AI-PRISM

D1.2 – Use cases scenarios and requirements analysis (I)

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Disclaimer

Abstract

This deliverable presents the use case scenarios and requirement analysis of the AI PRISM system design. It includes the initial description of the five different use cases of the AI PRISM project and the related key performance indicators (KPIs). Furthermore, the deliverable contains the initial set of hierarchical requirements for subsequent system development: the high-level requirements identified so far by the stakeholders, and the system requirements (related to Hardware, Human Robot Collaboration aspects, the AI Enhancing Tools and the Social Collaboration aspects) resulting from the analysis of the stakeholder requirements.

Acronyms and definitions

Acronym	Meaning
AI	Artificial Intelligence
KPI	Key performance indicator
Cobot	Collaborative Robot
DoA	Description of the action
HMI	Human Machine Interface/Interaction
PC	Computer
MWIR	Middle Wavelength Infrared
WP	Work package
LWIR	Long Wavelength Infrared
GDPR	General Data Protection Regulation
RSI	repetitive strain injury
PCB	Printed circuit boards
CAD	computer aided design

Contents

Executive Summary

This deliverable presents the results of Task “Task 1.3 Use cases scenarios and KPIs” and Task "Task 1.4 Requirements Analysis", carried out within the framework of the European Union Horizon Europe Project “AI Powered human-centred Robot Interactions for Smart Manufacturing (AI PRISM)”. The primary aim of this deliverable is to provide details about the use cases. Also, this deliverable will provide details about the requirements as derived by the analysis of the industrial scenarios. A preliminary report is available internally in M6 to enable a smooth start of development tasks. The requirement analysis and specifications presented herein have been defined on the basis of the stakeholder requirements derived from the use cases break-down towards defining the system specifications, the necessary H/W components and the requirements of the Human Robot Collaboration, AI enhancing tools and the Social collaboration aspects of AI PRISM. The functional requirements, together with the available technology base and the design constraints serve as the basis for the establishment of the performance requirements that will be interpreted in terms of hardware and software. These components comprise the overall requirement specifications of the AI PRISM system.

First the details about the use case scenarios envisioned in AI PRISM and the related Key performance indicators KPIs are presented. Details about the use case facility, the scenario overview and the process overview are given. In all cases, the unitary objectives and tasks (guided by WP) to propose the relation between KPI and objectives were considered and tabulated accordingly. In addition, the relationship between the use case and AI PRISM objectives is also illustrated. A methodology to formalize the requirement specifications is chosen and detailed. This includes the following steps a) Elicitation of functional and non-functional user requirements, constraints and applied standards/regulations, on the way of the interviews (surveys) with the users, use case scenarios analyses, original project vision. It should result in the stakeholder requirements (for more details see Section 3.1); and b) Analysis of the stakeholder requirements, which leads to the definition and the specification of system requirements (Hardware, Human Robot Collaboration, AI Enhancing Tools and the Social Collaboration aspects). Finally, it should be noted that although this report is delivered according to the AI PRISM DoA in Month 6 of the project, an improved version of this document will be provided in D1.3 Use cases scenarios and requirements analysis (II) in M12.

1. Introduction

1.1. Deliverable Purpose, Scope and context

The purpose of this document is to provide details about the use cases. Also, this deliverable will provide details about the requirements as derived by the analysis of the industrial scenarios. This document is intended to be the preliminary report to be made available internally in M6 to enable a smooth start of development tasks.

This document D1.2 (Use cases scenarios and requirements analysis (I)) is a public document (PU) and therefore is intended for the European Commission, the AI PRISM Project Officer and the members of the AI PRISM consortium and general public.

1.2. Relationship with other AI PRISM Deliverables

The first version of the use case descriptions and the requirements (hardware and software) are detailed in this deliverable. The second and final version of this document is provided in D1.3 (Use cases scenarios and requirements analysis (II)) in M12. The deliverable D 2.3 (AI-PRISM Reference Framework and specification (II)) describing the AI-PRISM reference architecture, design principles and guidelines to develop the use models will build on input provided by this document.

2. Use Case Scenarios and KPI specification

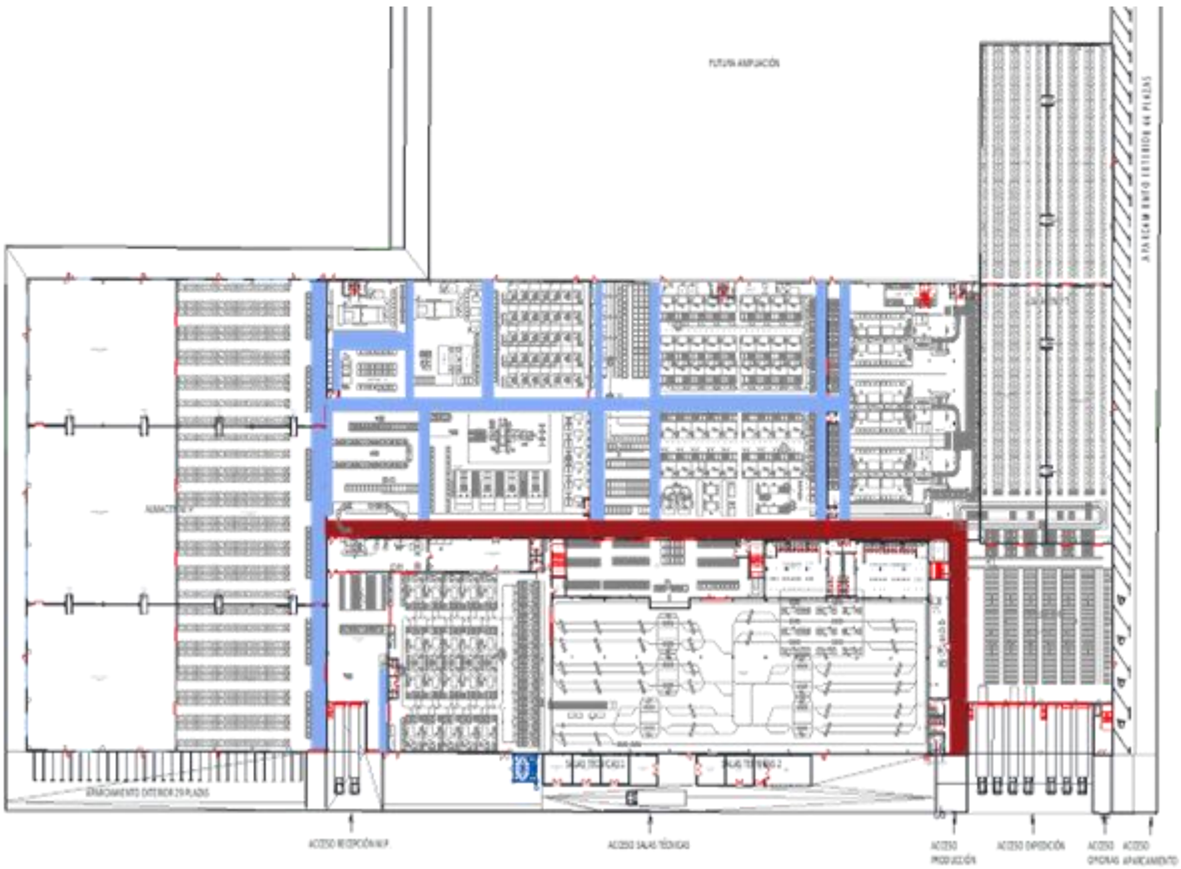
This section provides details about the use case scenarios envisioned in AI PRISM and the related KPIs. Details about the use case facility, the scenario overview and the process overview are given.

2.1. Use Case 1: Furniture

2.1.1. Company and Facility overview

Andreu World is a company that designs, develops, and manufactures contemporary furniture with high added value for the global market. Experts on ancillary and loose furniture, we offer solutions for residential segments as well as hospitality and corporate spaces. Andreu World is a leading company in export business and sustainable design based in a solid industrial culture. Our company is well known as a success case industrializing craftmanship in the furniture industry.

Andreu World Factory called Andreu Est and located in Valencia is a manufacturing facility which includes the following production processes: Raw Material and Finish Product Logistics, Upholstery (fabric cutting, sewing, foaming and upholstery), Woodwork (assembling and painting) and Packaging. This factory has 24000 m2 with 200 technicians at the facility. See below image:



2.1.2. Scenario Overview

2.1.2.1 *Scenario Collaborative Robots in painting process*

This use case regards the preparation, painting, and finishing of wooden parts involving different layers of paint. This is a difficult process to automate due the handcraft work and the complexity inherent to the large variety of products. It is also subject to strict quality requirements, which demand high accuracy on the sanding and painting processes.

Process overview

The different steps of the process are depicted in the following figure and described in detail in the next section.

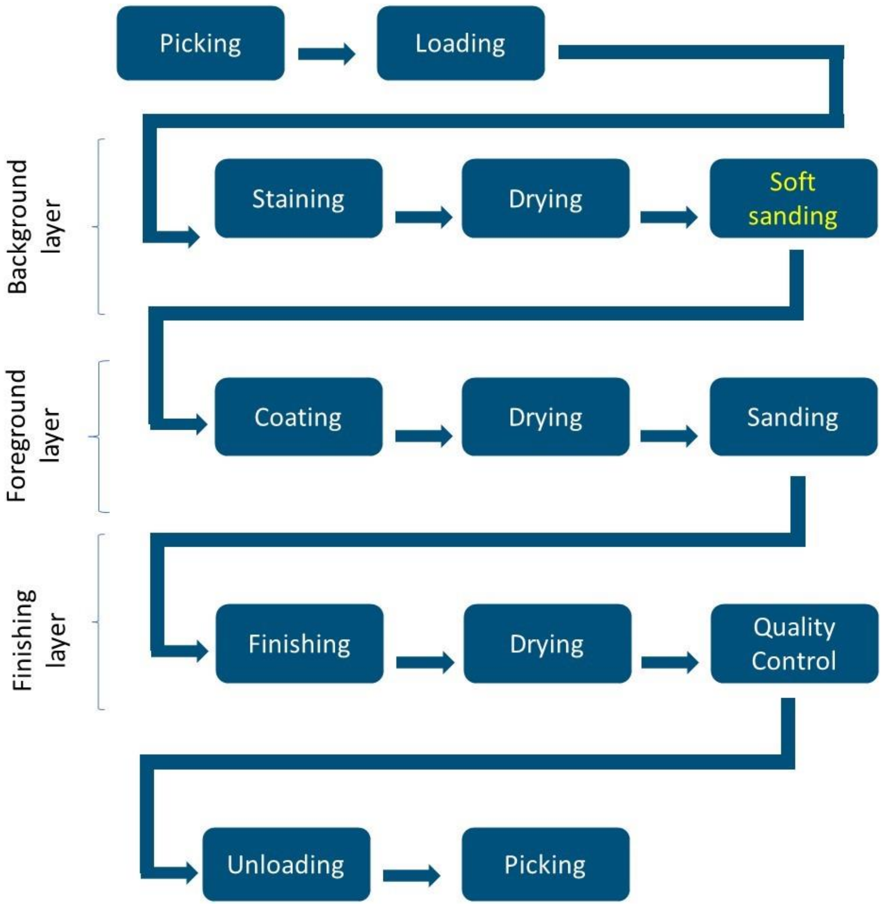


Figure 1 Process steps

- The painting and sanding process are performed manually by technicians. There is a wide variety of models and different shapes: irregular and with patterns. Technicians have technical mastery and expertise on this process, and it is time consuming and difficult to train new operators.

Step by step decomposition and requirements derivation

Painting process: it consists on the application of different layers of paint: background, foreground and finishing. Between application of each layer, the pieces of furniture are first dried and then sanded. Some operators take care of picking up the pieces of furniture and loading and unloading them to different work areas and machines. The main problems to solve are the efficiency of the robot training process, the safety of humans in the collaborative environment and the quality of the sanding and painting processes.

About human tasks to be delegated to robots:

- *Application of all coats of paint to the piece (*staining, coating and finishing). That includes robot manipulates and turn every piece when is necessary to cover all surface.
- *Cover between 60% and 80% of sanding process,* letting finishing to specialist operator. It is important to consider that between every phase of painting (staining, background and finishing), sanding of pieces is needed. Thus, the added value of cobot is carrying on the majority of the activity´s effort and time.

Target improvements in Painting Process:

- Increase of productivity, finishing more painted furniture per hour.
- Ergonomic conditions improvement of specialists.
- Increase of capacity of the Painting Process line
- Higher and better traceability of data related to quality and machine occupation time (robot)
- The specialist will be able to dedicate most of the time to control and improve critical bearings of the process, such as paint recipes according to the pieces and the base wood, analyse the paint load level that each part requires according to the base tone of the wood and apply those improvements continuously throughout the process.

Step 1: Staining

- **Loading:** The products (either chairs or parts of furniture) are loaded to the power and free conveyor manually. This process is out of the scope of the use case.
- **Transport process:** The transportation of products along the line is already automated.

First coat (staining):

- **Rotate product.** First, the operator needs to turn the product to reach the face that is going to stain. Currently, this is a manual process, but it can be automated in the use case through an ad-hoc integration with the power and free conveyor system, or through a robot arm rotating the furniture to reach a new face just as the human does.
- **Apply stain.** The operator uses a spray gun to apply the coating. This process is also manual but can be automated in the use case. We foresee a robot arm installed in each workstation where the human can teach the collaborative robot how to stain a new project and let it continue the batch e.g. confirming the operation on an HMI menu.

Step 2: Sanding process

- **Load product**. The product is loaded to the table workstation. This process is currently manual but it can be automated in the use case.
- **Sand product.** The operator uses a sanding tool to manually sand the product. Automating this process is quite challenging and there are few solutions in industry and none that are suitable to our needs.

Step 3: Second coat (background paint)

- Turning chair to achieve all the faces manually done but able to be automatic. This is a process done by a person that can be transferred to a robot with an arm, generating this rotating movement needed for the background coat application.

Step 4: Sanding process

- **Load product**. The product is loaded to the table workstation. This process is currently manual but it can be automated in the use case.
- **Sand product.** The operator uses a sanding tool to manually sand the product. Automating this process is quite challenging and there are few solutions in industry and none that are suitable to our needs.

Step 5: Third coat (finishing)

- Turning chair to achieve all the faces is manually done but able to be automatic. This is a process done by a person that can be transferred to a robot with an arm generating this rotating movement needed for the finishing coat application.

- Applying finishing manually done but able to be automatic. This is a process made by a person that can be executed by a collaborative robot, starting the programming process, e.g, just after a person activates what is needed to work with this robot.

Step 6: Unloading process

Unloading and Quality Control Area: Area to unload parts and chairs from the conveyor chain and perform the final quality control.

Additionally, there is a **Process Control area** with a work station to monitor and control the line. All processes are defined in the Painting System (the control and monitoring software of the line). The number of chairs, their position, the painting process and all parameters (temperature, pressure, air, lights, doors, time) are controlled by this specific software, which includes a connection with SAP to report the working order. There is a control PC in the process control area providing information at the line level and tablets at every work station providing information at the work station level.

