1.2. Elevator Pitch

As a summary, AI-PRISM is about tearing down the fences between robots and humans, so that they can collaborate efficiently. We are not talking only about the physical barriers that isolate robots in manufacturing environments to protect humans, but also about the technical, cultural, and psychological barriers that hinder human robot collaboration. We all tend to see robots as a replacement for humans in work environments, but what if instead we regard AI as a facilitating technology, enhancing human-robot collaboration? We think that together, humans and robots can empower each other, and that the margin of improvement achieved through enhanced collaboration is so big that it is the best strategy to scale up current industrial settings. This is depicted in Figure 2.

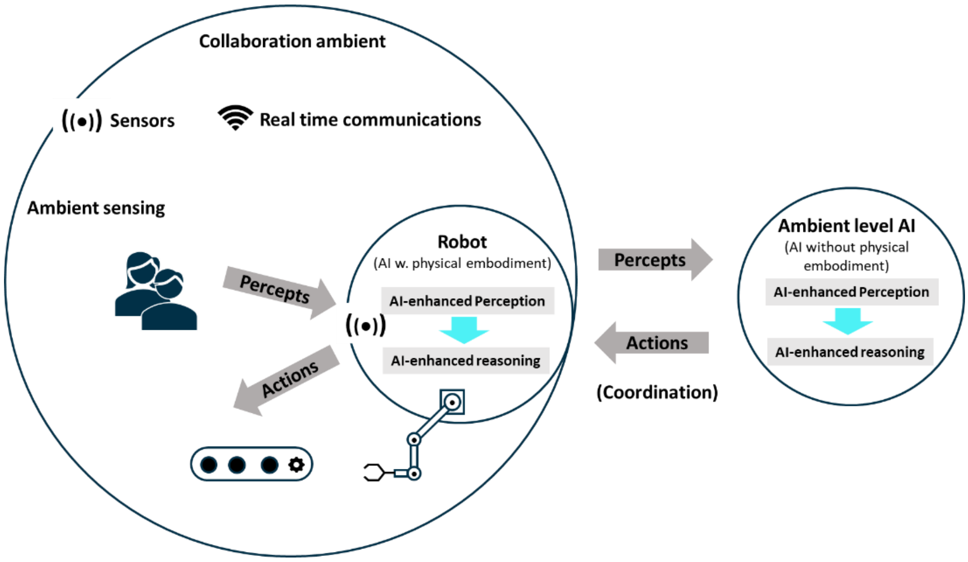


Figure 2 AI-PRISM in a nutshell

2.2. Stakeholders

AI-PRISM stakeholders are considered as organizations that may be interested in the project results, and will, potentially, make use of them. This section gathers the different stakeholders' profiles and categories identified at this moment for the AI-PRISM Project and how we expect that they engage:

2.2.1. Manufacturing Industry

Segments: Factory/Plant Managers, Production Line Managers, CTOs, R&D Departments/ Units, Mechatronics Engineers, Human Workforce

AI-PRISM will engage managers from manufacturing industries and also the workforce who execute the concrete tasks to: 1) provide specific requirements and feedback that will be used during project implementation (such as understanding internal processes, system integration and risk management); 2) having access to quality data acquisition; 3) getting to know how the positive impact that collaboration of human and robots through smart tools have in real manufacturing scenarios.

2.2.2. Digital Tech Providers

Segments: IoT Manufacturers/ Platform Providers, Robot Manufacturers/Suppliers, AI Engineers/ Data Scientists, Service/App Providers, Autonomous System Integrators, Standardisation Technical Committees.

AI-PRISM would like digital tech providers to: 1) demonstrate how the automation of processes benefits using robots, 2) how AI can be applied to obtain reliable prediction models and 3) how datasets can be secured and processed getting to more innovative decision-making systems.

2.2.3. Social Innovation Sector

Segments: Human-Robot UX Researchers, Civil Society Organisations, Privacy, Security, Legal Agencies, Ethical AI Researchers, Digital Education Providers, New European Bauhaus

Social innovation and human factors are in the core of AI-PRISM. Therefore, this is a very important stakeholder group able to build bridges between workers and the ever-evolving technology and also, capable of assure workforces needs. Also, AI-PRISM will be committed to the New European Bauhaus, being situated at the crossroads between social inclusion, science and technology.

2.2.4. Advocate Ecosystem

Segments: Horizon Europe Partnerships, EU Technology/ Manufacturing Associations, EU DIHs / Digital Europe Programme, EIT Digital/ Manufacturing, H2020 Projects

AI-PRISM has a strong and well-defined collaboration framework that will create and enhance synergies between the project and the different actors in the public and private domains. Therefore, the participation of the consortium in different ecosystems to create new collaborations will actively be promoted.

In particular, we aim at reaching: 1) the European partnerships emerging from Horizon calls (i.e. 'AI, Data and Robotics' Partnership and 'Made in Europe'); 2) EU-wide associations conforming the AI, Data and Robotics Association (Adra) and in which several consortium partners already participate (i.e. euRobotics, DARIO, CLAIRE, ELLIS, EurAI, and EFFRA); (3) ecosystems concentrating large communities of private-sector organisations such as European Digital Innovation Hubs; (4) previous H2020 projects driving missions in digital transformation for manufacturing and also sister projects funded under the same call (e.g.: CONVERGING)

2.2.5. Policy Makers

Segments: European Commission, Public Agencies, Regulators, Observatories/Think Thanks

This group of stakeholders comprise public bodies and task forces related to policy-oriented activities. The main target in our case will be the European Commission, although different policy makers at local and country level may be targeted as well.

2.2.6. Society

Segments: General Public, Non-specialized media

General public awareness is crucial for technological acceptance and positive impact of the Industry 5.0 paradigm where human centred sustainable approaches are widely considered, Therefore, through our communication and dissemination strategy we will promote both the project itself and also the most important outcomes through the "not specialized" society to increase engagement as much as possible.

2.3. Brief explanation of Use cases

2.3.1. Use Case 1: Furniture Sector: Furniture (Design Chairs)

Andreu World is a company that designs, develops, and manufactures contemporary furniture with high added value for the global market. Andreu World company is well known as a success case industrializing craftmanship in the furniture industry.

The painting and sanding processes are currently performed manually by skilled operators. The shape of the pieces of furniture, the material used, the wide variety of models and the high degree of accuracy required make it difficult to automate these processes. In AI-PRISM, a collaborative environment (i.e. robot plus a human operator) will be developed, in which the robot will learn different tasks by human demonstration and in which robots and humans can collaborate in a meaningful and safe way. Ideally, the expected endpoint is to have a human with skills in painting and sanding in charge of training and supervising the entire process and robots handling all the repetitive tasks.

2.3.2. Use Case 2: Reduction of environmental pollution with waste from production of semiconductors

VIGO Photonics is a European manufacturer of semiconducting materials and instruments for photonic and microelectronic, specialized in MWIR and LWIR detectors and modules.

The precise positioning of small (1-2mm) semi-finished electronic components against a wire to be attached is performed manually using XY adjustable tables with position control under a microscope and support of measuring software. This is followed by the gluing the wire. Precise positioning of the components is fully based on the experience on the worker, whose tiredness and inattention may cause incorrect attachment of the wire, resulting in producing a waste and delays. Due to the delicate nature of the components and variable production volume (short series or even single pieces), the automatization of the production is very difficult and uneconomical. In AI-PRISM, the solution will feature automatic positioning of the electronic component against the wire, in order to be glued, with the support of electromechanical or/and pneumatic effectors and a AI-enhanced vision system, that will recognize the appropriate place to attach the wire on the electronic component, based on the shape, color and additional markers if needed. The operator will teach the robot the correct positioning of the elements to be glued together.

2.3.3. Use Case 3: Brewery/Food industry transformation towards Industry 5.0

Athenian Brewery (AB) is the largest beer production and distribution company in Greece, producing and distributing its products in 19 countries across 5 continents. The company has invested in the modernization of its manufacturing process, the adoption of an integrated environmental policy and the creation of a safe and fair working environment.

Although the brewing production line is highly automated, there are tasks that are difficult to automate due to complex activities and activities that require dynamic and fast repurposing and reconfiguration actions in automation, such as: extra labeling, returned bottles classification, packing and palletizing custom orders, heavy tasks in the filtration preparation process and garbage collection and disclose in geofenced areas based on safety protocols. In AI-PRISM, robots will learn from human demonstrations, so as to execute dynamically defined and customized tasks.

2.3.4. Use Case 4: Adaptable & Collaborative Workstation for Packaging & Quality Control of Hoods Human&Cobots

The main activity of SILVERLINE is the production of classic and exhaust hoods, gas stoves and built-in ovens for household appliances.

In the final control workstation, three human operators are working manually together, leading to long cycle time, non-ergonomic working conditions (both physical and mental), and unsafe and unhealthy working environment, among others. In AI-PRISM, an adaptable/collaborative control station will be implemented at the end of a hood assembly production line, where human-robot collaboration is applied for the control and packaging of the final products, increasing the efficiency of resource use (with subsequent reduction in production costs and increase in production volume) and the safety of human operators.

2.3.5. Use Case 5: Generic Demonstrator: AI-Control for Natural, Multi-modal Collaboration Sector: Discrete Manufacturing

KEBA deals with three strong business areas for the future. Industrial Automation develops and produces automation solutions for machines and robots. Handover Automation enables the secure and contactless transfer of cash, parcels or goods as well as controlled access to shared objects. Energy Automation is one of the pioneers of charging solutions for electric vehicles, heating controls for heat pumps as well as biomass heating systems.

Nowadays automation control systems for discrete manufacturing are designed for fast execution of repetitive tasks (as found e.g. in mass-production). Since few years, cobots are developed to enable closer human-robot collaboration, but with a cost of less speed and precision for task execution. In AI-PRISM, natural ways to teach a new process (and gripper), to adapt existing processes and "debug" the execution of such processes by non-programmers will be developed, with the support of multi modal, ambient sensor networks that help to determine deviations in the execution, to determine the need for adaptation.

3. Positioning

3.1. Business Opportunities

3.1.1. Market context

In the framework of AI-PRISM project, the main focus is to study and develop new AI-based robotic solutions to be applied in different sectors of industry both in Small and Medium Enterprises (SME) and Large Enterprises (LE). Robotics is already present in many industrial scenarios and the mass-production is almost completely automated. The main challenge of the next future is to convert the current production tasks based on manual work to a hybrid production scenario where humans and robots can collaborate together connected with AI-based platform that will improve the overall production scenario.

Taking the above into account, AI-PRISM would address this new approach through several topics:

- **Support the operators** in repeatable, monotonous strenuous tasks and not ergonomic operations in higher-risk area.
- **Improve the quality** of final product that will not depend on the operator sensitivity and skills
- **Improve production** order management and tracking
- **Reduce product waste** (material scrap, not conformity, etc.)
- **Introduce new flexible solutions** for an easy reconfiguration of production line essential for scenarios where low batched volume or high level of product variant are present.
- **Maximize the production** with improvement in terms of delivery, efficiency and cycle time
- **Improve the training** phase of operators

From this short analysis, the market context of AI-PRISM project appears strongly related to the human-robot collaboration sector and adoption of AI tools for easy management of the robotics applications.

3.1.1.1 *Drivers*

The main drivers that could consider for the adoption of collaborative robotics are listed below:

- Skilled workers shortage: Europe is facing a shortage of skilled workers, and cobots can help bridge the gap to ensure operations and scale up businesses
- Increased productivity and efficiency: cobots can do some repetitive tasks faster and with higher repeatability, they also have longer shifts, leading to increased productivity.
- Improved quality: cobots perform tasks in a standardised way, reducing process variability and improving quality, plus they can perform inspection and testing tasks.
- Improved safety: Collaborative robots are secure-by-design, lightweight and compliant with safety guidelines (IS&TS 15066).

- Improved ergonomics: the adoption of collaborative solution can support the operator in repetitive and heavy task avoiding brief and long terms injuries.
- Flexibility and versability: robots can be reprogrammed and reconfigured to adapt to specific use cases or tasks with minimal configuration
- Fenceless approach and cost saving in the new redesign of industrial layout with less structured space needed (e.g., less barriers, fixtures, etc.)
- Hybrid collaborative solutions: recently several manufacturers offer new cobots able to have a double approach with collaborative features when the process require an interaction with the operator and a complete industrial mode (full speed) when no interaction is foreseen. With the adoption of specific sensors and signal is possible to switch from one to the other modality in very fast and efficient way,

3.1.1.2 *Limitations*

On the other hand, collaborative robotics still face limitations due to relatively new approach and technology adopted. Below some of the main limitations present at the moment in the industrial scenario compared to traditional industrial robot

- Lower payload capacity: due to the reduced mass and inertia to be considered for a possible impact with operator
- Lowe speed: this is one the main constrains that deeply affect the cycle time and the requirements of the customer in terms of productivity
- Lower precision and accuracy: the rigidness of the collaborative solution is not yet comparable in most of the case with the standard industrial robots with an impact of the accuracy of the robot itself. Nevertheless in the last years even more manufacturers started to offer solution almost comparable with standard solution in terms of precision.

3.1.1.3 *Challenges*

- Still high costs limit their adoption by SMEs even if the ease of installation, programming and use of the new products has facilitated the spread into new market and industrial segments with no need of high skilled personnel and a consequent reduction of overall costs.
- Impact of cobots on employment: the adoption of robotics solutions could entail the replacement human workers in certain tasks and industries. This aspect could be also seen as an opportunity to relocate the operators in more skilled and more add valued tasks and processes with a benefit in terms of quality of work and productivity.
- Social acceptance by operator: robotics and automated solution have been introduced since a relative few time and some social aspect as the possibility to work in cooperation with movable machine needs to be completely accepted by the operators.

– Regulatory framework and restrictions, adapting to new collaborative robot standards (ANSI/RIA R15.08), or cybersecurity standards such as ISA/IEC 62443.

3.1.1.4 *Key Players*

Most of the main robots manufactures starts to offer in their portfolio new collaborative solutions; starting from the pioneers in this field, such as Kuka and Universal robot that almost ten years ago started to put on the market the first collaborative robots, plenty of robotics companies launched on the market their own collaborative solution trying to cut a niche in the market. Beside well know companies (such as, Fanuc, ABB, Yaskawa, Comau, Omron, Denso, etc.), a certain number of new companies around the world started to produce and launch new collaborative robots trying to attract the market with affordable and easy-to-use solutions (Doosan Robotics, Dobot, etc.)

3.1.2. Cobots on the market

Having clear in mind the normative framework, it is possible to analyze the different products available on the market, identify the different technologies applied in order to perform the collaborative function (e.g., current monitoring, capacitive sensing, resistive sensing, toque/force monitoring, etc.), compare the level of accuracy and the reachability and evaluate the IP grade protection and any additional feature available.

Usually, several are the features that are taken into account in the selection of the system for the specific application. They are as follow:

- **Payload**: is the maximum load in terms of weight that the robot is able to carry (including not only the end effector but also the part to be manipulated). It is expressed in weight, even if also the shape of the part and its inertia are relevant in the application and in the performance (specific software option are used for a more detailed setting)
- **Reach**: it is the maximum reachability of the robot in mm. The best performance of the robot is usually in the mid-range of this value
- **Speed:** this value for collaborative robots is strongly dependent to the norms that regulates the maximum force to be applied for a safety contact with the operators. Some models can work in both limited collaborative and full industrial speed.
- **Repeatability:** is one the main measurable characteristic to evaluate the performance of the robot in terms of quality of the motion and task achievement.
- **Weight**: this is an important factor to be considered in the installation and setup phase
- **Manual guidance:** this option indicates if the robot can be moved directly by hand

The following tables report the most relevant collaborative robots available on the market; a summary of the cobots distribution with the most important features (payload and reach) is reported on Figure 3:

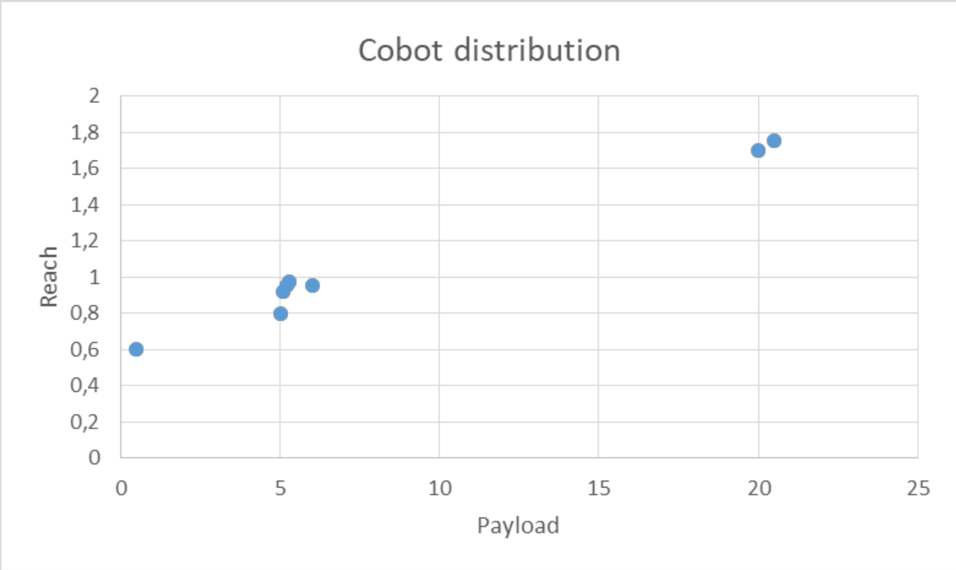


Figure 3: Cobots distribution

<table>
<tr><th colspan="2">COMAU Racer5 Cobot</th></tr>
<tr><td>Key features:
- Payload: 5kg
- Reach: 809 mm
- Speed: 6000 mm/s (not collaborative) / 500mm/s (collaborative)
-Repeatability: 0.03 mm
- Weight: 32 kg
- Manual guidance: Yes</td><td></td></tr>
</table>

Table 1 COMAU Racer5 Cobot

<table>
<tr><th colspan="2">UNIVERSAL ROBOT UR5e</th></tr>
<tr><td>Key features:
- Payload: 5kg
- Reach: 950 mm
- Speed: 1000 mm/s (hold to run) / 250mm/s (collaborative)
-Repeatability: 0,03mm
- Weight: 20,6 kg
- Manual guidance: No</td><td></td></tr>
</table>

Table 2 UNIVERSAL ROBOT UR5e

UNIVERSAL ROBOT UR20	
Key features: - Payload: 20 kg - Reach: 1750 mm -Speed: 1000mm/s - Repeatability: 0,05 mm - Weight: 64 kg - Manual guidance: Yes	

Table 3 UNIVERSAL ROBOT UR20

ABB YuMi single arm	
Key features: - Payload: 0,5kg - Reach: 559 mm - Speed: 1500 mm/s (tcp velocity) -Repeatability: 0,02mm - Weight: 9,5Kg - Manual guidance: Yes	

Table 4 ABB YuMi single arm

MITSUBISHI Melfa Assista	
Key features: - Payload: 5kg - Reach: 950 mm - Speed: 1000 mm/s (tcp velocity) -Repeatability: 0,03 mm - Weight: 32 kg - Manual guidance: Yes	

Table 5 MITSUBISHI Melfa Assista

FANUC CRX family	
Key features: - Payload: 6 to 10 kg - Reach: 950 mm - Speed: 1000 mm/s (tcp velocity) - Repeatability: 0.05 mm - Weight: 40 kg - Manual guidance: Yes	

Table 6 FANUC CRX family

ABB GoFa	
Key features: -Payload: 5 kg - Reach: 950 mm -Speed: 2200 mm/s (tcp velocity) - Repeatability: 0.05 mm - Weight: 27 kg -Manual guidance: Yes	

Table 7 ABB GoFa

YASKAWA C20DTP	
Key features: -Payload: 20 kg - Reach: 1700 mm -Speed: 2000 mm/s (not collaborative) / 1000mm/s (collaborative) - Repeatability: 0.05 mm - Weight: 140 kg - Manual guidance: Yes	

Table 8 YASKAWA C20DTP

Analyzing the tables, it is possible to see that all robots are aligned in terms of precision (repeatability) and the payload is almost in the range 0-5kg, with some specific cases able to reach 20kg. While the speed could be an important factor in terms of cycle time achievement, the robots' weight and the reach are the main factors, that could influence the final choice. The different use-cases will be deeply analyzed in order to select the most suitable solution and to identify the areas of improvement of actually available solutions.

3.1.3. Mobile platforms on the market

Analogously to the cobots, an analysis of the current solutions presents in the market has been executed also for the mobile platforms taking into account the different technologies and features for each model:

- **Payload**: is the maximum load in term of weight that the robot is able to carry. It is expressed in weight (KG).
- **Speed:** also for mobile robot this value is dependent to the norms that regulates the mobile robotics.
- **Environment**: if for Indoor or outdoor purposes
- **Autonomy**: max duration of battery
- **Dimensions**: this is a crucial factor for navigation in small or big environments and to carry bulky objects.

Moreover, extra information about type of navigations, sensors used, type of batteries, etc., are reported when available.

The following tables report the most relevant mobile platform available on the market; a summary of the distribution with the most important features (payload and length) is reported on Figure 4.

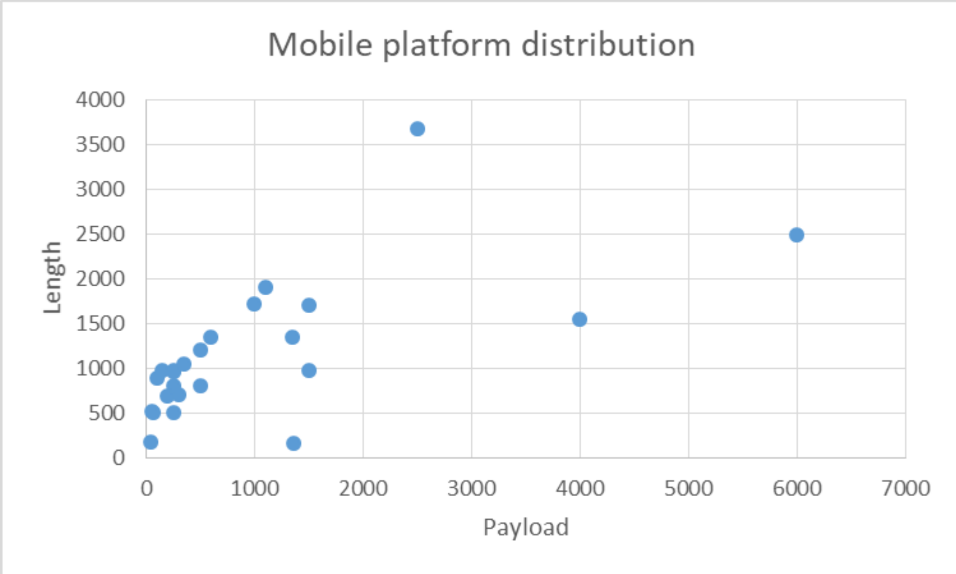


Figure 4 Mobile platform distribution

MiR100 Mobile Robot	
Key features: Payload: 100 kg Speed: 1.5 m/s Dimensions: 890 x 580 x 348 mm Autonomy: 8-10 hours Navigation: Autonomous, using 2D LiDAR sensors Safety features: 3D camera and ultrasound sensors, emergency stop button, obstacle detection and avoidance.	

Table 9 MiR100

MiR250 Mobile Robot	
Key features: Payload: 250 kg Speed: 2 m/s Dimensions: 800 x 580 x 330 mm Autonomy: 13 hours Navigation: Autonomous, using 2D and 3D LiDAR sensors Safety features: 3D camera and ultrasound sensors, emergency stop button, obstacle detection and avoidance.	