The images below display the different areas of the line.

Figure 2 Process Control area

Figure 3 Loading area

Figure 4 Staining area cabin (exterior)

Figure 5 Staining area cabin (interior)

Figure 6 Coating area cabin (exterior)

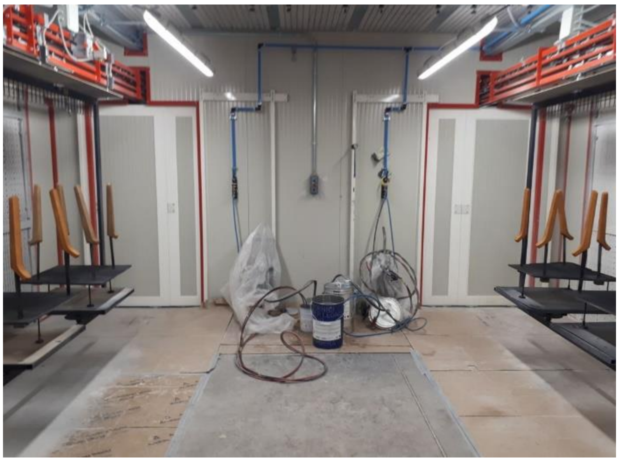


Figure 7 Coating area cabin (interior)

Figure 8 Sanding area cabin (exterior)

Figure 9 Sanding area cabin (interior)

Figure 10 Finishing area cabin (exterior)

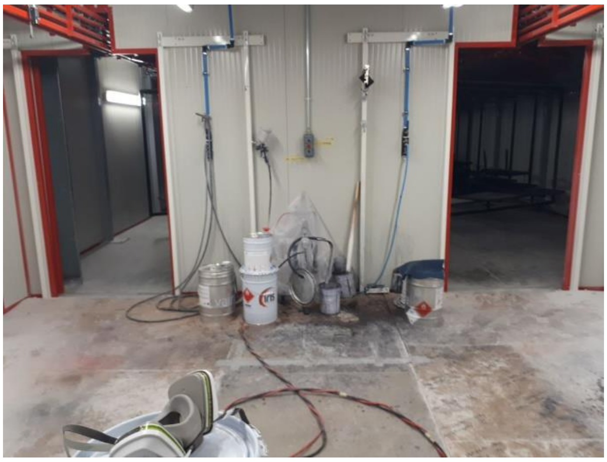


Figure 11 Finishing area cabin (interior I)

Figure 12 Finishing area cabin (interior II)

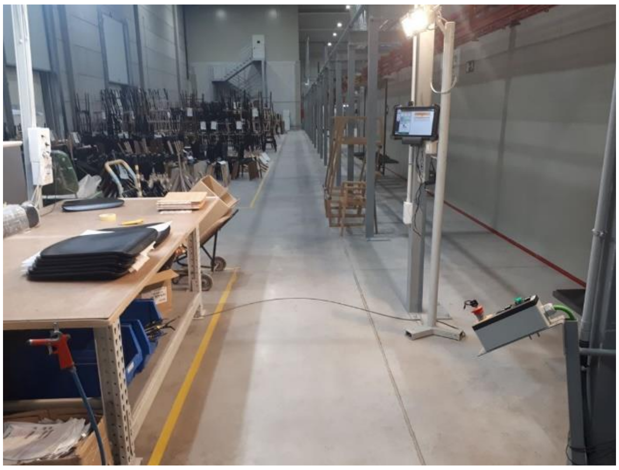


Figure 13 Unloading and Quality Control Area

2.1.3. **Relation to AI PRISM**

The most accurate integration between the scope of AI-PRISM project and the technical/functional requirements in this use case, are demonstrated basically in two points: firstly, the possibility to automate complex operations that are, currently, manually done , which supposes a high challenge in order to ensure the human-robot interaction throughout technological development. Secondly, the use case promotes the integration between different stakeholders/partners, considering a wide range of interaction and points of view such as smart and flexible manufacturing, academic and research support and highly qualified technological manufacturers and suppliers.

2.1.4. **Specification of Key Performance Indicators (KPIs)**

As a note in this section, the expectations as end users of the robots are aligned to its functional performance, which is possible to see better in an ended job phase than in the design/initial phase.

In all cases, the unitary objectives and tasks (guided by WP) to propose the relation between KPI and objectives has been considered as follows:

Table 1: Indicative list of KPIs

KPI	Description	Validation Metric	Related Task/s, Deliverables	Relation to Objectives
U1_KPI1	***Quality***, from which we expect to measure the decrease in defects, mainly reprocessed parts.	20% increase in acceptance of parts. (Accepted units/Total produced units) * 100	T5.2	O5
U1_KPI2	***Productivity***, where we expect to measure the increase in the number of finished units per unit of time, considering available time and cycle time.	30% increase in finished units per unit of time. Productivity= (Total Time used in Staining and/or Sanding Process/Total Time available in Staining and/or Sanding) *100 Cycle Time=Task finished time – Task start time +1	T5.2	O5
U1_KPI3	***Capacity***, to measure the increase in finished and/or processed units or parts on the line.	+/- 30% increase in finished units on the Painting Line Capacity= Batch size/ (Set-up Time + Run Time*Batch size) Performance=Total number of finished	T4.2	O4

		units/Theoretical Max. Robot Cycle		
U1_KPI4	***Comfort and Satisfaction,*** with which to measure the perception of reached wellness in workers, since the incorporation of the collaborative robot.	Comfort and Satisfaction levels above 95%. % achieved, according to **comfort survey:** numerical scale from 1 to 10, being 1 absolutely comfortable, about: ▪ Non-ergonomic positions ▪ Muscle pain caused by prolonged positions % achieved, according to **satisfaction survey**: numerical scale from 1 to 10, being 1 absolutely satisfied, about: ▪ Improvement actions applied in the work area.	T3.2 T5.3 T5.4	O3 O5

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

2.2.1. Company and Facility overview

VIGO Photonics is a European manufacturer of semiconducting materials and instruments for photonic and microelectronic, specialized in MWIR and LWIR detectors and modules, produced with the use of internally-developed technology.

The use case will take place in the clean room. The shop floor has controlled environment parameters.

Figure 2: VIGO assembly line

Figure 3: VIGO precision manufacturing area

2.2.2. Scenario Overview

2.2.2.1 *Scenario 1 automatic positioning*

The solution will feature automatic positioning of the electronic component against the wire, to be glued, with the support of electromechanical or/and pneumatic effectors. They will have input from an AI-enhanced vision system, that will recognize the appropriate place to attach the wire on the electronic component, based on the shape, colour and additional markers if needed. AI algorithms will adapt to the differences in components, in case of their exchange. The operator will teach the robot the correct positioning of the elements to be glued together. This will be initial role of the operator, who, at later stage, will still be in the loop for the task, mainly for its most critical phase - to confirm the correct positioning of the elements, but also to perform supporting actions, such as glue application.

Process overview

Very 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 of the wire. Due to the differences between holders for wires and the wires' curvature, the procedure of positioning is repeated for every pair of components and due to the manual positioning it lasts few minutes. It is a bottleneck of the whole production process, as the processing machines, that work on glued components sometimes wait unused for the next delivery. 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. Automatization of this work using conventional methods is difficult as the components may change in size, so adjustment of the method of the positioning in necessary. Usage of intelligent solution would help to overcome these barriers

Step by step decomposition and requirements derivation

- Placing chip on adjustable table – wax attachment (wax is used to hold chip, can be replace by vacuum)
- Depends on solution – human can feed one by one or place set of chips in tray or the robot with 3D camera can pick and place + force control to avoid crashing/crumpling chips

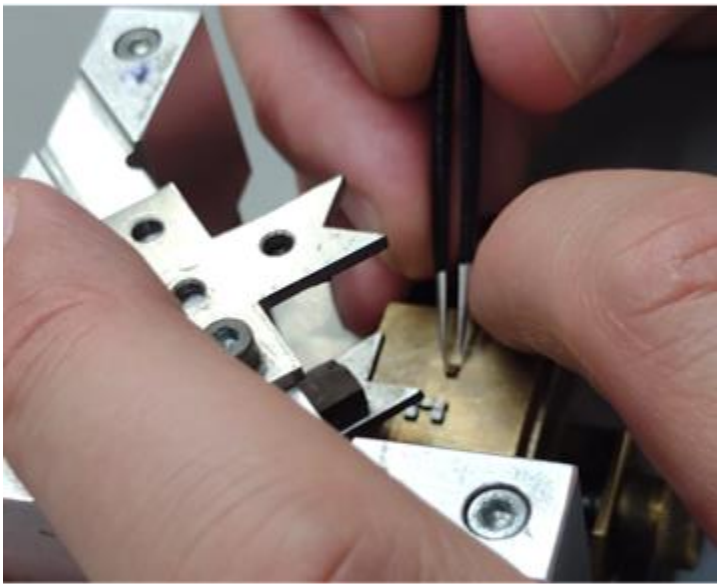


Figure 4:Chip placement on adjusteable XY table

- Placing table onto bracket of microscope - elimination of this step in favor of a robotic solution / new solution for positioning is welcome

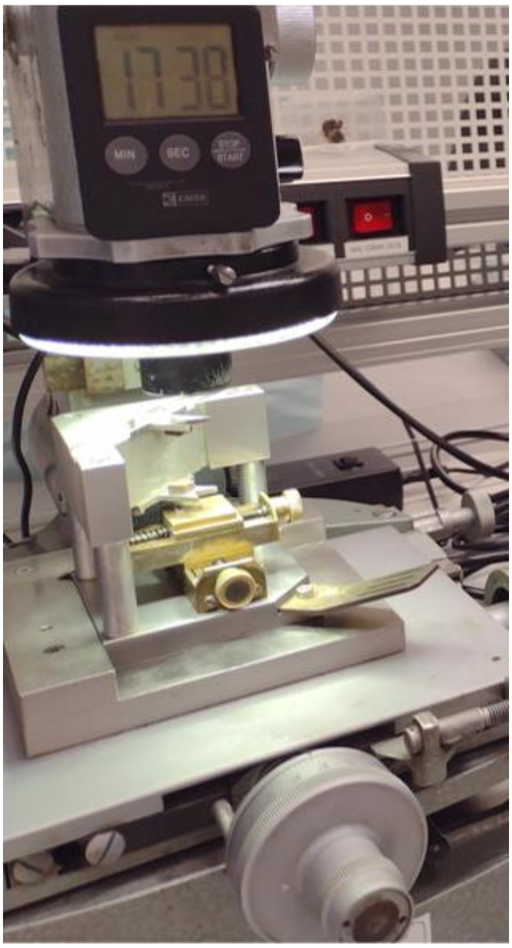


Figure 5: XY table placed in microscope bracket

- Focusing microscope on chip pattern and matching angle orientation between microscope and chip – to be replaced by robot/automatic station.
- Table movement to laminate area (issue: non-ergonomic station, little space for hand operation) - to be replaced by robot/automatic station/ calibration method based on AI i.e. once per day instead of each piece.

Figure 6: XY table adjustment

- Putting master tool in fork shape bracket to do mark on laminate (issue: master tool loose or damage) - instead of this step use AI solution.

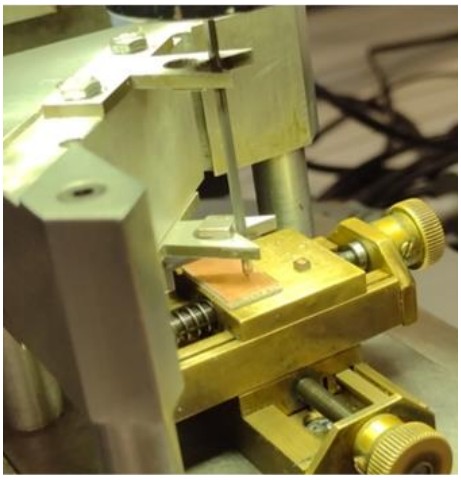


Figure 7: Marking tool – calibration process

- Adjustment centricity of microscope and prepared mark on laminate (issues: many old marks – easy to make mistake during search of current mark, different height of laminate and chip – provides lower precision due to blurry image, time consuming adjustment due to microscope backlash – human fingers precision lower than robot)
- AI solution usage + robot.

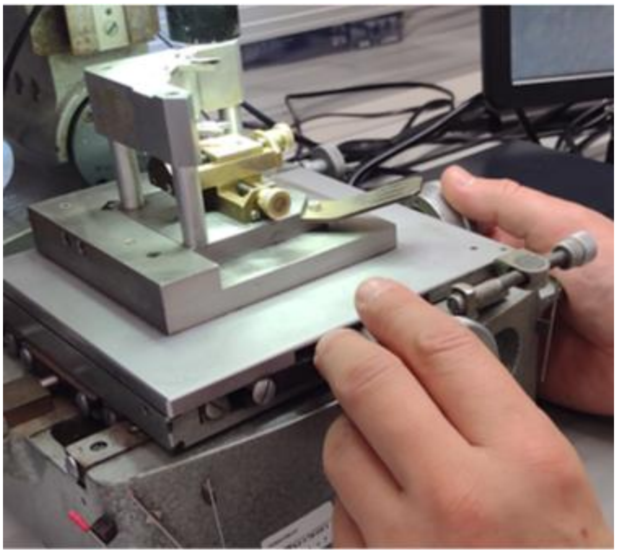


Figure 8: Microscope adjustment – centering on the mark

- XY table movement to chip position - to be done by robotic solution.

Figure 9: XY table movement to chip position

- Centering attempts to match chip and microscope (issue: time consuming adjustment due to XY adjustable tables backlash – even new tables have backlash, human fingers precision lower than robot) - to be done by AI.
- Dipping the top of wire/rod/shaft in glue (issue: lack of repetitive amount of glue) - nice to have vision/X-ray system to check amount and classify.
- Human-robot collaboration – current glue technology doesn't allow to use dispenser.
  - → Nice to have AI vision inspection to verify amount of glue.
  - → Nice to have solution equipped in automatic dispensing/ solution for speeding the glue curing (cyanoacrylate).

Figure 10: Precision wire

- Placing wire/rod/shaft in fork bracket (forks equipped in magnets to hold the shaft) - robotic solution.
- Moving down the shaft to attachment position (issue: components perpendicularity and surfaces parallelism, alignment of components) - robotic solution/force control. Can be still done by operator.
- Removing table from microscope bracket and waiting 20 minutes for glue curing - robotic solution / possibility to speed up glue curing.
- Removing assembly and placing in box with unique traceability QR - human – robot collaboration.

Figure 11: Chip glued to wire before machining

2.2.2.2 *Scenario 2 automatic positioning (Extended autonomy)*

Figure 12: Chip glued to wire before machining

Figure 13: Chips in final shape attached to wires

- De-attached chip is sent to measurement station to measure centriticty and height after machining – nice to have robotic solution for measurement:
    - Picking chip in random position.
    - Placing in correct orientation for vision supported by AI.
    - AI controls the drives to centre the shaped chip in camera field of view instead of manual operation. Current solution below. Final solution should be inverted. Camera on the bottom, XY drive with glass and chip on top of it.

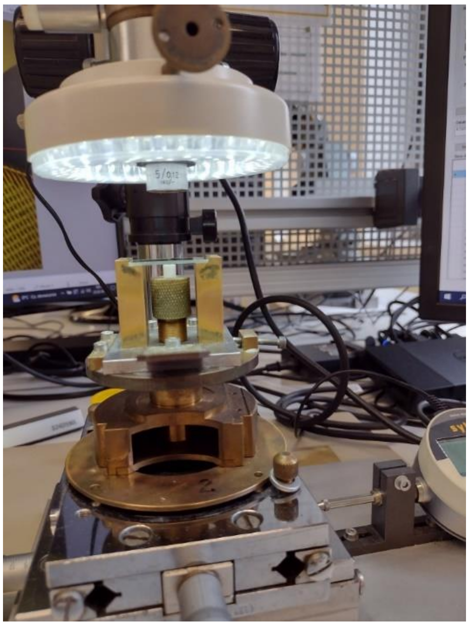


Figure 14: Measurement station

- Second camera with backlight required to measure height of chip.
- When the measurement passed robots picks chip and place in GelPak/Boxes in specific orientation to allow next machine picking, where range of part rotation is +/-6 angle.

2.2.3. Relation to AI PRISM

The final 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. They will have input from an AI-enhanced vision system, that will recognize the appropriate place to attach the wire on the electronic component, based on the shape, colour and additional markers if needed. AI algorithms will adapt to the differences in components, in case of their exchange. The operator will teach the AI PRISM robot the correct positioning of the elements to be glued together. This will be initial role of the operator, who, at later stage, will still be in the loop for the task, mainly for its most critical phase - to confirm the correct positioning of the elements, but also to perform supporting actions, such as glue application. During the development phase, VIGO will generate quality requirements concerning the glued joint, to which PIAP will reply with a technical solution. Advances in development will be systematically consulted with VIGO. In-between and final tests of the solution will be carried out by both cooperating parties.

2.2.4. Specification of Key Performance Indicators (KPIs)

The expectations as end users of the use case are aligned to its functional performance, which is possible to see better in an ended job phase than in the design/initial phase. In all cases, we have considered the unitary objectives and tasks (guided by WP) to propose the relation between KPI and objectives as follows:

Table 2: Indicative list of KPIs

KPI	Description	Validation Metric	Related Task/s, Deliverables	Relation to Objectives
U2_KPI1	The sight perception and movements are precise enough	precision of 1-2 µm	WP3, WP4, WP5	O3, O4, O5, O6
U2_KPI2	Cycle time duration	around 1 minute	WP3, WP4, WP5	O3, O4, O5, O6
U2_KPI3	Amount of chips's properly positioned	> 95% of them	WP3, WP4, WP5	O3, O4, O5, O6
U2_KPI4	The robot can succesfully understand the small variations between the diferent kind of chips	95% of the times	WP4, WP5	O4, O5, O6
U2_KPI5	The robot will succesfully glue stick to the chip	>95% of the times	WP3, WP4, WP5	O3, O4, O5, O6

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

2.3.1. Company and Facility overview

2.3.1.1 *Company overview*

Athenian Brewery (from now on AB) is the largest beer production and distribution company in Greece with an active presence in the country, for more than 55 years. It was founded in 1963 by a group of Greek entrepreneurs and it is member of Heineken NV Group.

Athenian Brewery S.A. produces a wide variety of beers in Greece, such as Amstel, Amstel Dark, Amstel Radler, Amstel Free, Amstel Free Lemon, Amstel KARGO IPA, Heineken, ALFA, ALFA Strong, ALFA Weiss, ALFA Alcohol Free, Fischer, MAMOS (licensed by the Mamos' family), NIMFI and Buckler from 100% Greek barley. The company also brews two apple ciders, MILOKLEFTIS and Strongbow at its unit facility in Patras, using purely Greek raw materials. Simultaneously, Athenian’s Brewery S.A. portfolio includes IOLI, a Natural Mineral Water, while it imports well- known beer brands such as: Sol, Mc Farland, Erdinger, Murphy’s and Duvel. The brewing process takes place in the company’s three facility units, which are in Athens, Thessaloniki, and Patras. Moreover, AB owns a bottling unit of IOLI Natural Mineral Water, located in Lamia.

Since 2008, Athenian Brewery has been carrying out the first and biggest Contract Barley Cultivation Program in the country, through which the company covers 100% of its needs with purely Greek barley. Hence, the success of the company's products is attributed to the use of solely Greek raw ingredients, as well as a vertically integrated process involving its locally based advanced breweries and two privately held malting plants.

Athenian Brewery produces and distributes its products in 19 countries across 5 continents, thanks to an extensive distribution and sales network. Along with its business growth, the company has invested in the modernization of its manufacturing process, the adoption of an integrated environmental policy, the creation of a safe and fair working environment, the promotion of responsible alcohol consumption, and its social impact, all while maintaining transparency and accountability.

2.3.1.2 *Facility overview*

Athenian Brewery’s geographical position is far from the main consumption areas (Athens, islands) and close to the main 2 external competitors. We have an overall low annual utilization of our Brewery technical capacity. The Brewery equipment is old with a set up designed for high productivity / low flexibility. Production volume is dropping but complexity increases creating capacity limitations in production and warehousing during the high season. Investments related to NPIs are limited. There is a high number and turnover of temporary employees who seek for security in their working life. The main asset is people and the WoW (explain what it means).

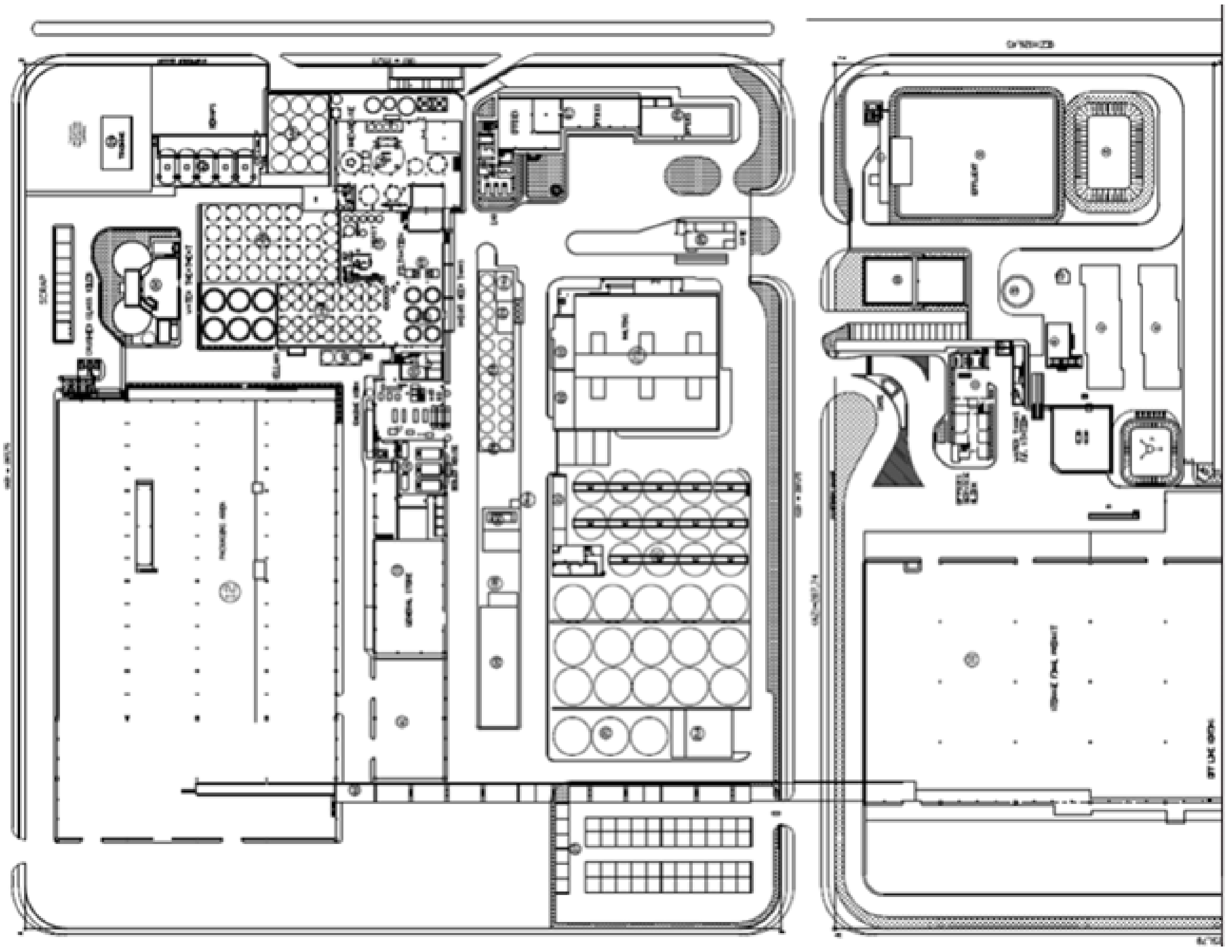


Figure 15: Top down schematic of Thessaloniki brewery

2.3.2. Scenario Overview

2.3.2.1 *Scenario 1 Filtration Powder preparation*

Process overview

There is a process in the brewery, where filtration powder must be prepared. Sacks of 22,7kg of the powder need to be lifted from a palette and placed upon a conveyor for further processing. The powder is dangerous and considered carcinogenic. Therefore, due to its nature and weight, it’d be much better to have the process being done by a robot.

Figure 16: Kieselguhr preparation (powder filtration)

<u>Step by step decomposition and requirements derivation</u>

There are 2 different powders in 2 different pallets.

- Choose pallet of material
- Input quantity in integer numbers of sacks
- Lift the sack
- Move above the conveyor
  - Height from the conveyor should not be more than 20-30cm, otherwise, the sack with be destroyed
- Let the sack go, on the conveyor
- Repeat
  - The repeat step should be at least 20sec away from each other

2.3.2.2 *Scenario 2 Sorting of return bottles from the market*

<u>Process overview</u>

There is a process in the plant, where crates, filled in with different brands of returnable bottles, return from the market to our premises. These need to be sorted to the corresponding crates with the corresponding bottles. Foreign brands need to be separated. i.e.: Amstel 500ml bottles to Amstel

500ml crates, Heineken 330ml bottles to Heineken 330ml crates, Corona to foreign crates (Corona is a foreign brand), and so forth.

Step by step decomposition and requirements derivation

Possible implementation through PRISM will impact Productivity & Cost KPIs.

There is no video due to GDPR (could be monitored during the visit), but two links[1],[2] with a machine that does the same job (in another plant) are shown below, although, the process would be a lot different if a human/robot does it versus a machine.

- There are empty crates from different SKUs around the robot
- In front of the robot there is the pallet that needs sorting
- Robot needs to lift the bottle to identify it
    - Volume identification
        - Could be done by judging the height of the bottle versus the crate in front of it, even before lifting it (smaller volume, shorter bottle)
    - Brand identification
        - Different brands have different shapes & colors of bottle
            - It should assume that the label is destroyed
                - Heineken green bottle
                - Alfa green bottle, different shape than Heineken
                - Amstel amber bottle
                - Foreign brands have their differences as well
                    - Basically, although there are many more different brands than the ones mentioned, they share the same bottle, so, we could focus on them
        - Robot needs to put the identified bottle to the corresponding crate
    - Repeat

2.3.2.3 *Scenario 3 Stickering the bottles for export with the tax sticker*

Process overview

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[1] https://www.youtube.com/watch?v=0E2U1pxoTnE

[2] https://www.vision-tec.de/en/home-2-2-2/

There is a process in the plant, where bottles & cans intended for export, need to have a sticker on top of them, so that it is obvious that the tax is paid. Currently, the operation is done by hand with a stickering gun (like the ones in S/M for prices).

Step by step decomposition and requirements derivation

Possible implementation through PRISM will impact Productivity & Cost KPIs.

There is no video due to GDPR (could be monitored during the visit).

- The sticker must not be damaged, as it is actual money (much more from the value of the paper)
- There is a sheet of paper with the stickers on it
- Sticker needs to be taken out of the above sheet
- Robot needs to face the crate with the bottles/can
- Robot needs to lower in order to put the sticker down
    - Care needs to be taken in order not to damage the bottle/can
- Repeat

2.3.2.4 *Scenario 4 Cleaning the packaging floor from broken glass, dirt, labels*

Process overview

As the packaging operates, there are broken bottles from the process, the debris of which fall down on the floor and are a hazard to the people that are collecting them, and to the operators as there might be some parts that are pushed away (currently they are handled through pressurized water) to a point and then gathered by a broom.

Step by step decomposition and requirements derivation

Possible implementation through PRISM will bring improvement in safety KPIs and improve quality of life for both operators and cleaners and will reduce the water consumption at the packaging area.

- Scan the area for debris (cameras)
- Decide when the accumulation is at a critical point (AI, thresholds)
- Initiate robot for cleaning procedure
- Pass through the area without disturbing people (AI enabled Cameras)
    - Always be aware of surroundings

- Return to base for emptying
    - Repeat

2.3.2.5 *Scenario 5 Packaging and palletizing of custom orders*

Process overview

There is a process in the brewery, where packaging and palletizing of custom orders is performed, comprising a dynamic number of X mark, Y mark, Z mark of beer in a same small pallet.

Step by step decomposition and requirements derivation

- instructions from SAP/invoice on the exact containers of the pallet
    - quantity/SKU
- operator is situated in the center of the area, while around him/her there are pallets with the different SKUs
- knowing what needs to be filled (from the instructions above) the operator starts filling in a new empty pallet by taking the exact quantity from the full pallets at the perimeter and putting it in the pallet to be built in the center
    - X crates of SKU X, Y crates of SKU Y, etc
- when all the quantities are filled in, the operator encloses the pallet with wrap
- The operator moves the pallet to a specified place to be taken out for delivery

An assisted robot could do the lifting/moving of the crates, in order to positively impact the safety KPI (no health issues due to weight lifting). Performance, so 100% accuracy of the order, could also be improved/be a KPI. For safety it'd be a win all around, as it is required to eliminate the existence of persons and forklifts in the same place.

2.3.3. Relation to AI PRISM

The first scenario of filtration powder preparation relates to heavy, monotonous and strenuous tasks, which expose the staff to repetitive strain injury (RSI) or musculoskeletal disorders risks. In addition, the powder is dangerous and considered carcinogenic; therefore, due to its nature and weight, it'd be much better to have the process being done by a robot. The rest of the scenarios (sorting of return bottles from the market, stickering the bottles for export with the tax sticker, cleaning the packaging floor, packaging and palletizing of custom orders) comprise tasks that are difficult to automate due to complex activities and activities that require dynamic and fast repurposing and reconfiguration actions in automation. The robot should be trained and teached to perform these tasks through human-robot collaboration. In all scenarios, the robots should be able to interact with the surrounding space with sensors to ensure human safety, while being seamless connected with the other systems of the factory, to be able to execute dynamically defined logistics tasks and custom and dynamic orders.