Table 10 MiR250

MiR600 Mobile Robot	
Key features: Payload: 600 kg Speed: 2 m/s Dimensions: 1350 x 920 x 330 mm Autonomy: 10.45 hours	

Table 11 MiR600

MiR1350 Mobile Robot	
Key features: Payload: 1350 kg Speed: 1.2 m/s Dimensions: 1350 x 910 x 330 mm Autonomy: 9.5 hours	

Table 12 MiR1350

Kivnon K03 Twister	
Key features: Length: 700mm x Width: 500mm x Height: 280mm Transport type: Lifting Maximum speed: Up to 1 m/s Battery: Lithium and online charging in integrated circuit Safety measures: Laser scanner, safety PLC and LED signaling	

Table 13 K03 Twister

Kivnon K05 Twister	
Key features: Length: 800mm x Width: 800mm x Height: 280mm	

Transport type: Lifting Maximum speed: Up to 1 m/s Battery: Lithium and online charging in integrated circuit Safety measures: Laser scanner, safety PLC and LED signaling	

Table 14 K05 Twister

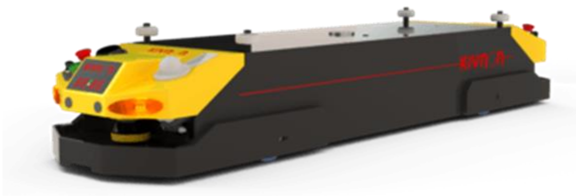
Kivnon K10/K11 OneWay/Two-ways	
Key features: K11: Length: 1900mm x Width: 460mm x Height: 280mm K11P: Length: 2010mm x Width: 500mm x Height: 280mm Transport type: Towing Maximum speed: Up to 1 m/s Battery: Lithium and online charging in integrated circuit Safety measures: Laser scanner, safety PLC and LED signaling	

Table 15 K10/K11

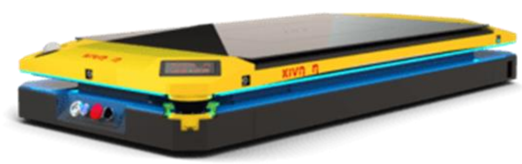
Kivnon K41 Slim	
Key features: Length: 1550mm x Width: 800mm x Height: 220mm Transport type: Lifting Maximum speed: Up to 1 m/s Battery: Lithium and online charging in integrated circuit Safety measures: 360º safety via laser scanners, safety PLC and LED signaling	

Table 16 K41 Slim

Kivnon K20 Tractor	
Key features: MOVEMENT One-way movement LOAD	

Towing capacity of up to 6,000kg on a wheeled trolley GUIDANCE Magnetic guidance navigation Transport type: Towing Maximum speed: Up to 1 m/s	

Table 17: K20 Tractor

Kivnon K55 Pallet Stacker	
Key features: MOVEMENT Two-way movement LOAD Load capacity of up to 1,000 kg ELEVATION Lifting capacity of up to 1,000 mm GUIDANCE Mapping navigation Transport type: Lifting Maximum speed: Up to 1 m/s	

Table 18: K55 Pallet Stacker

Jugheinrich EKS family - Self-Supported Stacker AGV	
Key features: Load capacity: 1500kg Lift height: 6000 mm Travel speed: 7 km/h Overall length: 2492 mm Battery voltage: 24V	

Table 19: EKS family

Jugheinrich ERE Automated Pallet-Truck	
Key features: Load capacity: 2500kg Lift height: 125 mm Travel speed: 7.2 km/h Overall length: 3666 mm Battery voltage: 24V	

Table 20: EKS family ERE Pallet-Truck

Jugheinrich – Arculee AMR	
Key features: Dimensions505 x 540 x 400 mm Payload: 250 Kg Speed: 2.3 m/s Environment: Indoor Autonomy: 8 Hours Batteries: Li-ion	

Table 21: Arculee AMR

Fetch Freight	
Key features: Weight 68kg (150lbs) Height 359mm (14in) Base footprint 508mm (20in) wide, 559mm (22in) dia. 2D laser 25m, 220 degrees Max speed :2.0m/s (4.47mph) Environment :Indoors	

Table 22: Fetch Freigh

Fetch Freight 1500	
Key features: Payload: 1500 kg (3300 lbs) Payload Dimensions: 150 cm (59") x 115 cm (45") Max Speed: 1.5 m/s	

Table 23: Fetch Freigh 1500

Locus Origin	
Key features: Dimensions: 22" diameter x 57.8" H Payload: CE Certified to 36 kg. / 80 lbs. Safety: 8 sensors and cameras Autonomy: 14 hours Charge Time: 50 minutes to full charge	

Table 24: Locus Origin

Locus Max	
Key features: Dimensions: 166.6 x 118.4 x 41.9 cm Payload: Up to 1361kg Safety: Dual, 2D safety-rated LiDAR Autonomy: 8-10 hours Charge Time : 90 minutes to full charge	

Table 25: Locus Max

Omron HD - 1500	
Key features: Dimensions: 1696 x 1195 x 370 mm Payload: 1500 kg Speed: 1.8 m/s Environment: Indoor Autonomy: 9 Hours	

Table 26: Omron HD – 1500

Omron LD- 250	
Key features: Dimensions: 963 × 718 × 383 mm Payload: 250 kg Speed: 1.2 m/s Environment: Indoor Autonomy: 13 Hours	

Table 27: Omron LD – 250

ABB (ASTI) Flexley Mover	
Key features:	

Payload: 350 kg Lifting height: 120 mm stroke Dimensions: (L×W×H) 1052 × 660 × 352 mm Movement: Omnidirectional	

Table 28: Flexley Mover

Robotnik RB-1	
Key features: Dimensions: ø 515 x 303-338 mm (with optional lifting unit) Weight: 30 Kg Payload: 50 Kg Speed: 1,5 m/s Environment: Indoor Autonomy: 6 h in industrial application	

Table 29: Robotnik RB-1

Robotnik RB-Theron	
Key features: Dimensions: 687 x 550 x 305 mm Weight: 55 Kg Payload: 200 Kg Speed: 1,25 m/s Protection: IP30 Environment: Indoor Autonomy: 8 h (industrial use case)	

Table 30: Robotnik RB-Theron

Robotnik Summit-XL Steel	
Key features: Omniwheels	

Dimensions: 978 x 776 x 510 mm Weight: 105 Kg Payload: Up to 250 Kg Speed: 3 m/s Protection: IP52 Autonomy: Up to 12 h	
Robotnik RB-Robout	
Key features: Dimensions: 1.717 x 850 x 350 mm Payload: 1.000 Kg Speed: 1,1 m/s Environment: Indoor/Outdor Protection: IP42 / Weatherproof Autonomy: Up to 10 h	

Table 31: Robotnik RB-Robout

The combination of a mobile platform with a cobot manipulator mounted on the top brings to the market also an hybrid cobot mobile able to enhance the flexibility and reusability of the system in several industrial context; some example are reported below:

Robotnik RB-Kairos	
SummitXL Steel + UR10e integrated robot Collaborative mobile manipulator for industrial applications Dimensions: 978 x 776 x 1.542 mm Weight: 115 kg + 33,5 kg Omniwheels Safety scanners + safety plc	

Table 32: Robotnik RB-Kairos

Oppent EvoCobot	
PAYLOAD 500kg SPEED 0,1 m/s – 1 m/s KINEMATICS Omnidirectional+ safety plc AUTONOMY 20 hours	

Table 33: EvoCobot

3.1.4. AI tools

The adoption of Collaborative robots within the different production scenarios could be enhanced with AI tools able to improve their use in all the phases of production such as deployment, setup, execution and maintenance.

Below a list of tools can be found below:

- **Digital twin:** introduction of a digital representation using the real system data allows to create simulations that can predict how a product or process will perform with advantage in terms of time and costs

- **New way of programming:** the use of new tools and features such as AR, MR, intuitive GUI, wearable device, vocal or gesture commands gives to the user an easier and intuitive experience with the system, reducing the time for training
- **Monitoring of the process:** using proper sensors, data collection and analytics within an IoT framework the entire process can be monitored guaranteeing better performance of the system and an improved efficiency of the production both at edge and server side for real time or offline corrections and improvements.
- **Predictive maintenance:** machine learning techniques that use the data collected from a single component or from the overall automated cell can help to monitor the status of the system allowing to predict possible failure in advance and consequently to reduce downtime due to sudden stop of the system.

3.1.5. Exploitation Pathways

The exploitation pathways of a project are structured in five main directions: research, education and training, commercialisation, standardization, and policy recommendations. Each of them is briefly explained below:

- **Further Research:** This pathway consists of using the project results in new research projects (outside the project action), which may be internal or through collaboration with others. This is usually carried out with open results developed by academia and research and technology centres.
- **Education and Training:** This pathway consists of using the project results to augment and complement teaching materials and seminars, both in academia or for the development of practical skills.
- **Commercialisation:** This pathway consists of transferring the results of project to the market with the aim of being profitable for the respective entity/entities involved. This pathway is usually carried out by industrial partners. Under this pathway there are multiple approaches: Developing and selling new products/services, Spin-off activities, Cooperation agreement/Joint Ventures, Selling IP rights / Selling IP-related business, and Licensing IP rights.
- **Standardization:** This pathway consists of using the project results to develop new standardization activities or to contribute to on-going standardization work. It can be made through interacting with the relevant technical standardization committees.
- **Policy recommendations:** This pathway consists of using the project results to contribute to policy making (knowledge, collected feedback about some topics or directive, etc.).

AI-PRISM aims at creating an integrated and scalable environment with solutions adapted to dynamic and unpredictable manufacturing scenarios. In the long-term the developments will move towards a more mature tools for resilient, flexible, reconfigurable, and responsive data-driven manufacturing lines. Therefore, the exploitation approach is focused on making possible that the different developments flow into the future smart manufacturing ecosystem in Europe.

In the case of AI-PRISM project, the expected pathways are depicted in Figure 5 below and are expected as follows:

- **Further Research:** The AI-PRISM AI Enhancing toolset (reasoning, perception and coordination abilities) and the Human Factor in HRC scenarios assessment can be further developed and improved through new research projects. Both results will be developed by Academia and RTOs, so it is expected that the results will be open for sharing with the research community.
  Additionally, another relevant AI-PRISM result to be shared and used by the research community will be the open datasets generated in the project (info from industrial elements of the platform, productive workflow, or robot-human interaction, among others).
  The entire scientific output of the project can be directed to this line of exploitation. In this sense, at least 10 peer-reviewed scientific publications in journals, and 30 peer-reviewed publications and presentations in conferences are expected.
- **Education and Training:** the documentation and training material generated during the project could be used by Academia to share the gained knowledge about the project technologies.
- **Commercialisation:** The AI-PRISM Human Centred Collaboration Platform and the Open Access Pilots will be commercialized to collect revenues from their use by third parties. The commercialization approach for each of them must be defined, although a first approximation could be the following:
  - In the case of the AI-PRISM Human Centred Collaboration Platform, it would consist of the open AI-PRISM framework platform, the Human-Robot cooperation ambient (complete environment formed by the physical elements (sensors and cobots, among others) and software modules), and professional commissioning and training services. These last two elements (the cooperation ambient and the professional services) will be under payment. It could be also that the extension of some features on the platform will be also under pay-per-use scheme.
  - In the case of the Open Access Pilots on AI-PRISM simulation services, the access to the infrastructure would be under an affordable pay-per-use scheme. The access

to the materials and documentation generated to learn how to use the platform will be open.

- **Standardization:** AI-PRISM will build upon existing standards during the development of the novel processes and products ensuring compatibility with market conditions and increasing transparency for customers. AI-PRISM is linked with ongoing standardisation work like, e.g., in ISO/TC 159 'Ergonomics', ISO/TC 199 'Safety of Machinery', ISO/TC 299 'Robotics', CEN/TC 310 'Advanced Automation Technologies & Applications' or ISO/IEC JTC 1 with its SC 41 'IoT' And SC 42 'AI'. This will support the exploitation of the project results, contributing to the development of new standards by forwarding inputs from AI-PRISM developed technologies.
- **Policy recommendations:** Contributions on this pathway are not expected a priori.