2.3.4. Specification of Key Performance Indicators (KPIs)

The expectations of the end users of the use case are aligned to its functional performance, which is possible to see better in an ended job phase than in the design/initial phase. In all cases, the unitary objectives and tasks (guided by WP) to propose the relation between KPI and objectives has been considered as follows:

Table 3: Indicative list of KPIs

KPI	Description	Validation Metric	Related Task/s, Deliverables	Relation to Objectives
U3_KPI1	Improvement of workers safety and wellbeing	Reduction by 30% in number of workers working in heavy tasks and high-risk areas (Baseline 20-30 persons)	T3.1 T5.3 T5.4	O3 O5
U3_KPI2	Reduction of operational expenditures	Reduction by 50% in OPEX for custom/dynamic tasks (Baseline 300K-350K Euros per year)	T3.1 WP4	O3 O4
U3_KPI3	Increase of cost-efficiency	Reduction by 30% in time to execute custom/dynamic tasks (Baseline cleaning 24 hours/day, sorting 12 hours/day)	T3.1 WP4	O3 O4

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

2.4.1. Company and Facility overview

In Silverline production plant, there are some different production stages such as sheet metal processes, powder coating, bonding of the glass pieces and also assembly lines. At the end of each assembly line, there is a Quality Control Box to perform Final Quality Control and clean the product before the packing operation.

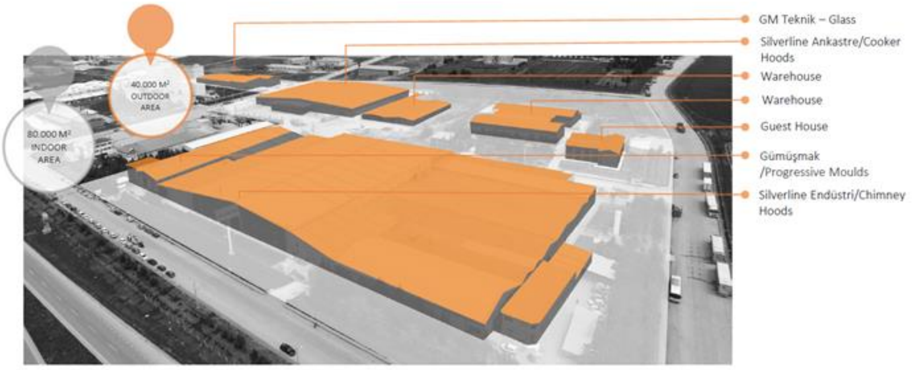

Figure 17 Production Plant

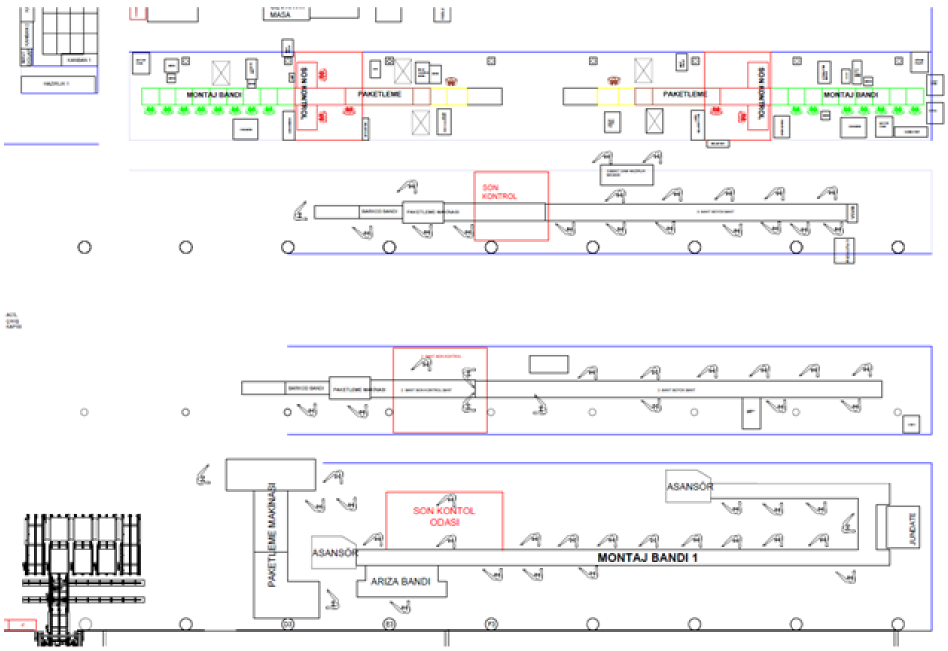

Figure 18 Final Workstation

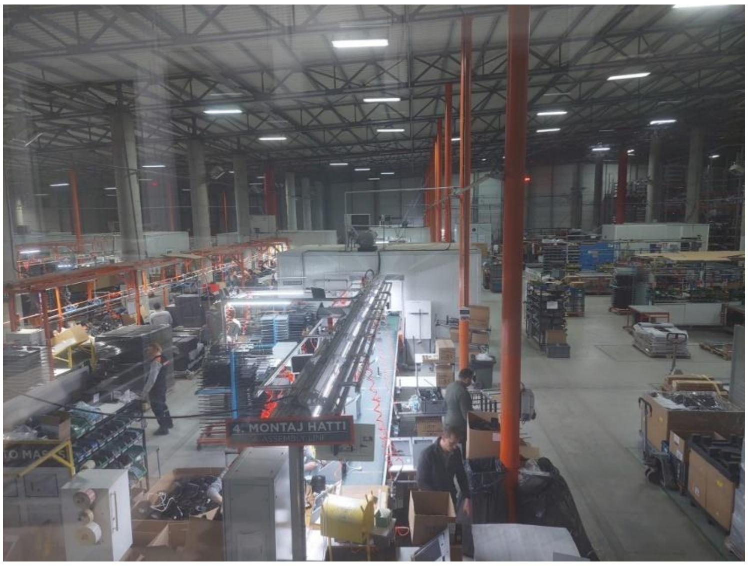

Figure 19 Production line

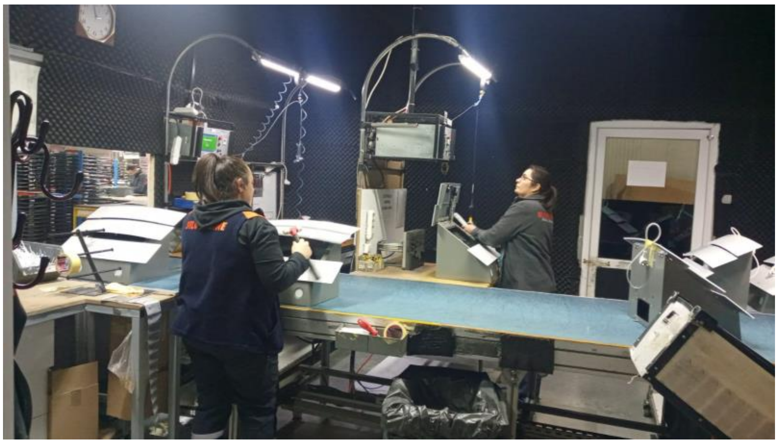

Figure 20 Quality Control Box

Range Hood

Figure 21 Range Hood

Final Control of Range Hood Production Line

The use case is focused on range hood production's final control workstation. The current final control workstation's plant layout is shown in figure below.

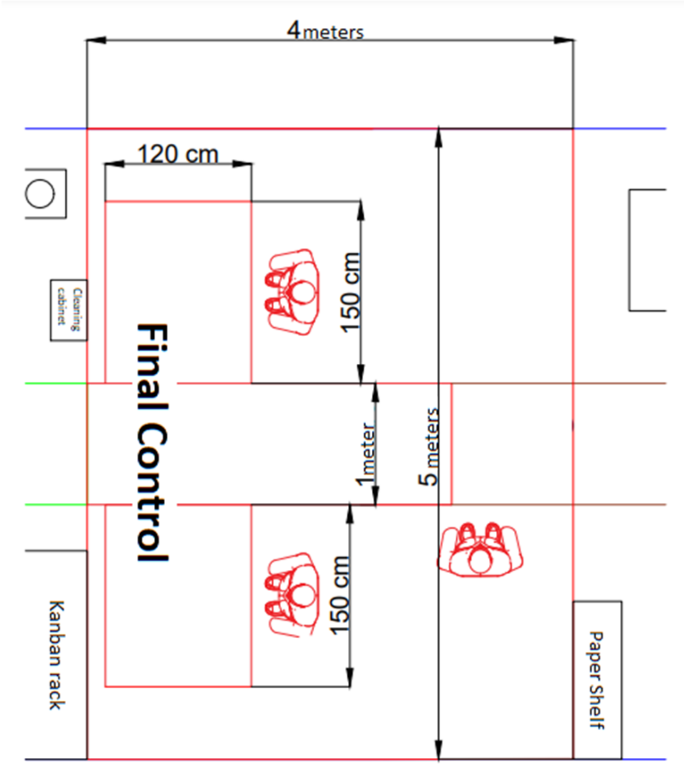

Figure 22 Plant Layout

The application of a robotic solution and the integration into the workstation will increase the efficiency of resource use (with subsequent reduction in production costs and increase in production volume) and the safety of human operators.

2.4.2. Scenario Overview

2.4.2.1 *Scenario 1 "2 Robot – 1 Human" Solution*

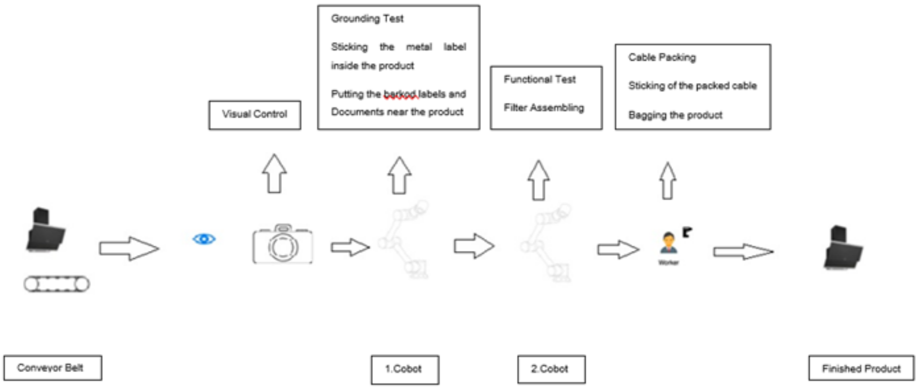

Figure 23 The flow of the Scenario 1

The proposed solution scenario 1 designed in the way where two robot operators (R1, R2), 1 human operator (H1) and adjusted AI-based camera will work together. By using this scenario, the total devoted time for final control is aimed to decrease from 30 to 24 seconds according to the approximately defined durations. The details are shown in Figure 24 and Figure 25 below.

Before AI-PRISM

	Processes	Current Duration
H2	Visual Control	12
H1	Grounding Test	13
H1	Funtional Test	17
H2	Cable Packing	5
H2	Sticking of the Packed Cable	7
H3	Sticking the Metal Label Inside the Product	7
H3	Filter Assembling Process	6
H3	Bagging the Product Process	11
H3	Putting Barcode Labels and Documents near the Product	4

Figure 24 Time distribution for final control before AI-PRISM

In Figure 24, the blue horizontal bar represents human operator 2 (H2), the yellow horizontal bar represents human operator 1 (H1) and the green horizontal bar represents human operator 3 (H3).

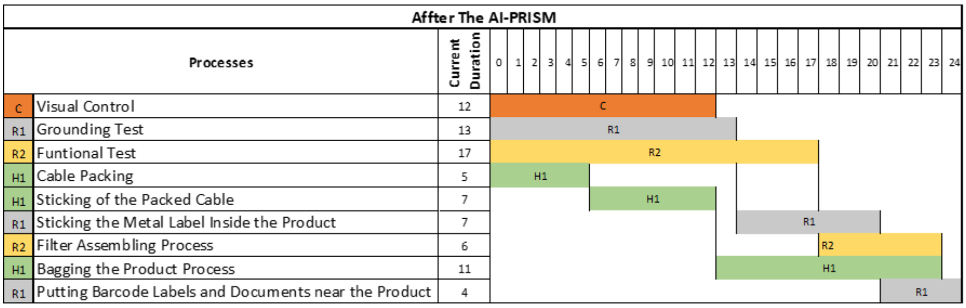

Figure 25 Time distribution for Scenario 1

In Figure 25, the orange horizontal bar represents AI-based camera, the grey horizontal bar represents robot 1 (R1), the yellow horizontal bar represents robot operator 2 (R2) and the green horizontal bar represents human operator 1 (H1).

The distribution of processes delegated to each operator is represented in Figure 26.

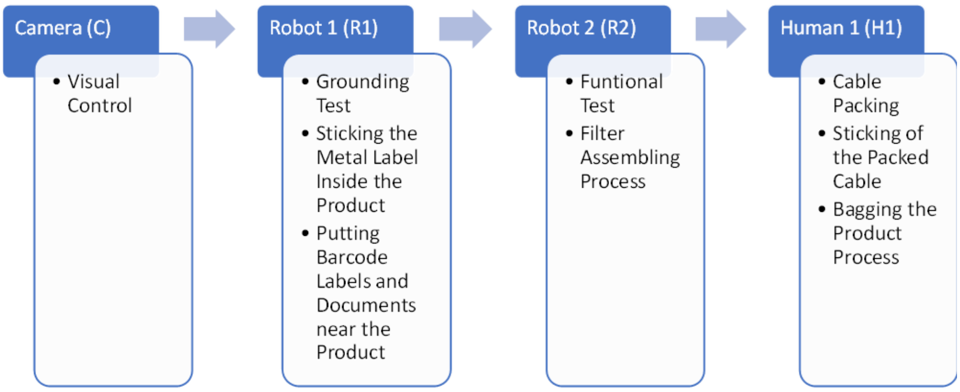

Figure 26 Distribution of processes for Scenario 1

Visual Control Process Overview

The visual control process will be held by a camera. The camera is expected to finish the visual inspection process of defects in twelve seconds.

Grounding Test Process Overview

In the visual control process, it is checked whether there are any external defects. The fixed cameras will make the visual control of the product. Images from the camera will be transferred to the artificial intelligence supported system. The product approved by artificial intelligence will continue in the process. Products that are not approved by artificial intelligence will be controlled by humans and necessary actions will be taken. In this way, the cognitive load on the human will be significantly reduced for this process and errors will be prevented. For the grounding test process R1 operator is delegated. It will start the process right after the visual control process is done and is expected to finish the process in thirteen seconds.

Functional Test Process Overview

In the grounding test process, R1 will do all the work. The measurement tool is touched to any screw on the product and the decision is made according to the values displayed on the screen. For the functional test process R2 operator is delegated. It is expected to finish the process in seventeen seconds.

Cable Packing Process Overview

In the functional test process, it is checked whether the engine, lights, and other functional features like touch keys of the product are working without any problem. For this process H1 operator is delegated. H1 will start packing the cable after finishing functional test. H1 is expected to finish this process in 5 seconds.