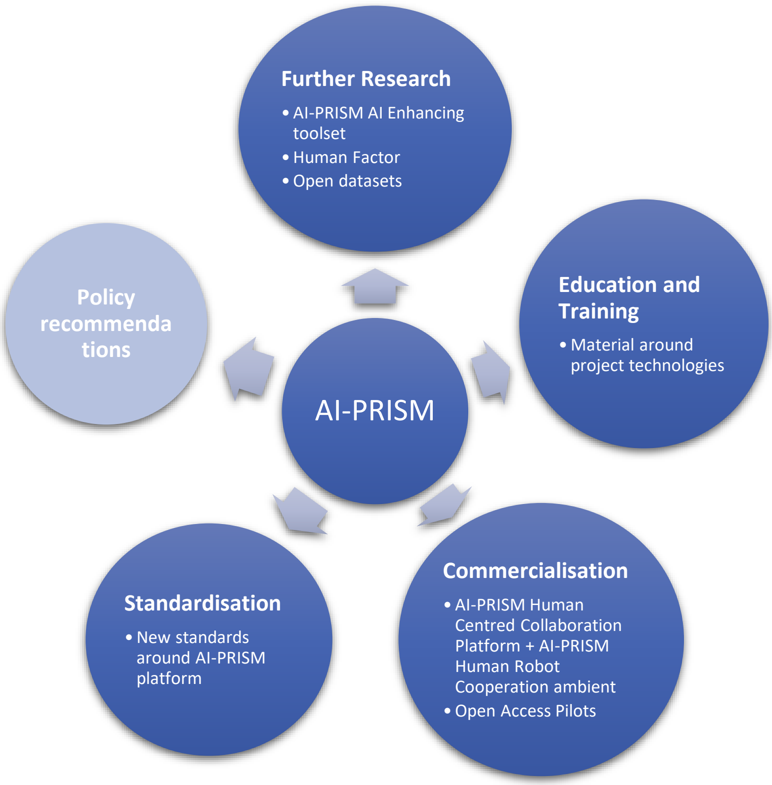


Figure 5 AI-PRISM project - Expected pathways

3.2. Research and Technological Opportunities

The Cobot market is a market segment that is growing year after year. In particular in last years, manufacturers around the world facing the COVID-19 pandemic in 2020 are confronting huge challenges: from the full or partial factory shutdowns, to the reduction of on-site teams to the most essential workers, who may be working in staggered shifts. And the relocation of everyone else (in sales, marketing, and even R&D) into work from home arrangements.

In the long term, business continuity and manufacturing resilience are priority outcomes. At a time when human workers' safety and productivity are of paramount concern, collaborative robots can take up work that is not fundamental for humans to do anymore.

Just to give an example, according to Next Move Strategy Consulting, the forecast of Cobot market [3] size is going to be the double of today in the next 5 year and nearly 3 times in 2030. Following graphs shows these figures.

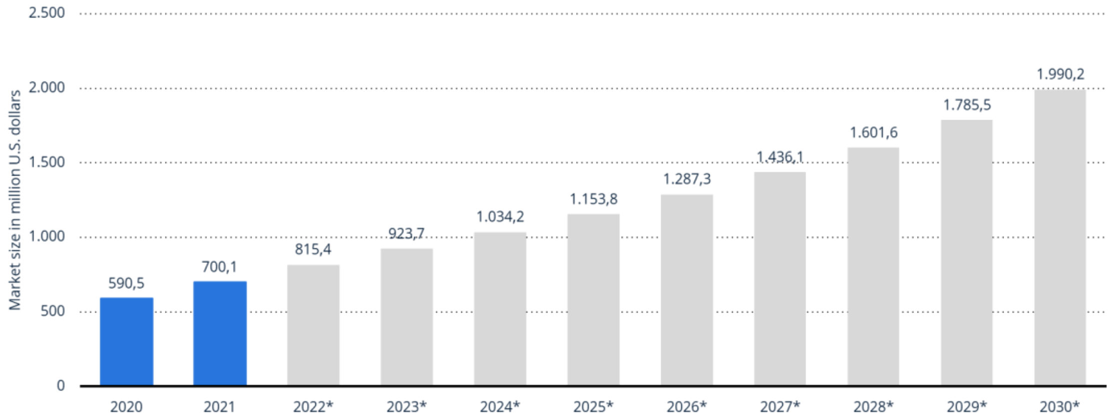


Figure 6 Cobots market size forecast

Talking about market application opportunities, according to Interact Analysis, today market size classified by application is concentrated in material handling, followed by assembly, with sorting and positioning in last places of the graph:

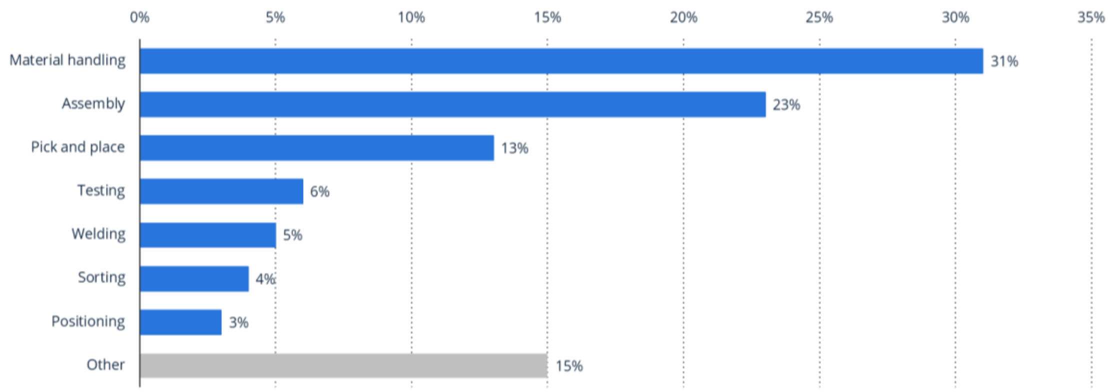


Figure 7 Cobots market share

Moreover, in the last years a relevant growth in the use of collaborative robots came up in many industrial sectors, not only in more conventional sectors where robotics was already well established but also in industries where the adoption of robotics solution was limited by technical and social limitation.

The following graphs shows the revenue share in the Cobot market in 2020, by industry:

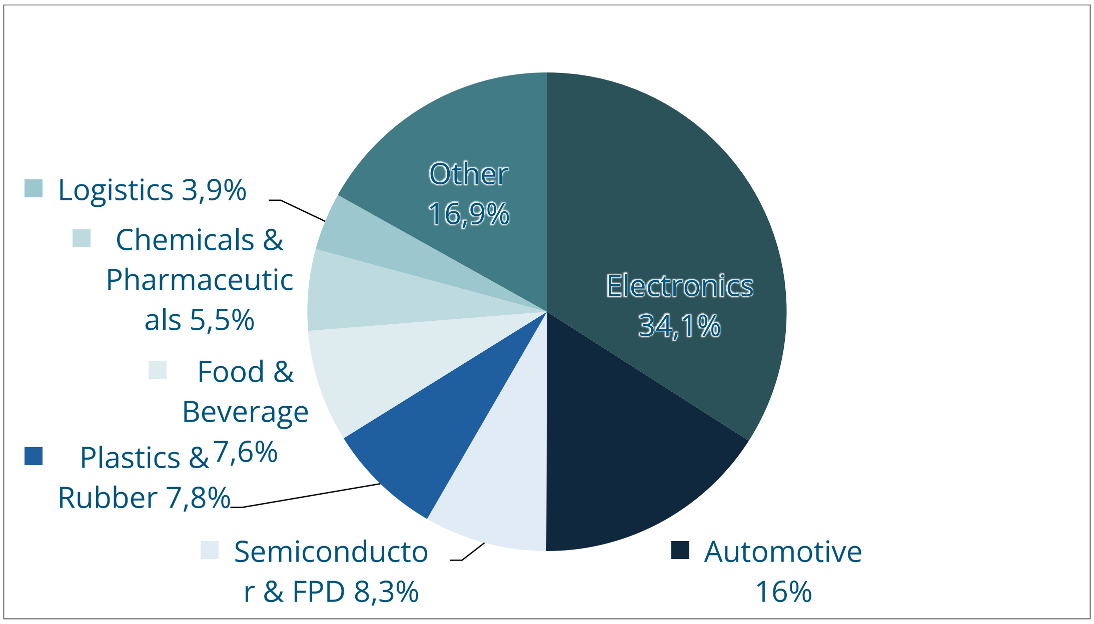


Figure 8 Cobots market revenue

In the AI-PRISM consortium, many of these industrial areas and applications are represented by the different end users, as listed in the table below:

End user	Application	Industry
Andreu World	material handling,	Furniture
Athenian Brewery S.A.	pick and place, sorting	Food and Beverage
Silverline	assembling, sorting	White goods, Built-in Appliances
Vigo System	positioning	Electronics
KEBA	assembling	Electronics

Table 34: Consortium end users, applications and industry

Another important information is given by the market share of Cobots vs traditional robots. According to Statista, the Cobots market share moved from 5% in 2018 to 13% in last year (2022).

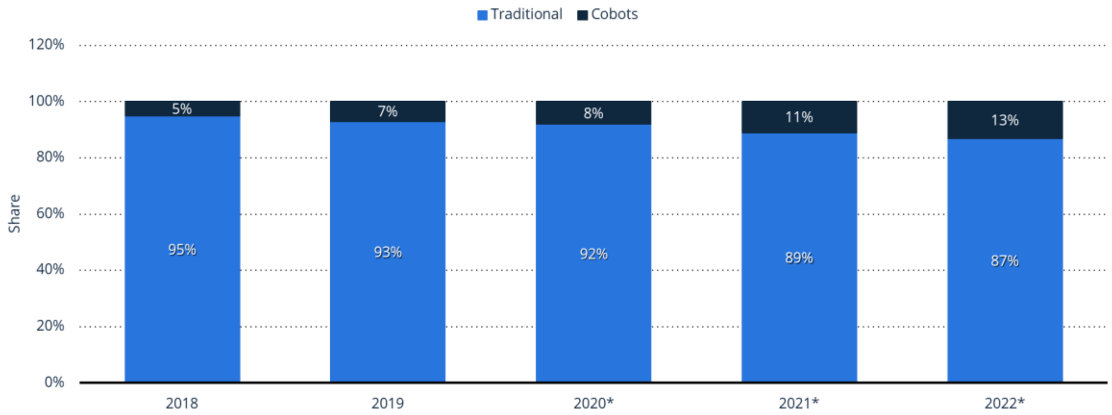


Figure 9 Cobots vs. traditional robots market share

Considering the figures proposed above it is extremely easy to understand which is the market direction: Increased automation, combined with robotics and artificial intelligence, is a viable alternative in the face the challenges of the future, also generated by the pandemic and the economic disruption. Cobots will also enable companies to adopt safer operating measures for their human workforces.

Restrictions on movement and work from home norms may become part of our manufacturing future. That does not prevent the industry sector from strengthening operational viability while protecting the welfare of its employees.

Human management will continue playing a key role in the factory setups of the future, especially when it comes to robot design, programming, maintenance, and supervision. In turn, collaborative robot adoption will enable manufacturers to devise new ways of achieving business continuity, protect their businesses against future challenges – and help them innovate along the way.

Analysing the business opportunities provide by the market, another important aspect that comes to the eyes, is that Collaborative robots have a very limited payload. It is important to extend the products families in order to cover all the sizes and payloads made available by the traditional robots. This will allow to have more interchangeability of robots and cobots, but also to generate more opportunities in markets not covered due to an insufficient payload.

4. AI-PRISM innovations

Being a collaborative research project, the innovations of AI-PRISM stem from the expertise of project partners (what each partner will bring into the project) and their expectations (what they hope to get from AI-PRISM). These are summarised in the table below.

Stakeholder:	**NTTD ES**
What will we provide:	Project management Emerging Trends and Market Insights Open Innovation
What we hope to get:	Improved outcome identification processes (both at individual and collective levels) Innovative processes of business models design and co-creation of business plans Better insights of AI-manufacturing market trends International cooperation
Stakeholder:	**EVR-IT**
What will we provide:	our experience in the sector our software platform
What we hope to get:	The development of a software platform able of increasing the level of safety in the interaction between workers and robots
Stakeholder:	**UPV**
What will we provide:	Technical Management Optimization algorithms Real time communications Robotic platforms
What we hope to get:	Innovative research results on collaborative robotics planning and scheduling Increased knowledge on AI-based solutions for robotic applications Improved collaboration between involved research groups
Stakeholder:	**IKER**
What will we provide:	Robotic framework based in ROS2 Assistance with the environment digitalization algorithms Assistance with the integration of real time communications and control Assistance with the implementation of a simulation platform Assistance with AI-based development Assistance with path-planning algorithms Assistance with the development of human-robot interaction solutions Assistance with the deployment of AI-PRISM in industrial environments

What we hope to get:	Strengthen our knowledge in ROS2 development Increased knowledge on AI-based perception solutions Increase knowledge on human-robot behavioral models Confidence with other partners for future projects
Stakeholder:	**FBK**
What will we provide:	Contributions to the overall architecture of the AI-PRISM platform and AI-related tasks conducted primarily in WP3 and WP4. Computer Vision algorithms for environmental digitalization, sensors calibration, and multi-sensor data fusion. Support for the ambient sensing infrastructure setup. Machine Learning algorithms for monitoring, understanding, and forecasting the tasks, interactions, and status human workers and robot agents perform in the environment. Support for the data annotation process.
What we hope to get:	Innovative digital industry focussed research results on the field of collaborative robotics planning and scheduling. Increased practical experience in AI-based solutions for robotic applications. New collaboration opportunities between European research groups and industrial stakeholders.
Stakeholder:	**KUL**
What will we provide:	Contributions to the overall architecture of the AI-PRISM platform and AI-related tasks conducted primarily in WP3 and WP4. This includes provision of relevant software and communication components. "Skills" with one or two robot arms, integrating vision or force sensing when needed. "Motion recognition" when needed in the above (and where possible wrt time and available software).
What we hope to get:	Real-world challenges that can feed our academic research.
Stakeholder:	**ITI**
What will we provide:	Flexible Multi-purpose and multi-platform optimization framework. Interoperable components for Real-Time Communication Platform. Centralized management and orchestration of network infrastructure. Wirelessly deterministic sensor communication platform.
What we hope to get:	New optimization components widening our framework capacities Real time algorithms for rescheduling optimization SDN controller with a global view of all AI-PRISM network technologies Software Defined Industrial Wireless Sensor Network (SD-IWSN)
Stakeholder:	**TAU**
What will we provide:	Development of a collaborative simulation platform. Development of human agents to integrate with the simulation platform. Lead the establishment of AI-PRISM alliance of open access pilots. Provide robots and equipment to demonstrate use cases.

What we hope to get:	Increase practical experience on digital twins and simulations development. Innovative research results on the development on human agents. Enhance experience on human-AI interactions. Confidence and collaboration with consortium partners. International collaboration opportunities for future projects.
Stakeholder:	**CRAN**
What will we provide:	Scientific human analysis and cognitive psychology New context-specific knowledge of user requirements Empirical data to improve human-robot work design, training and process improvement Quantified human impact assessment for system validation
What we hope to get:	New knowledge regarding human-robot interaction and shared task performance Transferable training and skills development framework Human-robot analysis methodology development / validation Opportunities to continue working with European partners on innovative research
Stakeholder:	**ROB**
What will we provide:	Knowledge on mobile robotics platforms Integration for the pilot lines
What we hope to get:	Novel mobile platform application
Stakeholder:	**COMAU**
What will we provide:	Knowledge on collaborative robotics Support on robotics integration for the pilot lines Sensor integration
What we hope to get:	Novel collaborative robotics solutions, applications and processes New collaboration and partnership with the involved partners and potential customer
Stakeholder:	**AUS**
What will we provide:	Communication & Dissemination Services Ecosystem building & Networking Professional Marketing Services
What we hope to get:	Increased knowledge on AI related technologies and concepts Enhance our know-how in the human-robot collaboration field New collaboration opportunities between European research groups and industrial stakeholders International (beyond EU) collaborations
Stakeholder:	**TEK**
What will we provide:	Functional Specification Computer vision for visual control of hoods Image processing techniques and ML/DL algorithms System integration

What we hope to get:	Increased practical experience in system integration Innovative research results on AI-based visual control International collaboration opportunities for future projects.
Stakeholder:	**SIL**
What will we provide:	SIL use case for hood quality control testing. Camera. Cobot. (if necessary, will be added mobile robot) Interface (for Production line). Smart devices (mobile phone, tablet) Network
What we hope to get:	A quality control station cooperated with cobot for finished products a different perspective for human operators Integrated AI-based technologies for control and product detection Creating a base station for other production lines
Stakeholder:	**ETRI**
What will we provide:	Our experience in the human factor analysis Requirement analysis for human status assessment Human status assessment methodology in human-robot collaborative work situation
What we hope to get:	New knowledge regarding human-robot interaction and collaboration Human analysis methodology development Opportunities to working with international partners on innovative research
Stakeholder:	**PIAP**
What will we provide:	Our experience in robotics and automation. Contributions to the architecture of the AI-PRISM platform (WP2) and AI-related tasks conducted primarily in WP3 and WP4. Provide CI tools. Robotics solutions to demonstrate in VIGO pilot.
What we hope to get:	New knowledge regarding human-robot interaction and collaboration. Increase knowledge on AI-based robotic solutions. Opportunities to make very precise automation solutions.
Stakeholder:	**VIGO**
What will we provide:	We share our unique production step. We provide possibility to base project efforts on our technology. We support with our technology knowledge and providing the components, personnel, shopfloor place for commissioning.
What we hope to get:	Robotic cell to glueing pins to chips, based on AI vision tool providing positioning of piezoelectric drives. Vision control station supported by AI to check output parameters of chip after polishing the chips and compare with input data for positioning as a synergy and preventive maintenance tool. Digital data provided to MES. Easy recognition of required pin as a support for personnel. Station solving the real production issue, which will increase capability and will reduce social disadvantages of high precision manufacturing, i.e., continuous focusing on same task which can effect on critical safety applications of our clients
Stakeholder:	**WINGS**

What will we provide:	WINGS-Chariot: an end-to-end solution that targets optimizations for the Intelligent Warehouse, comprising autonomous AGV powered freight/pallet transfers, human-AGV collaboration, storage optimization, order handling optimization, warehouse area geofencing & restricted access control, cargo localization, simulation, and worker Health & Safety. WINGS-Chariot will be extended in the context of AI-PRISM, to consider highly customized and dynamically defined tasks that are not easy to automate and program, as well as the need for dynamic and fast repurposing and reconfiguration actions in automation. AI-PRISM data platform: data services to support AI based solutions. The platform will comprise the AI-PRISM Data Model, the Data Broker, the Repositories, the Data Management functions.
What we hope to get:	Validate and demonstrate the WINGS-Chariot and the technologies/extensions performed in the AI-PRISM in the Athenian Brewery pilot demonstration.
Stakeholder:	**AB**
What will we provide:	We'll be offering a platform for the robotics solutions to be tested in a real, industrial environment, with real conditions and solving a real-world problem. It will demonstrate that the solutions provided are ready for commercial use. We'll also be providing feedback crucial for the correct solution of each case, that we do believe could make the difference for a sustainable solution.
What we hope to get:	We hope to be getting a solution to a few problems that we currently have and could be saved by assisted robotics. Lack of human resources is becoming a very serious issue; hence we do believe that robotics could be the solution for all industries. In cleaning, heavy lifting, picking/sorting and in every strenuous, repetitive task, we might be looking at a great solution.
Stakeholder:	**AW**
What will we provide:	We will provide our facilities (process to apply robots), know-how and personnel.
What we hope to get:	We would like to use robots in our painting and sanding processes and create a data base with all the parameters needed. We hope to get a good training process for our technicians.
Stakeholder:	**PROF**
What will we provide:	PROFACTOR as research partners will implement the generic demonstrator that develops the AI-control for natural, multi-modal collaboration, in partnership with KEBA; An AI based vision system to assist non-expert users during the robotic task configuration process. A task based programming paradigm for easy and quick configuration of robotic processes by non-expert users.
What we hope to get:	A robust Multi-modal human robot collaborative demonstrator, where non-expert users can quickly and efficiently program a complex robotic task Increased knowledge on AI-based vision solutions for robotic applications Improved collaboration between involved research groups

Stakeholder:	**KEBA**
What will we provide:	Use case for intralogistic, assembling, testing of electronical parts from KEBA. AI based control unit for autonomous AGVs, Robots. Technologies for user interface. Speech recognition, control by smart devices (mobile phone, tablet), 5G network
What we hope to get:	Vision, sensor, AI based technologies which helps to improve applications in terms of assembling, object detection, localization and interface to ERP, CAD. Including Feedback to continuously improve the production process. Grasping different geometries of PCBs autonomously.
Stakeholder:	**NTTD RO**
What will we provide:	Contributions around the overall architecture of the AI-PRISM platform and AI-related tasks residing in WP3 and WP4.
What we hope to get:	Technologies and knowledge on AI used for human-robot interaction. These will be used as input for future projects and of course, software solutions developed for our manufacturing clients according to their specific use-cases and requirements.
Stakeholder:	**UNE**
What will we provide:	- Supporting compatibility with existing technologies by the identification of relevant existing standards, maximize dissemination to proper stakeholders (including relevant standardization technical committees) and facilitate market acceptance. - the objective, content and results of this project will be considered by the Standardization community as possibly useful inputs for contributing to future or ongoing standardization works or for identifying standardization needs.
What we hope to get:	- In each of the work packages of the project, they will be identified, based on technical criteria, (possible interest for the entire sector stakeholders, structure similar to European standards, technical content-scope of the document) those deliverables already published within the consortium on which it is necessary to decide if they can be submitted to the European or International standardization system as potential content for new standards. - Once the deliverables have been identified that meet all the requirements set forth by UNE and have obtained the approval of all the partners of the consortium, they will be presented to the different standardization committees so that they may decide to include them in their respective work programs. - The deliverables that have been identified by UNE and by the members of the consortium as possible normative documents and that have not been accepted by the standardization committees either due to lack of interest or because their technical content is not within their fields of activity, they will be submitted to a later study in order to decide the possible creation of a Workshop for its publication as CEN WORSHOP AGREEMENT (CWA).
Stakeholder:	**TDIH**

What will we provide:	- We will work mainly together with Tampere University in creating an AI-PRISM alliance of open access pilots, and disseminate it towards European stakeholders, action which should contribute to the exploitation of the results obtained in the project. - Support for overall implementation of the project, where possible and we have capacity to do so.
What we hope to get:	- Access to the use-cases solved within the project. - Building good collaboration with partners of AI-PRISM and trust for future collaborations in delivering digital transformation services towards SMEs.
Stakeholder:	**A&G**
What will we provide:	- We will bring expertise and solutions in validation of technology by applying methods of quality control & assurance in the collaborative control station.
What we hope to get:	New knowledge regarding human-robot interaction and collaboration

5. Vision enablers

5.1. Knowledge and information

5.1.1. Reference architecture and Standards

5.1.1.1 *Collaborative robots: environment and norm*

To identify the proper environment, it is extremely important to know the related Norms. In particular, the ones applicable in this context are the mainly the ISO 10218 and the ISO-TS15066.

The first (ISO 10218) draws the four types of human-robot collaboration, as described following:

1. **Safety-rated monitored stop:** human and robot occupy distinct spaces. If access to the robot's space is detected, the robot enters safe operative stop. When its space is free again, the robot will start automatically or through a reset button.
2. **Hand guiding:** the human can get close to the robot only if this is not moving. Upon activation of the enabling device, the robot can be manually moved with a safe limited speed.
3. **Speed and separation monitoring:** protective devices are used to allow the human to get close to the robot at any time without risks. The distance between the human and the robot is monitored and the speed of the robot is gradually decreased upon approach. The robot is stopped before the collision takes place.
4. **Power and force limiting:** collisions between human and robot are expected and accepted within the biomechanical limits.

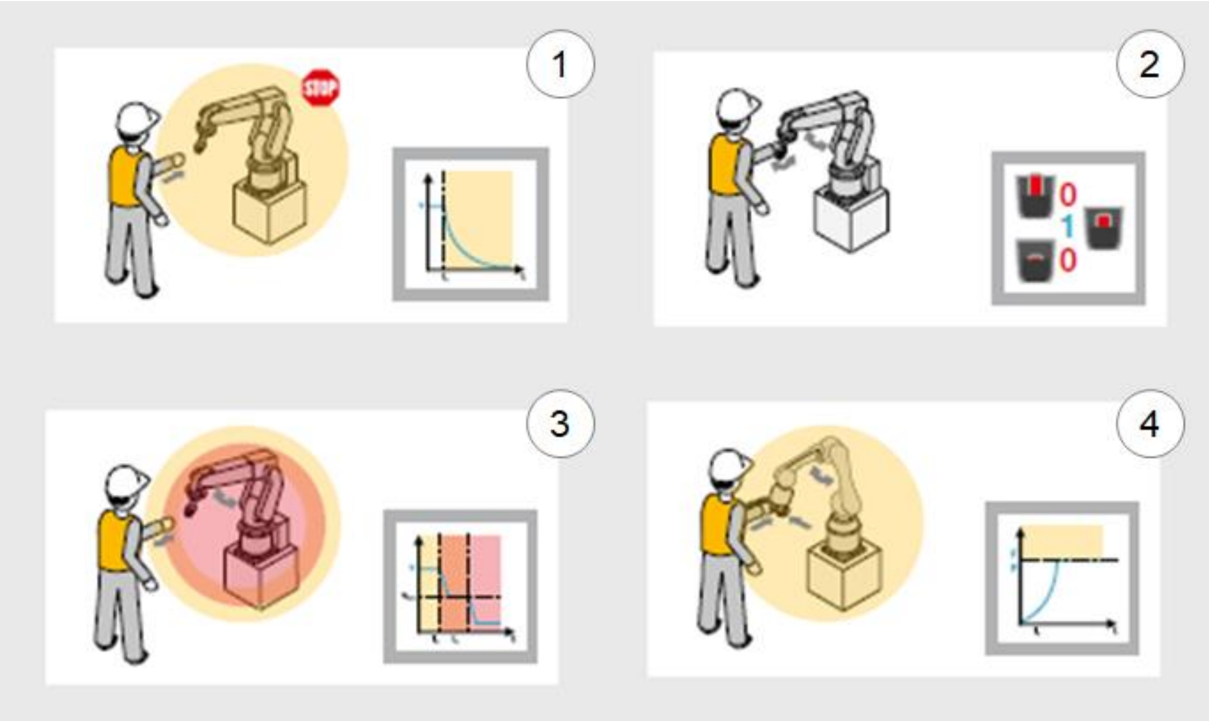


Figure 10 Types of human robot collaboration

Speed and separation monitoring receives particular focus. In such systems, a minimum protective distance between the robot system and the person is maintained to prevent contact.