Sticking of the Packed Cable Process Overview

The ends of the product's cable are folded together during the cable-tying process. It is fixed with the help of a wire. H1 is in charge of sticking the packed cable process. H1 operator will take the packed cable and stick it to the back of the product. H1 is expected to finish the work in 7 seconds.

Sticking the Metal Label Inside the Product Process Overview

In this process, the cable combined with the wire is adhered to the upper part of the back side of the product with tape. After finishing the sticking of the packed cable, R1 will start doing next process of sticking the metal label inside the product. R1 is expected to finish this process in 7 seconds.

Filter Assembling Process Overview

R1 will take the label from the paper shelf and paste it on the inside of the product. R2 will perform this process and is expected to finish it in 6 seconds.

Bagging the Product Process Overview

This process is planned to be carried out by robot operator R2. The quality status of the filter will be controlled by AI-based camera. If it is a defective filter, human will take the defective one and replace it with a defect-free one. Suitable filters will be mounted on the product. H1 is delegated to this process. It will take the product and put it in the bag. The devoted time is expected to be eleven seconds.

Putting Barcode Labels and Documents near the Product Process Overview

In this process, the product will be packed with a sachet. H1 will control if there are any defects on the sachet. R1 will take barcode labels and related documents from the paper shelf and place them near the product in 4 seconds.

Human Monitoring Process Overview (Optional)

Barcodes and related documents will be placed next to the packaged product. The robot operator R1 will take the barcode labels and related documents from the paper shelf and put it next to the product on the line. The human monitoring process will monitor the H1 and then generate alarms and/or inform the H1's status to H1, R1, and R2 when the H1 is stressed or overloaded. Based on the status of the H1, the robots will change their action by slowing down the process speed or by stopping the process. In the human monitoring process, the human operator's status is checked whether he/she is stressed or overloaded or not. The fixed cameras will capture the operator's behavior and the wearable sensor is used to get a physiological signal. The human monitoring process generates information on the human status, and based on the status, the robots will change their action by slowing down the process speed or by stopping the process.

2.4.2.2 *Scenario 2 "1 Robot – 2 Human" Solution*

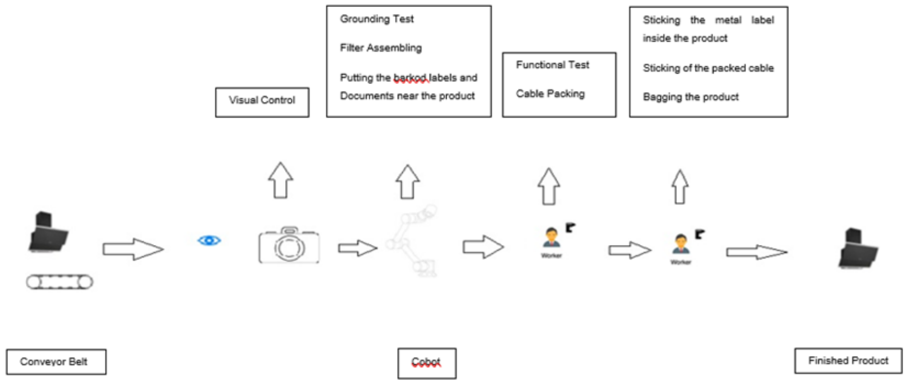

Figure 27 The flow of the Scenario 2

The proposed solution scenario 2 designed in the way where two human operators (H1, H2), 1 robot operator (R1) and adjusted AI-based camera will work together. By using this scenario, the total devoted time for final control is aimed to decrease from 30 to 25 seconds according to the approximately defined durations. The details are shown in Figure 28 and Figure 29.

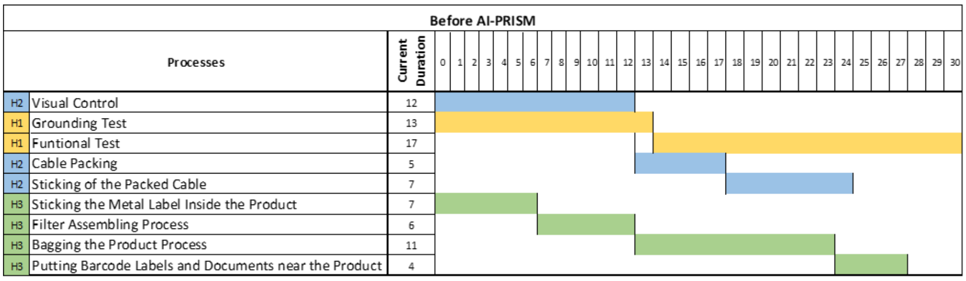

Figure 28 Time distribution for final control before AI-PRISM

In Figure 28, the blue horizontal bar represents human operator 2 (H2), the yellow horizontal bar represents human operator 1 (H1) and the green horizontal bar represents human operator 3 (H3).

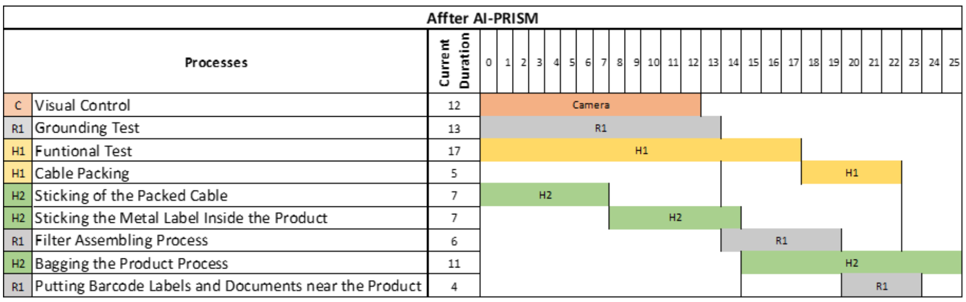

Figure 29 Time distribution for Scenario 2

In Figure 29, the orange horizontal bar represents AI-based camera, the grey horizontal bar represents robot operator 1 (R1), the yellow horizontal bar represents human operator 1 (H1) and the green horizontal bar represents human operator 2 (H2).

Visual Control Process Overview

The visual control process will be held by a camera. The camera is expected to finish the visual inspection process of defects in twelve seconds. In the visual control process, it is checked whether there are any external defects. The fixed cameras will make the visual control of the product. Images from the camera will be transferred to the artificial intelligence supported system. The product approved by artificial intelligence will continue in the process. Products that are not approved by artificial intelligence will be controlled by humans and necessary actions will be taken. In this way, the cognitive load on the human will be significantly reduced for this process and errors will be prevented.

Grounding Test Process Overview

For the grounding test process R1 operator is delegated. It will start the process right after the visual control process is done and is expected to finish the process in thirteen seconds. In the grounding test process, R1 will do all the work. The measurement tool is touched to any screw on the product and the decision is made according to the values displayed on the screen.

Functional Test Process Overview

For the functional test process H1 operator is delegated. It is expected to finish the process in seventeen seconds. In the functional test process, it is checked whether the engine, lights, and other functional features like touch keys of the product are working.

Cable Packing Process Overview

For this process H1 operator is delegated. H1 will start packing the cable after finishing functional test. H1 is expected to finish this process in 5 seconds. The ends of the product's cable are folded together during the cable-tying process. It is fixed with the help of a wire.

Sticking of the Packed Cable Process Overview

H2 is in charge of sticking the packed cable process. H2 operator will take the packed cable from H1 and stick it to the back of the product. H2 is expected to finish the work in 7 seconds. In this process, the cable combined with the wire is adhered to the upper part of the back side of the product with tape.

Sticking the Metal Label Inside the Product Process Overview

After finishing the sticking of the packed cable, H2 will start doing next process of sticking the metal label inside the product. H2 is expected to finish this process in 7 seconds. H2 will take the label from the paper shelf and paste it on the inside of the product.

Filter Assembling Process Overview

R1 will perform this process and is expected to finish it in 6 seconds. This process is planned to be carried out by robot operator R1. The quality status of the filter will be controlled by AI-based camera. If it is a defective filter, human will take the defective one and replace it with a defect-free one. Suitable filters will be mounted on the product.

Bagging the Product Process Overview

H2 is delegated to this process. It will take the product and put it in the bag. The devoted time is expected to be eleven seconds. In this process, the product will be packed with a sachet. H2 will control if there are any defects on the sachet.

Putting Barcode Labels and Documents near the Product Process Overview

R1 will place the barcode labels and documents near the product in 4 seconds. Barcodes and related documents will be placed next to the packaged product. The robot operator will take the document barcode from the paper shelf and put it next to the product on the line.

2.4.2.3 *Scenario 3 "1 Robot – 1 Human" Solution*

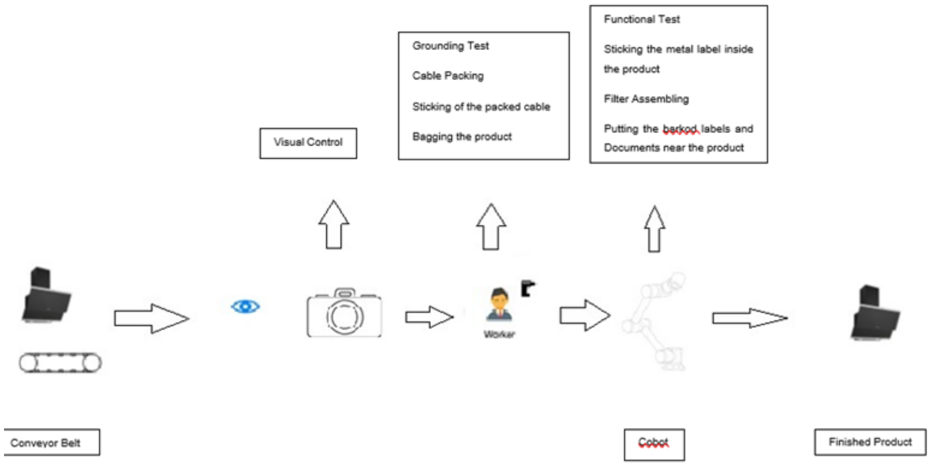

Figure 30 The flow of the Scenario 3

The proposed solution scenario 3 designed in the way where one human operators (H1), 1 robot operator (R1) and adjusted AI-based camera will work together. By using this scenario, the total devoted time for final control is aimed to increase from 30 to 36 seconds according to the approximately defined durations. The details are shown in Figure 31 and Figure 32.

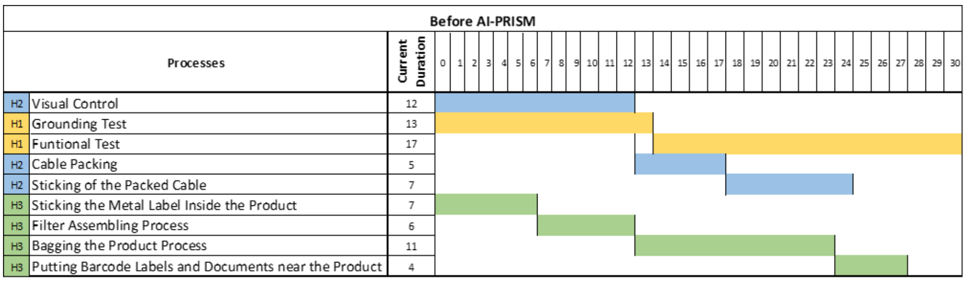

Figure 31 Time distribution for final control before AI-PRISM

In Figure 31, the blue horizontal bar represents human operator 2 (H2), the yellow horizontal bar represents human operator 1 (H1) and the green horizontal bar represents human operator 3 (H3).

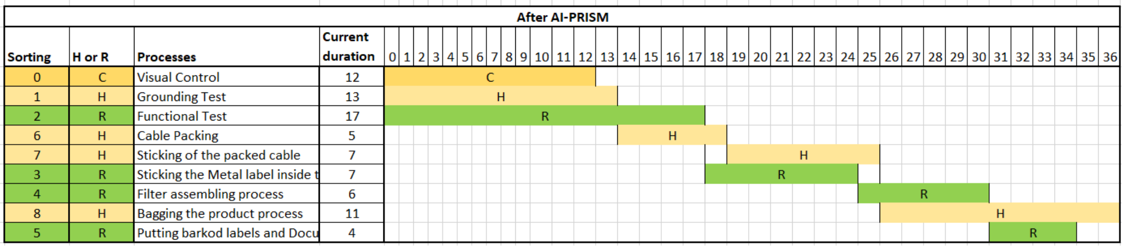

Figure 32 Time distribution for Scenario 3

In Figure 32, the orange horizontal bar represents AI-based camera, the green horizontal bar represents robot operator (R), the yellow horizontal bar represents human operator (H).

Visual Control Process Overview

The visual control process will be held by a camera. The camera is expected to finish the visual inspection process of defects in twelve seconds. In the visual control process, it is checked whether there are any external defects. The fixed cameras will make the visual control of the product. Images from the camera will be transferred to the artificial intelligence supported system. The product approved by artificial intelligence will continue in the process. Products that are not approved by artificial intelligence will be controlled by humans and necessary actions will be taken. In this way, the cognitive load on the human will be significantly reduced for this process and errors will be prevented.

Grounding Test Process Overview

For the grounding test process H operator is delegated. It will start the process right after the visual control process is done and is expected to finish the process in thirteen seconds. In the grounding test process, H will do all the work. The measurement tool is touched to any screw on the product and the decision is made according to the values displayed on the screen.

Functional Test Process Overview

For the functional test process R operator is delegated. It is expected to finish the process in seventeen seconds. In the functional test process, it is checked whether the engine, lights, and other functional features like touch keys of the product are working.

Cable Packing Process Overview

For this process H operator is delegated. H will start packing the cable after finishing functional test. H is expected to finish this process in 5 seconds. The ends of the product's cable are folded together during the cable-tying process. It is fixed with the help of a wire.

Sticking of the Packed Cable Process Overview

H is in charge of sticking the packed cable process. H operator will take the packed cable and stick it to the back of the product. H is expected to finish the work in 7 seconds. In this process, the cable combined with the wire is adhered to the upper part of the back side of the product with tape.

Sticking the Metal Label Inside the Product Process Overview

After finishing the sticking of the packed cable, R will start doing next process of sticking the metal label inside the product. R is expected to finish this process in 7 seconds. R will take the label from the paper shelf and paste it on the inside of the product.

Filter Assembling Process Overview

R will perform this process and is expected to finish it in 6 seconds. This process is planned to be carried out by robot operator R. The quality status of the filter will be controlled by AI-based camera. If it is a defective filter, human will take the defective one and replace it with a defect-free one. Suitable filters will be mounted on the product.

Bagging the Product Process Overview

H is delegated to this process. It will take the product and put it in the bag. The devoted time is expected to be eleven seconds. In this process, the product will be packed with a sachet. H will control if there are any defects on the sachet.

Putting Barcode Labels and Documents near the Product Process Overview

R will place the barcode labels and documents near the product in 4 seconds. Barcodes and related documents will be placed next to the packaged product. The robot operator will take the document barcode from the paper shelf and put it next to the product on the line.

2.4.3. Relation to AI PRISM

An intelligent and adaptable control station with the cooperation of humans and robots will be developed. The current tasks all performed by human will be conducted either by robot only, human only or both (Human and Robot). Application of the AI PRISM robotic solution will increase the resource efficiency (followed by reduction of production costs and increase of production volume) and safety of workers.

2.4.4. Specification of Key Performance Indicators (KPIs)

The expectations as end users of the use case are aligned to its functional performance, which is possible to see better in an ended job phase than in the design/initial phase. In all cases, we have considered the unitary objectives and tasks (guided by WP) to propose the relation between KPI and objectives as follows:

Table 4: Indicative list of KPIs

KPI	Description	Validation Metric	Related Task/s, Deliverables	Relation to Objectives
U4_KPI1	Resource efficiency	Increase by 15%	T6.1 - T6.3 - T6.4	O1
U4_KPI2	Total production time	Reduction by 20%	WP3	O5 - O6
U4_KPI3	Production cost	Reduction by 10%	WP3	O5 - O6
U4_KPI4	Production capacity for custom-made products	Increase by 15%	T4.5	O1 – O4 -O5
U4_KPI5	Reduction of cognitive load required from the operator	Reduction by 10%	T5.1 - T5.2 - T5.5	O2 -O3
U4_KPI6	Unwanted personnel movement	Reduction by 5%	T5.1 - T5.2	O2 -O3

2.5. Generic Demonstrator: AI-Control for Natural, Multi-modal Collaboration

2.5.1. Company and Facility overview

<u>Give a short description of the company</u>

The automation expert KEBA has quadrupled its turnover within the last 10 years. The number of employees also grew significantly. During the last decade, internationalization has also been driven forward massively. Three strategic acquisitions also expanded the product portfolio and strengthened the market presence. Today, the company is represented by its own subsidiaries all over the world, from the USA to Europe and Asia. With production sites in Austria, Germany, the Netherlands and China, KEBA is also strongly positioned in this aspect.

Close networking with its customers and a high level of understanding for their industries and challenges have always been as important to KEBA as offering correspondingly industry-optimized solutions.

Combined with the growth of the past years, this has driven KEBA to bundle its business into three strong business areas for the future:

1. Industrial Automation
2. Handover Automation
3. Energy Automation

The different industries, which underlie different economic cycles, ensure the growth course of the KEBA Group.

The three business areas have been operating as independent companies since the fall of 2021 and operate the operative business as part of the KEBA Group. They still act under the common strong KEBA brand.

Industrial Automation develops and produces automation solutions consisting of hardware and software for machines and robots. The solutions range from operation, control and safety technology to drive technology. These solutions are used in various mechanical engineering sectors and in robotics.

Handover Automation is a specialist for handover solutions. These enable the secure and contactless transfer of cash, parcels or goods as well as controlled access to shared objects. These solutions are known, for example, as ATMs for banks or parcel machines for postal and logistics companies, as well as handover machines in the vehicle trade, in the judiciary or in the healthcare sector.

Energy Automation is one of the pioneers of charging solutions for electric vehicles. The wallboxes not only allow electric cars to be charged safely and reliably, but can also be networked with various systems, such as a photovoltaic system, due to a wide range of interfaces. Another focus in this business area is on heating controls for heat pumps as well as biomass heating systems.

The three business areas have different characteristics. Industrial Automation has a focus on OEM (Original Equipment Manufacturer). Handover Automation is a project business with the production of self-service machines in the banking and logistics sector. And Energy Automation, which manufactures wall-boxes for e-cars as well as heating control systems, is a series business close to the end customer.

The KEBA Group is responsible for the overall strategy of KEBA as well as the strategic and financial management of the entire group of companies."

Facility overview

KEBA produces (Figure 33) a variety of several different PCBs for different applications. Permanent optimization of the throughput times and a flexible production line is necessary.

Figure 33 KEBA Production

Give a short description of the facility that the use case will take place

Any drawing of the whole facility is welcome.

In electronic industry different PCB shapes are used for different products (Figure 33). The employees at the testing point should be assisted by an industrial robot.

Figure 34 shows a part of the PBC testing area in the production of KEBA nowadays. The PBC are tested manually and should be assisted by an industrial robot in future. At first, the use case in the AI-PRSIM project should be done in an innovation Lab at KEBA.

Figure 34 Testing area at KEBA

2.5.2. Scenario Overview

The use case at KEBA can be divided to the following tasks:

2.5.2.1 *Scenario 1 Recognize PCB*

This Scenario mainly deals with introducing new PCBs to the process. It involves recognizing the PCB either using model-based methods (CAD, etc) or model less approaches (AI based vision)

2.5.2.2 *Scenario 2 Grasping*

This scenario concerns with configuring the robot grasping process for a given PCB. The process is based on AI enabled grasping (state of the art) approaches combined with user configuration to deal with variants and quick teaching process. possible) and also a feedback from the user after the process should help the process.

2.5.2.3 *Scenario 3 Manipulation Correction*

After grasping the object (PCB) the alignment of the object is the robot's 'hand' might not be suitable for the next process step (testing, deposition). So a correction step to re-orient the robot 'hand' is required. This is achieved with AI enabled vision and Robot control. possible) and also a feedback (using different modes of interaction) from the user after the process should help the process.

2.5.2.4 *Scenario 4 Positioning of the PCB for Testing*

After the reorientation of the PCB, the robot deposits the PCB in the testing adapter. The testing adapter is responsible to test the PCB and check if the PCB is OK/NOT-OK. In case of OK, the robot then proceeds with the next process step (see Scenario 5) otherwise it is places the PCB into a separate box for further processing by the human operator.

2.5.2.5 ***Scenario 5 Deposition***

This scenario concerns itself with bin packing where the goal is to efficiently place the tested PCBs on a plate in the transport box. This is achieved with AI enabled (geometry) optimization and robot control. It is vital also to consider user configuration (different modes of interaction are possible) and also a feedback from the user after the process should help the process.

2.5.2.6 ***Scenario 6 Interactive Process Workflow***

This is both a configuration step where the above scenarios are configured in a process flow (using an easy-to-use interface) by the user. The process flow is then executed using an execution system. In special cases, where the execution fails, recovery strategies should be applied to alleviate the failure. It could be done internally by the system using AI enabled methods. In case it cannot, user should be contacted for help (this requires relevant user interface).

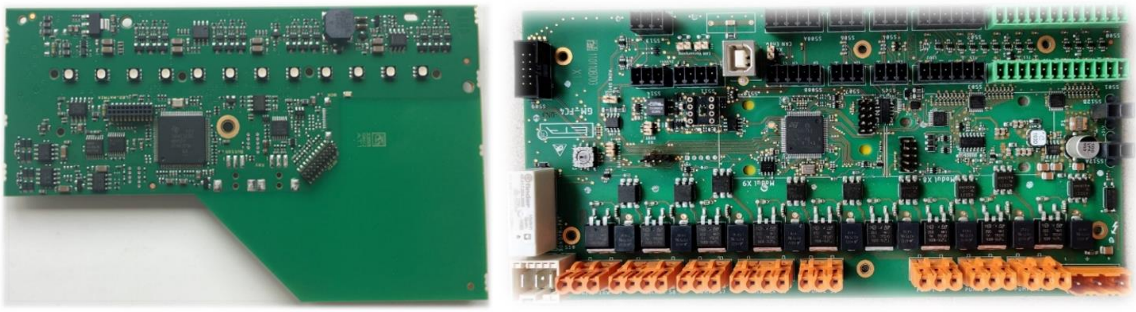

Figure 35 PCB with different shapes

Process overview

Figure 36 shows different areas of human-robot collaboration at KEBA. In each area, employees can be supported by a robot. The interaction between the robot and the human can take place in different ways, e.g. by pose estimation, voice control, vision based system, CAD Data for control…

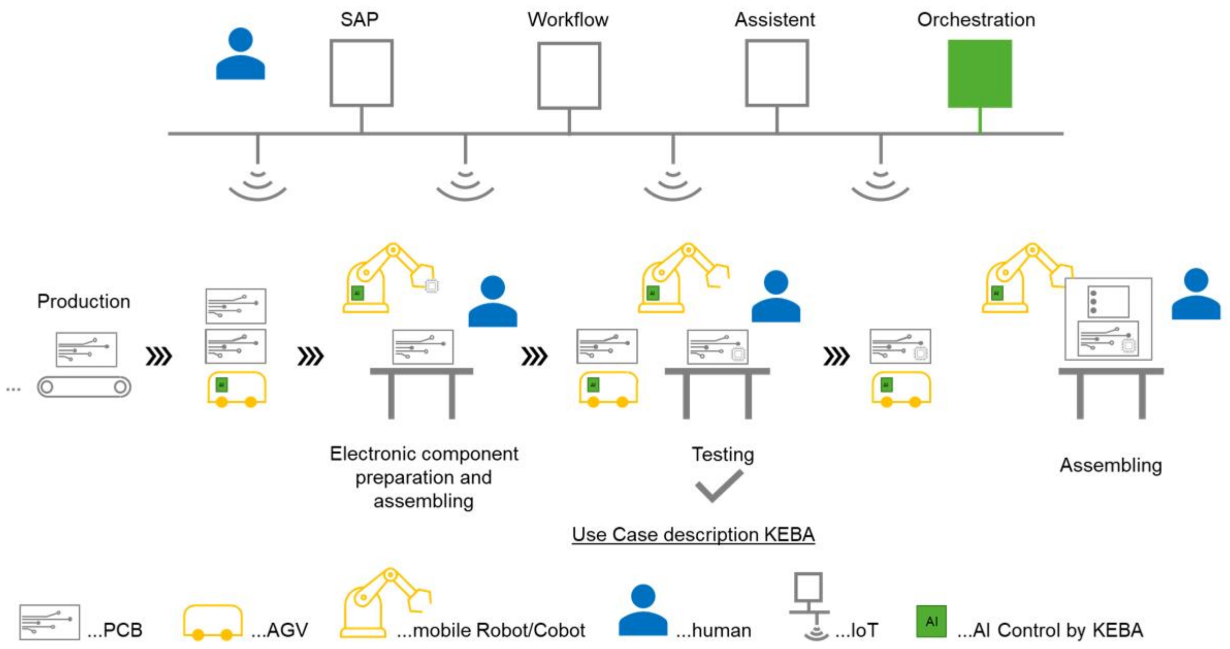

Figure 36 Human robot collaboration areas at KEBA

Step by step decomposition and requirements derivation

Recognize PCB

During the AI-Prism project the following different methods will be compared to recognize which PCB is at the pickup station. Some method which could be used are:

- Vision based systems
- Voice control
- Person (operator)
- CAD data for control

Grasping

The PCB will be taken by a robot and will be placed in a testing measurement setup. An AI algorithm will be implemented to grip the different PCBs in a proper way. Several points how to grip the PCB will be proposed to the human. The human can choose one of the proposed gripping points and give a feedback afterwards, if the suggestion of the gripping points were suitable or not suitable.

Correction

To place the PCB in the testing measurement setup it is necessary to know the actual position of the gripped PCB and to bring the PCB into the correct position. For these movements we will use the data from a vision system. The AI algorithm will be improved by implementing the feedback of the human.

Deposition

An optimized deposition (Figure 4) depending on the recognized PCB and the used boxes is implemented after the testing procedure. Again the feedback of the human will improve the AI based deposition.

2.5.3. Relation to AI PRISM

The most accurate integration between scope of AI-PRISM project and technical/functional requirements in this use case, is demonstrated with the overall robotic-process training and execution cycle e.g. when introducing a new product variant. AI-PRISM modules will be placed on the AI-Control of KEBA, to work with minimal training by end users in the most natural way. This will include natural ways to teach a new process (and gripper), to adapt existing processes and "debug" the execution of such processes by non-programmers. In particular, this last task on communication of irregularities in process execution will be a challenge that needs to be tackled to enable a kind of end-user programming for co-bot systems using natural collaboration like teaching by example. Multi modal, ambient sensor networks will help to determine deviations in the execution, to determine the need for adaptation.

2.5.4. Specification of Key Performance Indicators (KPIs)

The expectations as end users of the use case are aligned to its functional performance, which is possible to see better in an ended job phase than in the design/initial phase. In all cases, we have considered the unitary objectives and tasks (guided by WP) to propose the relation between KPI and objectives as follows:

Table 5: Indicative list of KPIs

KPI	Description	Validation Metric	Related Task/s, Deliverables	Relation to Objectives
U5_KPI1	Number of Human Robot Interaction modalities for configuring the robot to a complex task.	Min. 2 modalities used concurrently	WP3, WP4	O3, O4, O5, O6
U5_KPI2	The setup time required to configure the robot, as compared to traditional methods.	Reduced by 12%	WP4	O4, O6
U5_KPI3	The mental load experienced during training phase.	Improved acceptance of the new interfaces	WP4, WP5	O4, O5, O6
U5_KPI4	The level of technical knowledge required by users for operating and training.	Non-Robot process experts can easily use the training system	WP4 , WP5	O4, O5
U5_KPI5	The duration needed to train a non-expert user.	Reduced by 20%	WP4, WP5	O4, O5

3. Methodology for Requirement Specifications and Analysis

The methodology for formalization of the requirements specifications include the following steps

- Elicitation of functional and non-functional user requirements, constraints and applied standards/regulations, on the way of the interviews (surveys) with the users, use case scenarios analyses, original project vision. It should result in the stakeholder requirements (for more details see Section 3.1)
- Analysis of the stakeholder requirements, which leads to the definition and the specification of system requirements (for more details see Section 3.2)

3.1. Stakeholder Requirement Elicitation

The requirements definition process begins with the elicitation of stakeholder requirements. It is a complex process that consists of gathering, researching, defining, structuring, and clarifying a product’s requirements. The actions needed during the requirements elicitation process have been illustrated in Figure 37.

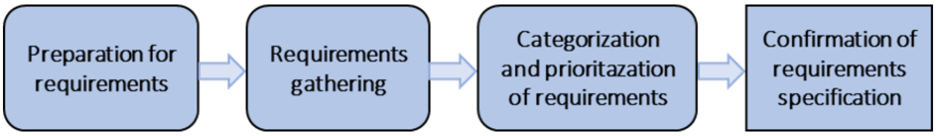

Figure 37:Requirement specification process

The first step of preparation for requirements elicitation is to understand the elicitation activity scope and to identify the stakeholders from whom those requirements are to be gathered. It is common in requirements engineering to define a stakeholder as someone who has a stake in the project—that is, someone who is involved in or affected by the project in some way, or can affect the project in some way and therefore are interested in its success. Next should be selected the right techniques for gathering the requirements. Gathering the requirements is a big part of the elicitation process and it might take a lot of time and effort to uncover all of the primary requirements from all of the stakeholder's requirements. It's quite possible to elicit many of these requirements from marketing experts and analysts who can obtain many requirements from a representative body. Other methods of capturing stakeholder requirements can include focus groups or conducting either individual or group interviews with process experts or even workers. Following the results of the user surveys and interviews, the next step of our approach concerns the categorization and prioritization of the gathered requirements. In this scope, the assessed user requirements should first be organized in specific categories, called:

i. **functional** (description of the system functions or tasks to be performed, usually obtained through use cases analysis),
ii. **non-functional** (specification of the quality attributes of the system),
iii. **constraint** (limitation of the options open to a designer of a solution by imposing immovable boundaries and limits),
iv. **normative** (applied standards/regulations).