When considering possible contact events between humans and robots, it is important to keep in mind that that these can only take place in power and force limited applications. The other types of collaborative operation do not allow physical contact between the moving robot and their human co-workers. Consequently, such events do not need to be considered in risk assessments.

The second (ISO/TS15066) is the first world's technical specification of safety requirements for collaborative robot applications. It is designed to supplement the requirements and guidance on collaborative industrial robot operation provided in ISO 10218-1 and ISO 10218-2 ('Safety Requirements for Industrial Robots'). ISO/TS 15066 specifies safety requirements for collaborative industrial robot systems and the work environment.

Among the topics covered by this technical specification are:

- **Design** of a collaborative industrial robotics system and application
- **Hazards** identification and risk assessment / reduction
- **Performance** of the safety systems
- **Design** of the collaborative workspace and robot operation
- **Protective measures** and stopping functions
- **Information to be provided** about the system

5.1.1.2 *ISO/IEC/IEEE 42010*

ISO/IEC/IEEE 42010: "Systems and Software Engineering - Architecture Description" [1] defines conventions and definitions for architecting complex software systems. The main definitions in this standard are *concerns*, which refers to topics of interest pertaining to the system, *stakeholders*, which are individuals, teams, organizations or classes having concerns in the system. A *viewpoint* is a description and analysis of specific concerns. An architecture *view* is the set of ideas, models, and concept diagrams representing and resolving an architecture viewpoint, and an architecture reference is a collection of architecture representations comprising the different architecture viewpoints and architecture views.

ISO/IEC/IEEE 42010 is the underlying standard used in AI-PRISM to design the system architecture, together with the Industrial Internet Architecture Framework (IIRA) as described below.

5.1.1.3 *Industrial Internet Reference Architecture (IIRA)*

The Industrial Internet Architecture Framework (IIRA) [2] is an example of a Reference Architecture applying the ISO/IEC/IEEE Architecture Description definitions. IIRA describes four different viewpoints: The business viewpoint (addressing the identification of the stakeholders and their business vision), the usage vision (addressing the concerns of expected system usage, the functional viewpoint) the functional viewpoint (addressing the definition of functional components, the internal communications between functional components, and their internal procedures), and the implementation viewpoint (dealing with the underlying technologies used to implement the functional components).

AI-PRISM adopts these viewpoints in WP2 to design the system architecture. To facilitate that the usage, functional, and technical views of the system architecture are developed in parallel, first it develops a high-level architectural description of the system, the reference architecture, to provide a common reference upon which the other architecture views are developed. Then it develops usage models addressing the usage concerns, the functional specifications addressing functional concerns, and the technical specifications framing implementation concerns.

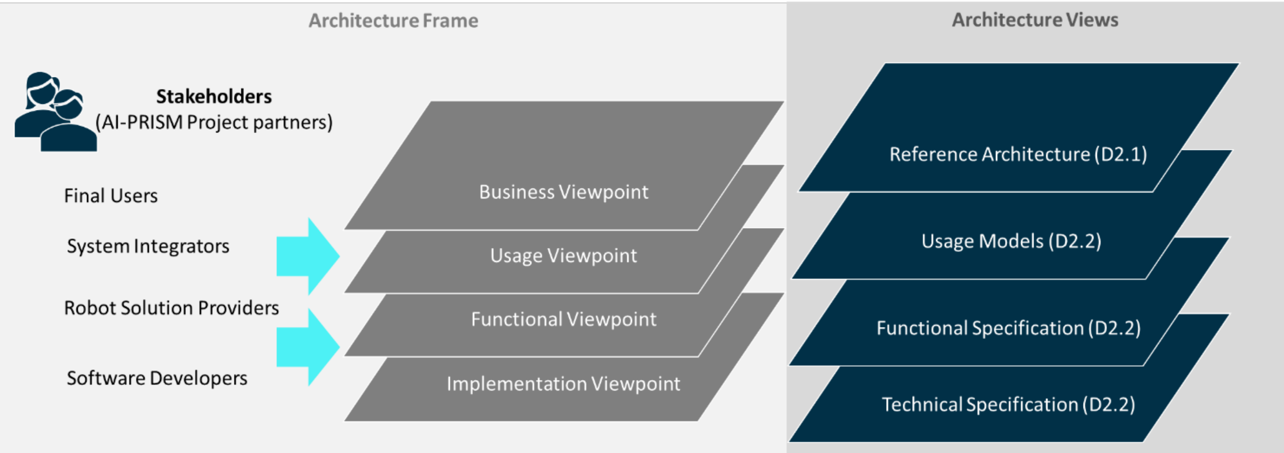


Figure 11: AI-PRISM Architecture Framework

5.1.1.4 *Safety Requirements standards*

ISO 10218-1:2011 specifies safety requirements for industrial robots. EC 60947-5-2 specifies safety requirements for industrial control systems.

5.1.1.5 *MQTT*

MQTT (Message Queuing Telemetry Transport) is a lightweight messaging protocol designed for low-bandwidth networks and high-latency IoT devices. TCP/IP is the basis of communication and publisher/subscriber is the topology used by this protocol. Broker and clients are the most important network entities of the MQTT protocol. The messages are received by the broker and sent to the clients that have subscribed to the topic. A client publishes (sends) messages to the broker and receives (subscribe) messages from the broker. Data is not transmitted continuously. The client and broker send information only when new data is available. MQTT can be used in AI-PRISM to enable internal communications with edge devices (sensors and robots). It is also required when VDA 5050 described below is used.

5.1.1.6 *VDA 5050*

VDA 5050 is an open standard for communication between automated guided vehicles (AGV) and central master control. The master control is responsible for the orchestration and management of the operation, the AVG executes the orders and the basic information is provided by the operator. VDA 5050 offers the possibility to use vehicles with different degrees of autonomy. It uses wireless networks and considers the effects of connection failures and loss of messages. It uses MQTT and JSON structure. MQTT allows the distribution of messages to topics, and participants subscribe to and receive information from the topics. MQTT 3.1.1 is the minimum required version for compatibility. If an application requires AGVs from two or more suppliers and they share the same workspace or the same paths, it is important to coordinate them. VDA 5050 manages the fleet to allow multiple AGVs to work together.

In AI-PRISM, the adoption of VDA 5050 could facilitate the integration and interoperability with AMR and AGV fleets.

5.1.1.7 *RAMI Asset Administration Shell (AAS)*

The Asset Administration Shell (AAS) integrates different standards to implement the digital twin concept: Digital representations and administration interfaces for real world assets. According to the specification, an asset is any real world object or concept (such as manufacturing equipment, tooling, materials, contracts, or documentation) that can be connected in an Industry 4.0 solution. Specifically, the AAS provide data models and interfaces to enable the exchange of assets information between supply chain collaborators. It also defines a file format – Asset Administration Shell Package exchange (AASX) – to persist and exchange the AAS structure.

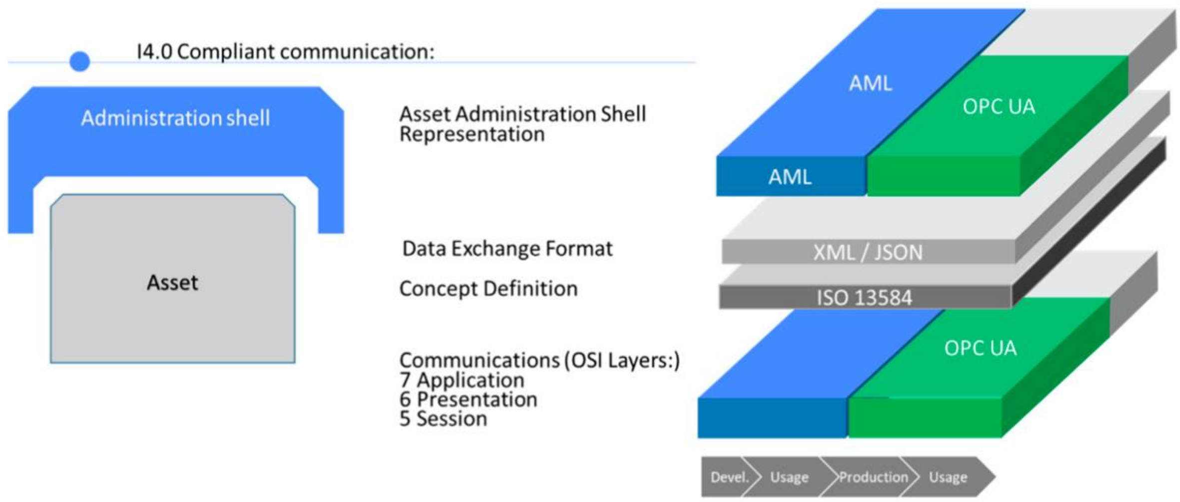


Figure 12 AAS standards (source https://www.plattform-i40.de/IP/Navigation/EN/Home/home.html)

In AI-PRISM, the adoption of RAMI 4.0 AAS can facilitate the integration of assets in the ambient, providing a unified data exchange format and interfaces for any device.

5.1.1.8 *OPC UA*

OPC UA (Open Platform Communication Unified Architecture) is a data exchange standard for industrial communication. It doesn't depend on the manufacturer, vendor, or operating system used for an application. Therefore, it can be used to securely exchange information between heterogeneous systems. It uses reliable communication mechanisms and detects errors. When communication is lost, it is automatically re-established so that no data is lost. OPC-UA uses different protocols and standards.

The AI-PRISM project will use machines from different vendors which work with their manufacturer's own software or different programming languages. OPC UA enables the communication of different elements regardless of the platform or vendor.

5.1.1.9 *AutomationML*

AutomationML (Automation Markup Language) is an open standard that provides a common format for exchanging data between different automation systems and tools. AutomationML is designed to enable the exchange of data between different systems, including control systems, simulation tools, and product data management systems. The standard is based on the eXtensible Markup Language (XML) and provides a way for different systems to share information about automation projects, such as the configuration of devices, control algorithms, and data structures.

In AI-PRISM, AutomationML can be used to improve the interoperability and scalability of robotic systems. AutomationML can be used to share information between different components of a robotic system, such as the robot controller, sensors, and actuators, and also share information of other manufacturing equipment. This can enable more efficient communication between these components and allow for more dynamic reconfiguration of the system. AutomationML can also be used to share information between different robotic systems, allowing for the coordination and optimization of multiple robots working together.

5.1.1.10 *Standard Data models for point clouds*

There are several standards for point clouds. Some of the most commonly used are the Point Cloud Library (PCL), the XYZ file format, the PLY file format, the LAS format, or the PCD file format. PCL is a popular open-source library for working with point clouds. It provides a wide range of algorithms for filtering, segmentation, registration, and visualization. The XYZ file format is a simple text file format that stores the coordinates of a point cloud as a set of (x, y, z) tuples. The PLY file format is a more versatile file format that can store point clouds along with colour information and other attributes. The LAS file format is a binary file format that is commonly used for storing lidar data. The

PCD file format is a file format native to PCL for storing point clouds in binary format. The OBJ file format is a file format commonly used to store 3D models and can also be used to store point clouds.