For each category, a requirements prioritization analysis should be performed, so as to specify the importance value:

i. Must have (requirements that are critical to meeting the project's objectives),
ii. Should (requirements that are critical and should be included if possible, but which can be excluded),
iii. Could (requirements that are part of the project's scope and add or enhance project benefits),

iv. Would (requirements that do not have a significant impact on project benefits or could be considered as a "would like to have").

Finally, the stakeholder requirements gathered in the elicitation session/s and collected in the table (for example see Table 6) are checked for accuracy.

3.2. Mapping of Stakeholder Requirements to System Requirements

The workflow for mapping the stakeholder requirements into the fundamental structures in terms of hardware, human robot collaboration, AI enhancing tools and Social Collaboration requirements is shown in Figure 38.

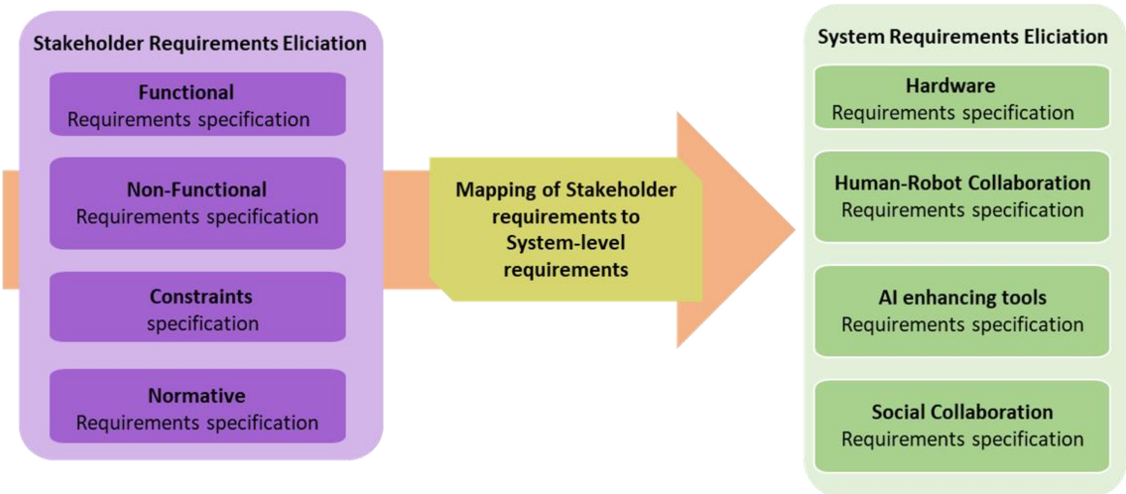

Figure 38: Specification of Requirements – the Workflow

4. Requirement Analysis

This Section provides the relevant "Stakeholder Requirements" of each use case described in Section 2 and contains the top-level requirements sourced from i) the overall idea of the AI PRISM project as stated in the project proposal ii) the needs and opinions of the prospective end-users represented by respective end users of each use case. This is followed with the requirement analysis including the required hardware, the aspects of Human Robot Collaboration, the required AI enhancing tools and finally the social collaboration requirements. The needs and ideas of the Consortium members conducting the research work in each of the use case is detailed respectively.

4.1. Use Case 1: Furniture

4.1.1. Stakeholder Requirements

ID	Category	Priority	Criterion	Specification
U1St_R1	Functional	Must	Operational	The system must get the information it requires (eg. product identifiers, product colour, shape, material) from corporate software (Finiture or SAP)
U1St_R2	Functional	Must	Operational	Cobot must learn painting and sanding new products based on few examples provided by a specialist
U1St_R3	Functional	Must	Operational	The cobot must be able to learn and perform the painting and sanding processes for different shapes, group of colors, and wood types
U1St_R4	Functional	Must	Operational	Robot programming by example must be intuitive, the operator must be able to program the robot performing the operation (painting or sanding) on a sample product (either physical or virtual)
U1St_R5	Functional	Must	Operational	The cobot must work under human supervision, the operator needs to confirm the actions to be performed by the robot
U1St_R6	Functional	Must	Mobility	The cobot must be able to paint pieces of furniture in the three positions of the frame, change from one position to another, and turn the frame in the horizontal axis
U1St_R7	Functional	Must	Operational	The cobot must be able to paint all pieces of furniture that do not need to be turned vertically and those that, when turned vertically manually by an operator, are fixed to the frame in a stable position
U1St_R8	Functional	Must	Safety	The cobot must stop or adapt the operation speed when operators are within safety distance
U1St_R9	Functional	Must	Perception	The cobot must be able to perceive the properties of the piece of furniture

				that needs to be painted or sanded (colour and shape)
U1St_R10	Functional	Must	Operational	The system must use intuitive visual and/or audible interfaces to alert and communicate with operators
U1St_R11	Functional	Must	Operational	The digitalization system must install ambient data sensors to ensure optimal conditions for painting and worker safety.

Table 6 Stakeholder requirements

4.1.2. System level requirements specification for hardware

ID	Requirement Source	Priority	Requirement
U1H_R1	**Robot System General**		
U1H_R1.1	U1St_R1	High	The robot must be able to connect to the services necessary to obtain the date and time
U1H_R2	**Manipulator**		
U1H_R2.1	General		
U1H_R2.1.1	U1St_R7	High	6-axis collaborative manipulator robots with a minimum payload of 10kg and a minimum reach of 1000 mm. (One for painting and one for sanding)
U1H_R2.2	Gripper		
U1H_R2.2.1	U1St_R7	High	A tool that can be mounted on the manipulator robot and used to paint the wood
U1H_R2.2.2	U1St_R7	High	A tool that can be mounted on the manipulator robot and is able to sand
U1H_R3	**Network Infrastructure**		
U1H_R3.1	U1St_R1	High	Connectivity to network time services, OT (Finiture), or IT (SAP)
U1H_R3.2	U1St_R1	High	The Cobot shall be equipped with at least 1 communication port. (Ethernet, wifi)

U1H_R3.3	U1St_R1	High	The physical layer should have a bandwidth of 1 GB for wired network.
U1H_R3.4	U1St_R1	High	The physical layer should have a latency < 5 ms for the wired and <20 ms for wireless network.
U1H_R3.5	U1St_R11	High	Wireless suspended ambient and particle monitoring for each cabin (Staining, coating, finishing and sanding).
U1H_R3.6	U1St_R11	High	Wireless systems must have a sufficient range to cover the entire industrial facility and enable reliable communication between devices.
U1H_R3.7	U1St_R11	Medium	Wireless devices must be able to operate for extended periods without the need for battery replacement or other maintenance.
U1H_R3.8	Derived	Medium	Capability to obtain real-time data from the process control area at line and workstation level.
U1H_R3.9	Derived	High	The communication system must allow for remote access to industrial devices and equipment from external locations, enabling remote monitoring and control of AI-PRISM components.
U1H_R4	**Perception Sensors**		
U1H_R4.1	U1St_R10	High	RGBD cameras (1 to visualize the object to be painted, 1 to visualize the object to be sanded, 1 static in the painting booth, 1 static for sanding area)
U1H_R4.2	U1St_R7	High	In the sanding process, it is necessary to control the applied force, so a force sensor is needed.
U1H_R4.3	U1St_R6	Medium	4 laser scanners to detect human proximity
U1H_R5	**Equipment**		

U1H_R5.1	U1St_R10	High	The illumination of the environment must be controlled, for which light panels are needed.
U1H_R5.2	Derived	Medium	A PLC is needed to control the different elements of the system.
U1H_R5.3	U1St_R8	Medium	To move the robot between the three frames, a railway and a robot base is needed.
U1H_R5.4	U1St_R10	Medium	Embedded system for connecting cameras

Table 7: System-level requirements specification for hardware

4.1.3. System level requirements specification for Human-Robot Collaboration

Human-Robot Collaboration (corresponding to WP3 solutions),

ID	Requirement Source	Priority	Requirement
U1HR_R1	Human Robot Interactive Interfaces		
U1HR_R1.1	**General**		
U1HR_R.1.1.1	U1St_R3	High	The system must be able to model and store the sequence of movements performed by the operator during cobot training
U1HR_R.1.1.2	U1St_R4	Medium	User interfaces must provide visual alerts to warn users of errors
U1HR_R.1.1.3	Derived	Medium	User interfaces must be responsive and adapt to different end user devices
U1HR_R.1.1.4	U1St_R4	High	The cobot must only start if alerts generated have been attended to or closed previously
U1HR_R1.2	**Configuration Interface**		
U1HR_R1.2.1	U1St_R1	High	The system must provide user interfaces to configure and verify the connection to other corporate software (line control and SAP)
U1HR_R1.2.2	U1St_R1	Low	The system must provide user interfaces to select which product references will be integrated, out of

			all the existing references in the corporate ERP system (SAP)
U1HR_R1.2.3	U1St_R1		The system must provide user interfaces to verify the actual product reference
U1HR_R1.3	**Training**		
U1HR_R.1.3.1		Medium	The system must provide an interface to start and stop a new training sample for a piece of furniture (shape, colour group, and wood type)
U1HR_R.1.3.2		Medium	The system must provide interfaces to validate the results of the training, providing feedback on the performance of the operation learned (e.g. cycle time, materials used, compared to actual baselines)
U1HR_R1.5	**Operations Control**		
U1HR**_R.1.4.1**		Medium	The system must provide user interfaces to confirm the current production order and product information (colour, shape, wood type). If the operator does not confirm the robot will not perform any operation.
U1HR**_R.1.4.2**		Medium	The system must provide user interfaces to visualize the current status of the cobot (eg. whether it is operating or not, what is the current production order, what is the status of the process)
U1HR**_R.1.4.3**		Medium	The system must alert the operator if there is an error during an operation
U1HR**_R.1.4.4**			The system must alert the operator when it has finalised an operation step that requires manual intervention (e.g. turn a piece of furniture manually)
U1HR**_R.1.4.5**			The system must provide user interfaces to monitor performance indicators for the current production order (e.g. mean cycle time, cycle time histogram, paint used, OEE)

U1HR_R1.5	**Performance Monitoring**		
		Medium	The system must provide user interfaces to visualize the evolution of performance KPIs

Table 8: System-level requirements specification for software

4.1.4. System level requirements specification for AI enhancing tools

AI enhancing tools (corresponding to WP4 solutions)

ID	Requirement Source	Priority	Requirement
U1AI_R1	Scene Perception		
U1AI_R1.1	General		
U1AI_R1.2	Object Detection		
U1AI_R1.2.1		High	The system must be able to detect any human in the collaboration ambient, their position and distance to the robot and their movements
U1AI_R1.2.2		High	The system must be able to detect the properties of the piece of furniture, colour, shape, roughness
U1AI_R2	High Level Decision Maker		
U1AI_R2.1.1	Derived	High	Use the collected data to model the operations steps needed to perform the painting and sanding, the available resources (robots and human agents), the characteristics of products (colour, shape, type of wood), the properties of materials, and their capabilities to perform the operation steps (whether they can perform the operation step and performance indicators that assess how the operation is performed)
U1AI_R2.1.2	U1St_R1	Medium	Organize scheduling around the robot's capabilities, also taking into account the capabilities of the personnel working around the robots at any given time.
U1AI_R2.1.3	Derived	Medium	Automate the program changes of each robot when there are changes in production
U1AI_R2.1.4	Derived	Low	Perform optimal allocation of tasks to robots and human agents based

			on different criteria, like maximizing robot utilization and minimizing robot time, or maximizing ergonomy, keeping the physical activity of workers within optimal, healthy values

Table 9: System-level requirements specification for software

4.1.5. System level requirements specification for Social Collaboration

Social Collaboration (corresponding to WP5 solutions).

ID	Requirement Source	Priority	Requirement
U1SC_R1	**Robot transparency** **U1**St_**R5**	high	Robot has to communicate its impending activities (kinetics, start / end actions, input requirements, error / disturbance alerts, etc.
U1SC_R2	**Error analysis** **U1**St_**R5**		Robot must indicate where errors occur but operator must remain responsible for analysis of criticality and final decisions
U1SC_R3	**Robot motion and speed** **U1**St_**R8**	High	Robot movements should be as smooth as possible and approach the user / shared task at an optimal speed for maintaining human trust
U1SC_R4	**Function allocation** **U1**St_**R2** & **U1**St_**R2**	high	The robot should be allocated monotonous activities to reduce operators' physical strain; operators should retain craft-based tasks and allocated supervision activities.
U1SC_R5	**Human supervision** **U1**St_**R5**	low	Operators must be able to input specific instructions or override/correct robot motion/behaviour.
U1SC_R6	**Teaching by demonstration** **U1**St_**R4**	high	Interface design must be user-centred and enhance usability to enable users to teach by demonstration

Table 10: System-level requirements specification for software

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

4.2.1. Stakeholder Requirements

ID	Category	Priority	Criterion	Specification
U2St_R1	Functional	Must	Operational	The system must get the information it requires (eg. chip type) and display it in UI

U2St_R2	Functional	Must	Operational	The system must automatically recognize middle of the chip using AI
U2St_R3	Functional	Would	Manipulability	The system would have robotic arm to pick and place chip on the table
U2St_R4	Functional	Should	Manipulability	The gipper should be safe for semiconductors.
U2St_R5	Functional	Should	Perception	The robotic arm equipped with low force sensor to prevent crumpling/crashing chips
U2St_R6	Functional	Would	Perception	The robotic arm equipped with RGBD to locate chips before process
U2St_R7	Functional	Must	Operational	The system must have full traceability of product, LOT ID reading, etc.
U2St_R8	Functional	Should	Operational	Communication with MES, operational time, parameters, LOT ID, other parameters to be saved in MES
U2St_R9	Constraint	Must	Safety	All solution must comply with the machinery directive and do not harm the operator
U2St_R10	Constraint	Must	Other	The system must comply with Clean Room ISO 8 requirements
U2St_R11	Functional	Would	Operational	The system would have a measurement station for machined chips to measure centricity and

				height after machining process.
U2St_R12	Functional	Would	Perception	The measurement station could measure height by vision or by contact sensor
U2St_R13	Functional	Should	Operational	The system should be able to manage priority of operations base on operator presence in working areas.
U2St_R14	Functional	Would	Operational	The system would have station for inverting chip - 90 or 180 degree when the active surface of chip hidden in the box