These standard models and file formats can be used in AI-PRISM to foster the interoperability and facilitate the development of AI-enhancing perception and reasoning modules.

5.1.1.11 *File formats for persistence AI models*

ONNX is an open-source format widely used to represent and persist machine learning models, including deep learning models. With ONNX, AI developers can deliver pre-trained models more easily. ONNX supports many frameworks and operating systems. Its built-in optimizations can significantly speed up procedures like training. The ecosystem supports scripts from many programming languages, like Python, C++, Java and machine learning operations from common cloud platform providers and MLOps frameworks. Another alternative to persist AI models is the Pickle file format. Pickle is a Python module that can be used to serialize and persist in disk Python objects and deserialize and load back in a Python runtime a serialized object from disk.

ONNX and/or Pickle can be used in AI-PRISM to facilitate the delivery and deployment of pre-trained models, as they significantly reduce the size of distributable objects.

5.1.1.12 *ISA-95 and ISA-88*

ISA-95 and ISA-88 provide definitions, guidelines, data models, and communication models for the integration of enterprise systems and industrial control systems. ISA-95 introduces a communication model based on 4 hierarchical levels that can be divided in two separated areas within a manufacturing company: the control domain (Level 3 and lower) where Manufacturing Execution Systems (MES) and Manufacturing Operations Management (MOM) systems are implement, and the enterprise level (Level 4) where the Enterprise Resource Planning is implemented.

The adoption of ISA-95 models and definitions allows for the integration of industrial robotic systems with other systems such as manufacturing execution systems (MES) and enterprise resource planning (ERP) systems to create a seamless and interconnected manufacturing ecosystem.

5.2. Technologies

In this section a list of the current most used technologies in the robotics, networking and AI domain are listed with a description of the specific functionalities and capabilities as well as a focus on the possible application and deployment on the AI-PRISM project.

5.2.1. Robotics

5.2.1.1 Robot Operating System (ROS)

ROS (Robot Operating System) is a set of software libraries and tools which allows developers to create applications for robots. It is commonly used in robotics because it allows the user to use hardware without previous knowledge of it. It is also used for device control, allowing the implementation of different functionalities. It is responsible for packet management and enables the transmission of messages between different processes. The processes are known as nodes and are connected using topics. These processes are able to transmit messages between them, make service calls to each other, provide services and obtain data from a common database, known as parameter server. ROS can be used in AI-PRISM to run some robots because a few of them work with ROS. ROS can also be used to enable the communication of several robots, which can be manipulators as well as mobile robots.

5.2.1.2 OROCOS

OROCOS (Open Robot Control Software) is a set of portable C++ libraries designed for advanced machine and robot control. It has two main parts: The Real-Time Toolchain and the Orocos Component Library. The Real-Time Toolchain allows to write C++ real time components. The Orocos Component Library is used to start an application and interact with it at run-time.

OROCOS has the same features as ROS but does not have as large a support community as ROS. So, it can be used for the same purposes as ROS in AI-PRISM

5.2.2. Networking

5.2.2.1 *Wireless Sensor Networks (WSN) and Quick Deployment Sensor Networks (QSDN)*

Quick Deployment Sensor Networks (QDSN) are networks of sensors that can be rapidly deployed and configured in a variety of environments. These sensors can be used to gather a wide range of data, including temperature, humidity, pressure, and motion. QDSN typically use wireless communication protocols such as Zigbee, Z-Wave, or LoRa to transmit data to a central hub, which can then be used to analyze and interpret the data. The sensors can be battery-powered and have low-power consumption, making them suitable for use in remote or hard-to-reach locations.

In AI-PRISM, QDSN can be used to deploy the ambient sensors that provide the robot with real-time information about its environment. For example, by deploying QDSN in a factory, the sensors can be used to gather data about temperature, humidity, and motion, which can then be used to optimize the performance of the robots. QDSN can also be used to monitor the health and status of the robot, as well as other manufacturing equipment elements, by gathering data on temperature, vibration, and other parameters, which can then be used to predict and prevent equipment failure. Additionally, QDSN can be used to provide real-time feedback on the progress of the manufacturing process, enabling more accurate and efficient control of the robot. This kind of monitoring and control can improve quality, safety and productivity of the manufacturing process.

5.2.2.2 *Software Defined Networking (SDN)*

Software-Defined Networking (SDN) is a network architecture paradigm that allows network administrators to manage network services through abstraction of lower level functionality. This is achieved by decoupling the control plane, which makes decisions on how traffic is forwarded, from the data plane, which forwards the traffic. The control plane is then managed through software, allowing for more flexibility and automation in network management. SDN also enables the use of open APIs, which allows for integration with other systems and easier development of network applications. Overall, SDN aims to make networks more agile, flexible, and easier to manage and scale.

Software-Defined Networking (SDN) can be used to improve the flexibility and scalability of industrial robotics systems. By decoupling the control plane from the data plane, it allows for more dynamic reconfiguration of the network. This allows for the creation of virtualized networks that can be tailored to the specific needs of the robotics system, such as high-bandwidth real-time communication for robotic arms, and low-latency data transfer for sensor networks. SDN can also be used to improve security in industrial robotics systems by providing granular control over network access, and by enabling the creation of virtualized firewalls and VPNs.

5.2.2.3 *Network Functions Virtualization (NFV)*

Software-Defined Networking (SDN) is a network architecture paradigm that allows network administrators to manage network services through abstraction of lower level functionality. This is achieved by decoupling the control plane, which makes decisions on how traffic is forwarded, from the data plane, which forwards the traffic. The control plane is then managed through software, allowing for more flexibility and automation in network management. SDN also enables the use of open APIs, which allows for integration with other systems and easier development of network applications. Overall, SDN aims to make networks more agile, flexible, and easier to manage and scale.

5.2.2.4 *Time Sensitive Networking (TSN)*

Time Sensitive Networking (TSN) is a set of IEEE standards that define a set of protocols and techniques to enable deterministic and low-latency communication in industrial networks. TSN uses techniques such as time synchronization, time-aware scheduling, and frame preemption to ensure that time-critical data is delivered with minimal delay and jitter. TSN also includes support for Quality of Service (QoS) to ensure that different types of traffic are handled appropriately. This makes TSN well suited for use in industrial environments where real-time communication and low latency are critical, such as in factory automation and control systems.

In AI-PRISM, TSN can be used to improve the performance and responsiveness of robotic systems. TSN can be used to synchronize the operation of multiple robots, allowing them to work together in a coordinated manner. TSN can also be used to ensure that sensor data is delivered to the robot controller in real-time, allowing for faster and more accurate control of the robot. TSN can also be used to provide a high-bandwidth and low-latency communication between the robot controller and other systems, such as manufacturing execution systems (MES) and enterprise resource planning (ERP) systems, enabling a more seamless and interconnected manufacturing ecosystem.

5.2.3. Industrial IoT

Industrial Internet of Things (IIoT) platforms are software systems that provide the infrastructure and tools needed to connect, monitor, and control industrial devices and systems. These platforms typically include features such as data management, device management, and application development tools, and can be hosted on-premises or in the cloud. They allow to easily collect, analyse and act upon data from various sources and devices such as sensors, machines, and equipment, providing real-time visibility and control over industrial processes.

In industrial robotics, IIoT platforms can be used to improve the performance, efficiency, and flexibility of robotic systems. By connecting robots to an IIoT platform, it becomes possible to monitor and control the robots remotely, and to gather data about their performance and usage. This data can then be used to optimize the operation of the robots, by adjusting parameters such as speed and accuracy. IIoT platforms can also be used to provide real-time information about the status of the robots, enabling predictive maintenance and reducing downtime.

5.2.4. Artificial Intelligence

5.2.4.1 *Perception and Situational Awareness*

AI perception refers to the ability of a system to interpret and understand the sensory information it receives from its environment. This includes tasks such as image and video recognition, object detection, and natural language processing. AI-based perception systems can be used to improve the ability of industrial robots to understand and interact with their environment. For example, by using image recognition, a robot can identify and locate specific objects in its environment, allowing it to perform tasks such as picking and placing objects. Additionally, by using natural language processing, a robot can understand and respond to spoken commands, making it easier for humans to interact with the robot.

Situational awareness refers to the ability of a system to understand the state of its environment and to make predictions about future events. This is typically achieved by using a combination of sensor data and machine learning algorithms. In industrial robotics, situational awareness can be used to improve the ability of robots to navigate and interact with their environment. For example, by using sensor data to understand the location and movement of other robots and humans, a robot can avoid collisions and safely navigate through a shared workspace. Additionally, by using machine learning algorithms to predict the behaviour of other robots and humans, a robot can plan its actions more effectively.

5.2.4.2 *Reasoning*

AI reasoning capabilities refers to the ability of a system to reason, plan, and make decisions based on the information it has available. This can include tasks such as problem-solving, decision-making, and planning. In industrial robotics, AI reasoning can be used to improve the ability of robots to perform complex tasks. For example, by using AI reasoning, a robot can plan a series of actions to accomplish a specific task, such as assembling a product. Additionally, by using decision-making algorithms, a robot can adapt to changes in its environment, such as a change in the location of an object it needs to pick up.

Finally, the use of AI in industrial robotics can also provide more autonomy to the robots, allowing them to make more decisions and operate more independently. This can lead to more efficient and adaptive production processes, where the robots are able to react to changes in the environment and adapt their actions accordingly. Additionally, AI can provide advanced analytics and prediction capabilities, improving the overall performance, productivity, and safety of the manufacturing process.

5.2.5. **Continuous Integration and Continuous Deployment (CI/CD)**

CI/CD (Continuous Integration/Continuous Deployment) is a software development practice that involves frequently integrating code changes into a central repository and automatically building, testing, and deploying software changes. The goal of CI/CD is to catch and fix issues as soon as they are introduced, and to make it easy to deploy new features and bug fixes. MLOps (Machine Learning Operations) on the other hand is a set of practices and tools that aim to improve the collaboration, automation, and scaling of machine learning workflows. MLOps is used to manage the end-to-end machine learning lifecycle, including data preparation, model training, model deployment, and monitoring.

In AI-PRISM, CI/CD can be used to speed up the development, testing, and deployment of robotic systems, by streamlining building, testing, and deployment of software changes. This can help to reduce the time it takes to bring new features and bug fixes to production, as well as to catch and fix issues early in the development process. Similarly, MLOps can be used to improve the training, model building, testing, and deployment of the AI enhancing modules that use machine learning. By automating these processes, MLOps can help, not only to optimize ML operations, but also to monitor the performance of machine learning models in production, allowing for early detection of issues and easy replacement of models that are no longer performing well.

5.3. AI-PRISM modules

The table below provides a brief overview of the identified technical project results considered in AI-PRISM.

Project Results	*Code*	*Lead by*	*Task*	*Description*
AI-PRISM Human Centred Collaborative Robotic Platform				
AI-PRISM ROS Framework	RF	IKE	T3.1	ROS Framework to manage the deployment of ROS modules. Core ROS (2) packages which together with a development guideline library will provide a technological common ground for the integration of the (AI-PRISM) functional modules. **Motivation:** ROS includes a handful of useful utilities, ranging from drivers to state-of-the-art algorithms, as well as powerful developer tools, remarking its strength to allow communication between the different modules. Stated this, the ROS Framework will simplify the task of enclosing the different modules developed within the reach of this project. **Purpose:** It will give the user access to an open enough platform for adding new elements in an easy and robust way.
AI-PRISM Base Hardware	BH	IKE	T3.1	Supported base hardware interfaces (for AGVs, mobile robots, industrial robots). Dedicated drivers for supported HW modules for human/robot collaboration. **Motivation:** It will allow each of the robots and end devices to have access to an edge computing unit which will allow, not only communication with the Fog cluster but also with the other end devices. This will ensure compatibility and easy integration over multiple devices, as well as easy scalability, in case we require extra elements in our environment. **Purpose:** The specified base hardware will allow the user to easily add additional modules for their robots or extra sensors for their environments without causing an undesired chain reaction to the rest of the devices.
AI-PRISM Communications Modules	CM	IKE	T3.3	ROS packages that will enable real time communication within the AI-PRISM platform and with other devices **Motivation:** ROS has built-in communication protocols as long as there is a compatible communication network between the platform and the devices. As such, it allows easy scalability with small need of configuration. **Purpose:** It provides the same scalability and easy to

				implement advantage for the user as it does for the project.
AI-PRISM Ambient Sensing infrastructure	AS	FBK	T3.2	The sensing infrastructure consists in a collection of different sensors which will monitor the environment and the moving components acting within it, such as human workers, robotic agents, obstacles, and tools. Sensing components will include both fixed and movable sensors to avoid potential sensing holes. Different sensor types will be considered to capture complementary information: RGB cameras to capture photometric information, depth sensors to capture geometric information, thermal or infrared sensors will be considered in case of poor visibility, multi-spectral cameras will be considered when the desired properties can be captured only by wavelengths invisible to the human eye. **Motivation:** Enables the digital reconstruction of the environment and, in turn, the AI-based perception modules. **Purpose:** The sensing infrastructure will supply the AI-PRISM Ambient Digitalization module the raw data acquired by the sensing components to allow for a real-time digital reconstruction of the environment.
AI-PRISM Real Time Communications Network	RC	ITI	T3.3	Supported real time communication hardware. SDN, QDSN, WSN sensor network control and management. The distributed nature of the AI-PRISM components (cobots, agvs, sensors, people, tools) will require a high-performance communication network to ensure their reliable and real-time operation and integration. Industry relies on classic technologies and architectures that are not flexible enough to enable these new Industry 4.0 needs, where wireless technologies and mobility requirements are more present day by day. This technological layer enables a robust, real-time and secure integration between all the AI-PRISM components, but with the challenge of providing also the needed flexibility, mobility and scalability. State of the art technologies based on deterministic ethernet, IIoT, flexible wireless sensing layers and the integration of Software Defined Networks in industry, will be the main drivers. **Motivation:** Current orchestration systems are focused on specific network technologies and, in many cases, don't provide the capability to dynamically adapt to changes and guarantee the quality of service in multi-

				flow environments. Moreover, they cannot easily extend their orchestration capabilities with external applications, making it difficult for them to evolve and adapt to specific environments. **Purpose:** Software-defined networking (SDN) addresses the challenge of successfully managing multiple sources as a convergence point that allows multiple network technologies to be interconnected and their resource management to be centrally orchestrated, guaranteeing high quality of service (QoS). That allows the creation of flexible and scalable architectures that dynamically adapt to application requirements. This integration in the SDN controller simplifies and abstracts the low-level configuration of network technologies through APIs, allowing the orchestration capability to be extended with external AI/ML applications with specific approaches.
AI-PRISM IIoT Platform	IP	IKE	T3.1	Edge/Cloud platform to support the deployment of data services, simulation services and ROS Framework. **Motivation:** The IIoT Platform allows us to monitor the health and status of the cluster. It also comes with easy-to-use services and management user interfaces to download and install Kubernetes applications from remote catalogues, which can balance the workloads of the different AI-PRISM software modules. **Purpose:** The IIoT Platform allows the system administrators to browse, select, deploy, monitor, update, and scale AI-PRISM services running in the fog cluster.
AI-PRISM Data Platform	DS	WINGS	T3.3	Data services to support AI based solutions. It comprises the AI-PRISM Data Model, the Data Broker, the Repositories, the Data Management functions. **Motivation:** Provide all the required data to the AI mechanisms supporting the human-robot collaboration and the operator. **Purpose:** Enable the interoperable communication among sensors and the AI-PRISM data platform, as well as among the AI-PRISM services.
AI-PRISM Simulation Environment	SE	TAU	T3.4	Software services to run Simulation models representing the collaboration ambient, including robots, industrial equipment, and human agents. **Motivation:** Helping industrial partners to simulate processes in a more realistic way, enhancing the state of the art of current Digital Twins and considering human operators in the simulation. **Purpose:** Providing a realistic simulation platform able to recreate production plants and lines, that takes into consideration interactions between the existing agents in the environment and that also integrates human avatars in its platform as another variable to integrate.

AI-PRISM Ambient Digitalisation modules	AD	FBK	T3.2	Software modules taking in input the raw data acquired by the AI-PRISM Ambient Sensing infrastructure and producing in output a real-time digital reconstruction of the environment. Algorithms will be developed to automatically calibrate sensors, fuse multi-modal sensor data, and to have a coherent reconstruction of the environment. **Motivation:** The more knowledge that any AI system has about a co-bot environment, the safer it is. The reconstruction of precise 3D models at a given time and the forecasting of their possible trajectories will help with the planning of near-future robotic actions and make it possible to describe current safety zones where people and robots can work together in a safe way (i.e., without physical damage to either). **Purpose:** The digitalization modules will supply the AI-PRISM Perception Enhancing modules with a spatio-temporal reconstruction of the environment and the static components and dynamic actors present in it. These modules will provide occupancy maps for safe task scheduling, and they will play a significant role in teaching robotic agents to imitate the sequence of tasks human workers carry on.
AI-PRISM Human Robot Cooperation Ambient				
AI-PRISM CI/CD Framework for AI-based Solutions	CD	PIAP	T4.1	Pipelines and infrastructure to support AI based development, integration and validation. The tooling and infrastructure required to manage AI-based solutions along their lifecycle, considering design, development, discovery, deployment, training, validation, use, monitoring, and improvement. **Motivation:** (To be completed) **Purpose:** (To be completed)

AI-PRISM AI-based Perception Enhancing Modules	PE	FBK	T4.2	AI-based modules to enhance perception capabilities. Deep learning models will be developed to perform several perception-related tasks given the spatio-temporal reconstruction of the environment as an input. Examples of such tasks include object detection and tracking, activity understanding, health status monitoring, and anomaly detection. Object detection and tracking will allow to detect the presence of tools and obstacles and predict their trajectories over time. Activity understanding will be used to recognize workers gestures to enable the remote control of robotic agents. Combining the previous two tasks it is possible to teach robotic agents to mimic human activities and safely collaborate with them in the same workplace. Health status monitoring will be used to improve human workers conditions either by preventing injuries or by judging how best to assist in, or replace, current parts of their activities. **Motivation:** Supports human workers and robotic agents in their tasks by providing advanced AI-based perception tools. Enables a safe collaboration between them in the same working environment without requiring the introduction of custom security protections or reserved areas of action. Improves working conditions by monitoring their health and the potential dangers they may be exposed to. **Purpose:** Provides perception-related tools that can be used in real-time to assist workers duties improving the quality and efficiency of their activities.
AI-PRISM AI-based Agent L evel Reasoning Enhancing Modules	DR	KUL	T4.3	An AI-based module that handles the discrete level reasoning/planning between a single robot system and a user interacting with the system. This system will closely interact with the low-level constraint-based controller and will need to exploit the information from AI-based ambient level reasoning modules in T4.4.

AI-PRISM AI-based Ambient Level Reasoning Enhancing Modules	CR	UPV	T4.4	AI-based modules to enhance collaboration of agents in the ambient. It includes models and algorithms to solve problems related to the coordination of humans and robotic agents in the ambient, like task allocation, or optimal routing. It also includes modules to enable the control of operations at the ambient level, monitoring events in the ambient and acting in response (e.g., re-allocating tasks or changing the routing) to ensure performance. **Motivation:** Aside from agent level reasoning, also the coordination of robot and human agents in dynamic manufacturing environments is an important factor to achieve optimal performance. For example, task allocation and workload balancing between robots and humans can be optimized balancing different (possibly conflicting) objectives besides completion time, like ergonomics. This would allow to prevent human fatigue and reduce stress levels while at the same time ensuring performance targets. In addition, this optimization can take into account the dynamics of the changing environment, for instance, implementing fall-back mechanisms in different modalities, like robot-to-human (e.g. re-assign tasks to a human if a robot becomes non-operational) or human-to-robot (e.g. re-assign tasks to an idle robot to reduce stress levels) **Purpose:** Improve the overall sustainability of the organisation, considering sustainability, economic, or environmental factors, through the optimisation of task allocation and workload balancing of hybrid human-robot workforces, using reinforcement learning, evolutionary algorithms or Mixed Integer Programming.
AI-PRISM Human - Machine Interaction (HMI) Modules	HI	KUL	T4.5	Integrate the sensor-modalities used in the project in a probabilistic motion/force model for use during execution using a constraint-based framework, both during the learning phase as during the execution phase.
AI-PRISM Programming by Demonstration Environment	PD	KUL	T4.5	Integration of the constraint-based framework eTaSL in the project middleware. Development of the appropriate drivers for the robot system. Programming-by-demonstration is realized by combining model-based constraints with motion and force information from demonstrations. Task definitions will be composed that are appropriate for the classes of tasks considered in the project. This continuous-level HRI module will integrate with discrete events from the agent-based reasoning modules.
Social Human-Agent-Robots				

Teams Collaboration				
AI-PRISM Human Safety Management Procedures	SP	NTTD IT	T5.3	The solution improves the safety in warehouses, and in general in workplaces where there are some risks of incident caused by wrong behaviour in particular zones or where there are machines with risk of collision. The AI-PRISM Human Safety Management Procedures allows us to check in real-time way the situation in every part of the plant and warn supervisors if something dangerous or non-compliant happens. The solution can be integrated with other systems/sources of information (i.e., information on parameters of use and operation of equipment such as temperature, pressure, position, etc.) that appropriately analysed and correlated could highlight any situations of alarm/danger. **Motivation:** Incident at work in automated factories are a deeply felt problem, so we decided to provide a tool that is able to monitor possible critical issues in the safety field. The worker who feels safer will be able to reduce his stress level **Purpose:** Improve the perception of safety in highly automated factories where robots move together with workers. It is proposed to control the areas with the highest content with the iterations with the robots by checking the positions, environmental data, and the correct provision of the necessary PPE.
AI-PRISM Human Skills Development	HS	CRAN	T5.4	Identifying the most important human skills that are needed for effective and seamless human-robot-interactions in industrial task performance using reliable / scientific techniques will enable the development of appropriate skills training strategies. **Motivation:** Technology is developed faster than our understanding of how it will impact on, or fit in with, human users. This is a primary cause of new technology failure or lack of user acceptance. As human-robot collaboration is going to transform traditional manual work roles it is important to accurately identify and accommodate new skills requirements. **Purpose:** To provide a reliable, empirical understanding of the new skills that will be needed for optimising industrial human-robot collaboration, not only focusing on technical skills but also on non-technical skills which will be an inevitable emergent challenge in shared task performance.
AI-PRISM Open Access Network Portal				

AI-PRISM Network Suite	NS	TAU	T7.1	service suite composed of a dynamic web-based user interface, an online Virtual Pilot builder, user access control, digital certification, interactive training engine, scheduling, and optimization engine. **Motivation:** Create new business model for sharing knowledge and equipment. and create new opportunities of collaboration **Purpose:** Building a network of open access pilots that support transferring knowledge form research to businesses. this can be reached by providing controlled access to the pilots by providing the proper training, certification, and resources management.

6. Conclusions

In the framework of AI-PRISM project, and more specifically within Task 1.1 - Project vision consensus, this deliverable depicts the AI-PRISM vision of enhancing the human robot collaboration in smart manufacturing environment, empowered with the aid of Artificial Intelligence. In this deliverable the main stakeholders and use-cases are described, with a specific focus on the market context related to collaborative robotics. For this reason, research of the current technological solutions in terms of collaborative robotics has been executed in order to have a wide view of available resources presents in the market.

A section of the deliverable is oriented on the related standards and data descriptions relevant for the project activities, with, for completeness, an excursus on programming languages and collaborative robots related norms.

A qualitative analysis of the business opportunity both in term of research and technology has been included demonstrating a huge potentiality in the several markets for collaborative robotics and AI solution related to the five pilot cases of the AI-PRISM project. No major focus has been given to description of the several pilot case since it will be described in detail in D1.2 and D1.3.

In last part of the document, the different available technologies are investigated, with a description of the AI-PRISM modules that will be developed and their aim.

As it is possible to see from the document, a lot of technologies and standards laid the foundations for the project developments. Considering the project stage, the list could not be exhaustive, and further updates of this analysis could be performed and the results will be included in future reports that will be produced in a more mature project stage.

ANNEX A: References

[1] ISO/IEC/IEEE: Systems and Software Engineering - Architecture Description. ISO/IEC/IEEE 42010:2011(E) (Revision of ISO/IEC 42010:2007 and IEEE Std 1471–2000), pp. 1–46, January 2011

[2] Lin, S. W., Miller, B., Durand, J., Joshi, R., Didier, P., Chigani, A., ... & Witten, B. (2019). Industrial internet reference architecture. Industrial Internet Consortium (IIC), Tech. Rep.

[3] https://www.statista.com/