Table 11 Stakeholder requirements

4.2.2. System level requirements specification for hardware

ID	Requirement Source	Priority	Requirement
U2H_R1	**Robot System General**		
U2H_R1.1	U2**St**_R1	High	The robot must be able to connect to the services necessary to obtain the date and time
U2H_R2	**Manipulator**		
U2H_R2.1	General		
U2H_R2.1.1	U2**St**_R3	High	6-axis collaborative manipulator robots with payload less than 1kg and a minimum reach of 300 mm.
U2H_R2.2	Gripper		
U2H_R2.2.1	U2**St**_R4, U2St_R5	High	A tool that can be mounted on the manipulator robot and used to pick single chip (i.e. Innocise Gekomer or vacuum suction cup)
U2H_R2.2.2	U2**St**_R4, U2St_R5	High	A tool that can be mounted on the manipulator robot

			and is able to pick pins dia. 1 mm, 1.6 mm and 2,5 mm
U2H_R2.3	Perception Sensors		
U2H_R2.3.1	U2**St**_R4, U2St_R5	High	Force sensor to detect contact with chip, force range 0-1N/0-2N
U2H_R2.3.2	U2**St**_R6	High	RGDB camera with high resolution, i.e. Intel® RealSense™ Depth Camera D405 or something better
U2H_R3	**Infrastructure**		
U2H_R3.1	U2St_R7, U2**St**_R8	High	Connectivity to network time services, IT (MES/ERP)
U2H_R3.2	U2**St**_R1, U2St_R6	High	The Cobot shall be equipped with at least 1 communication port. (Ethernet, wifi)
U2H_R3.3	U2**St**_R1, U2St_R6	High	The physical layer should have a bandwidth of 1 GB for wired network.
U2H_R3.4	U2**St**_R6, U2St_R8	High	The physical layer should have a latency < 5 ms for the wired and <20 ms for wireless network.
U2H_R3.5		Low	Wireless suspended ambient
U2H_R3.6		Medium	Wireless devices must be able to operate for extended periods without the need for battery replacement or other maintenance.
U2H_R3.7	U2**St**_R8, U2St_R6	Medium	Capability to obtain real-time data from the process control area at line and workstation level.
U2H_R3.8	U2**St**_R1	High	The communication system must allow for remote access to industrial devices and equipment from external locations, enabling

			remote monitoring and control of AI-PRISM components.
U2H_R4	**Perception Sensors**		
U2H_R4.1	U2**St**_R2, U2St_R6	High	High resolution RGB/GrayScale cameras (1 for positioning before glueing and quality check i active surface - expected resolution of measurement 1 um, 1 to measure height of shapped chip, 1 to measure centricity of machining, 1 static camea to measure dimension of pin with glue)
U2H_R4.2	U2**St**_R9	High	Safety devices to detect presence in working area
U2H_R5	**Equipment**		
U2H_R5.1	U2**St**_R6	High	The illumination of the environment must be controlled, for which light panels are needed.
U2H_R5.2	U2**St**_R14, U2St_R3	Medium	A PLC is needed to control the different elements of the system.
U2H_R5.3	U2**St**_R2	Medium	XY piezodrive for positioning before glueing + XY electric adjustable microdrive for positioning chip in the center of FOV at measurement station
U2H_R5.4	U2**St**_R1	Medium	Comsumer Tablet (programming robot, manipulation ….)
U2H_R5.5	U2**St**_R1	Medium	Operator Tablet/static monitor for control current process
U2H_R5.6	U2**St**_R7	High	QR readers for traceability

Table 12: System-level requirements specification for hardware

4.2.3. System level requirements specification for Human-Robot Collaboration

Human-Robot Collaboration (corresponding to WP3 solutions),

ID	Requirement Source	Priority	Requirement
U2HR_R1	U2**St**_R9	High	The system must alert the operator if there is an error during an operation/communication with MES
U2HR_R2	U2**St**_R9	High	The system must alert the operator when it has finalised an operation step that requires manual intervention
U2HR_R3	U2**St**_R9, U2St_R1	High	The system must provide user interfaces to monitor performance indicators for the current production process (i.e. mean cycle time, cycle time histogram, read LOT ID, list of LOTs done, OEE, process step, recognized type of chip, measured parameters of chips and pins and other KPIs)
U2HR_R4	U2**St**_R13, U2St_R8	High	The system must be able to model and store the sequence of movements performed by the operator during cobot training
U2HR_R5	U2**St**_R9, U2St_R1	Medium	User interfaces must provide visual alerts to warn users of errors
U2HR_R6	U2**St**_R1	Medium	User interfaces must be responsive and adapt to different end user devices
U2HR_R7	U2**St**_R9	High	The system must indicate when human detected in working area

Table 13: System-level requirements specification for software

4.2.4. System level requirements specification for AI enhancing tools

AI enhancing tools (corresponding to WP4 solutions)

ID	Requirement Source	Priority	Requirement
U2AI_R1	U2**St**_R2, U2St_R6, U2St_R3	High	Motion control functionalities based on vision to set the chip in proper position
U2AI_R2	U2**St**_R11, U2St_R12	High	The system must be able to detect the properties of the chip, size, edges, orientation, defects and dimensions of active areas.

U2AI_R3	U2**St**_R2	High	The system must be able to adapt and operate with new design of patterns on chip surface - human accept and correct the result at the early stage of production
U2AI_R4	U2**St**_R2, U2St_R14	High	Functionalities for recognizing chips (cube shape and lens shape) in random orientation and algorithms what calculate the grasping Point
U2AI_R5	U2**St**_R2, U2St_R11, U2St_R12	High	The system must be able to measure height and centricity of machined chip with resolution of 1 um
U2AI_R6	U2**St**_R2, U2St_R11, U2St_R12	Medium	The system should be able to measure of pin diameter
U2AI_R7	U2St_R11, U2St_R12	Medium	The system should be able to control amount of glue on pin, put by operator
U2AI_R8	U2**St**_R9	High	The system must have safety robot recovery strategies.
U2AI_R9	U2**St**_R9	High	The system must be able to detect any human in the collaboration ambient, their position and distance to the robot and their movements
U2AI_R10	U2**St**_R2, U2St_R14	Low	Virtual twin/Simulation enviroment for testing AI with new patterns on chips

Table 14: System-level requirements specification for software

4.2.5. System level requirements specification for Social Collaboration

Social Collaboration (corresponding to WP5 solutions).

ID	Requirement Source	Priority	Requirement
U2SC_R1	U2**St**_R2	high	Workload reduction - reduce time operator focuses on screen
U2SC_R2	U2**St**_R13	medium	Better ergonomic design of workspace
U2SC_**R3**	**Error analysis** U2**St**_R7	low	Robot should indicate where errors occur but operators should retain responsibility for quality control checks, analysis of criticality and final decisions.

Table 15: System-level requirements specification for software

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

4.3.1. Stakeholder Requirements

ID	Category	Priority	Criterion	Specification
U3St_R1	Functional	Must	Operational	The cobot or cobots must lift from a palette sacks of powder and place them upon a conveyor for further processing
U3St_R2	Functional	Must	Operational	The cobot(s) must choose pallet of material from different pallets
U3St_R3	Functional	Must	Manipulability	The cobot(s) must lift the bottle to identify it
U3St_R4	Functional	Must	Perception	The cobot(s) must identify the brands of returnable bottles
U3St_R5	Functional	Must	Operational	The cobot(s) must put the identified bottle to the corresponding crate
U3St_R6	Functional	Must	Manipulability	The cobot(s) must stick a sticker on top of bottles & cans intended for export
U3St_R7	Functional	Must	Perception	The cobot(s) must initiate the cleaning procedure
U3St_R8	Functional	Must	Operational	The cobot(s) must return to base for emptying the debris
U3St_R9	Functional	Must	Safety	The cobot(s) must pass through the cleaning area without disturbing people

U3St_R10	Functional	Must	Operational	The cobot(s) must receive instructions from SAP/invoice on the exact containers of the pallet quantity/SKU when packaging and palletizing of custom orders
U3St_R11	Functional	Must	HRC	The cobot(s) must assist the operator when packaging and palletizing of custom orders by doing the lifting/moving of the crates

Table 16 Stakeholder requirements

4.3.2. System level requirements specification for hardware

ID	Requirement Source	Priority	Requirement
U3H_R1	Robot System General		
U3H_R1.1	Operating environment and design		
U3H_R1.1.1	**U3St_R2**	High	The system shall work in the environmental temperatures between 20 and+35 deg C
U3H_R1.1	U3St_R1	High	The cobot(s) must be able to lift and place sacks of 22,7kg of the powder
U3H_R1.2	U3St_R1	High	The cobot(s) must put the sacks in a height from the conveyor not more than 20-30cm, otherwise, the sack with be destroyed
U3H_R1.3	U3St_R1	High	The cobot(s) must repeat step at least 20sec away from each other

U3H_R1.4	U3St_R11	High	The cobot(s) must be able to lift and move crates of about 11kg
U3H_R2	Manipulator		
U3H_R2.1	General		
U3H_R2.1.1	U1St_R6	High	The cobot(s) must have a manipulator to take out of the sheet a sticker and put the sticker down to the bottles & cans
U3H_R2.3	Gripper		
U3H_R2.3.1	U3St_R3	High	The cobot(s) must have a gripper to lift different bottles
U3H_R2.3.2	U3St_R6	High	The cobot(s) must have a gripper to hold a stickering gun for stickering
U3H_R3	Network Infrastructure		
U3H_R3.1	U3St_R10	High	The cobot(s) must support 4G connectivity to receive instructions from SAP/invoice (when required) when packaging and palletizing of custom orders

Table 17: System-level requirements specification for hardware

4.3.3. System level requirements specification for Human-Robot Collaboration

Human-Robot Collaboration (corresponding to WP3 solutions),

ID	Requirement Source	Priority	Requirement
U3HR_R3	Robot Manipulation		
U3HR_R3.2	Path Planning		
U3HR_R3.2.1	U3St_R11	High	The cobot(s) must be able to move the

			crates from palette to palette (distance around 1-2 metres)

Table 18: System-level requirements specification for software

4.3.4. System level requirements specification for AI enhancing tools

AI enhancing tools (corresponding to WP4 solutions)

ID	Requirement Source	Priority	Requirement
U3AI_R1	Scene Perception		
U3AI_R1.1	General		
U3AI_R1.1.1	U3St_R7	High	The cobot(s) must scan the cleaning area for debris
U3AI_R1.1.2	U3St_R9	High	The cobot(s) must always be aware of surroundings when pass through the cleaning area
U3AI_R1.2	Object Detection		
U3AI_R1.2.1	U3St_R4	High	The cobot(s) must identify the volume of the bottle by judging the height of the bottle versus the crate in front of it, even before lifting it (smaller volume, shorter bottle)
U3AI_R1.2.2	U3St_R4	High	The cobot(s) must identify the brand of the bottle by its different shape & color
U3AI_R2	High Level Decision Maker		
U3AI_R2.1	General		
U3AI_R2.1.1	U3St_R7	Must	The cobot(s) must decide when the accumulation of debris is at a critical

			point so as to initiate the cleaning process

Table 19: System-level requirements specification for software

4.3.5. System level requirements specification for Social Collaboration

Social Collaboration (corresponding to WP5 solutions).

ID	Requirement Source	Priority	Requirement
U3SC_R1	physical discomfort U3St_R1, U3St_R11	high	removal of parts of the process where humans are either: (A) experiencing high physical strain - lifting full crates of bottles, bags of powder (22.7 kg), (B) experiencing physical discomfort - lifting bottles which might have remaining water in them, (C) there is potential of injury - bottles breaking, glass cutting hands, (D) being exposed to dangerous materials - needing to handle bags of powder with potential harmful impact on their long term health
U3SC_R2	Safety U3St_R1, U3St_R3, U3St_R5, U3St_R6	high	reduction of handling materials by hand which are not dry and spilling water on themselves. reduction of instances where the user is dealing with the materials which could have potential impact on their health
U3SC_R3	self-efficacy U3St_R7, U3St_R11	High	Operators should retain responsibility for error and quality checks, analysis of criticality and final decisions.

Table 20: System-level requirements specification for software

4.4. Use Case 4: Adaptable & Collaborative Workstation

4.4.1. Stakeholder Requirements

ID	Category	Priority	Criterion	Specification
U4St_R1	Functional	Must have	Perception	The system shall inspect the hoods to detect defects while the cover of the product is open.
U4St_R2	Functional	Must have	Operational	The system shall pack the cable.
U4St_R3	Functional	Must have	Operational	The system shall stick the packed cable.

U4St_R4	Functional	Must have	Operational	The system shall conduct tests.
U4St_R4.1	Functional	Must have	Operational	The system shall conduct grounding tests while the cover of the product is open.
U4St_R4.2	Functional	Must have	Operational	The system shall conduct functional tests while the cover of the product is open.
U4St_R5	Functional	Must have	Operational	The system shall place the metal label inside the product.
U4St_R6	Functional	Must have	HRC	The system shall filter assembling. and the cobot shall to assist the operator by doing the manipulation of hood body.
U4St_R7	Functional	Must have	Mobility	The system shall bag the product process.
U4St_R8	Functional	Must have	Mobility	The system shall put barcode labels and documents near the product.
U4St_R9	Constraint	Must have	Perception	The inspection of the product shall take at most 12 seconds.
U4St_R10	Constraint	Must have	Perception	Making inspection is according to technical specifications
U4St_R11	Constraint	Must have	Operational	The grounding test of the product shall take at most 13 seconds.
U4St_R12	Constraint	Must have	Operational	The grounding test is ok/ ko

U4St_R13	Constraint	Must have	Operational	The functional test of the product shall take at most 17 seconds.
U4St_R14	Constraint	Must have	Operational	ok/ ko lighting lamp
U4St_R15	Constraint	Must have	Perception	ok/ko engine functional levels
U4St_R16	Constraint	Must have	Perception	ok/ko perception of button
U4St_R17	Constraint	Must have	Operational	ok/ko exhausting level of product (hood)
U4St_R18	Constraint	Could	Operational	The packing time is at 5 seconds
U4St_R19	Constraint	Could	Operational	Sticking of packed cable is at 7 seconds
U4St_R20	Constraint	Could	Operational	Placing the metal label inside the product is at 7 seconds
U4St_R21	Constraint	Must have	HRC	Assembling filter is at 6 seconds.
U4St_R22	Constraint	Could	Mobility	Bagging the product is at 11 seconds
U4St_R23	Constraint	Must have	Mobility	Putting the barcode labels and documents near the product are at 4 seconds
U4St_R24	Functional	Would	assessment	The system shall estimate human status
U4St_R25	Functional	Must have	Operational	The robot shall work into the closed working environment
U4St_R26	Functional	Must have	Operational	The robot shall work with human operators in the

				same working environment
U4St_R27	Functional	Would	Manipulability	The cobot(s) has to lift the hood from the conveyor to work station and between two different work stations

Table 21 Stakeholder requirements

4.4.2. System level requirements specification for hardware

ID	Requirement Source	Priority	Requirement
U4H_R1	Robot System General		
U4H_R1.1	Operating environment and design		
U4H_R1.1.1	U4St_R25	High	The cobot must work into the closed working environment
U4H_R1.1.2	U4St_R27 – U4St_R6	High	The cobot has to lift the hood with the weight approx. 10-12 kg
U4H_R1.1.3	U4St_R26	High	The cobot has to move the lifted hood approx. 2-3 meters between the work stations.
U4H_R2	Manipulator		
	TBD		
U4H_R2.3	Gripper		
U4H_R2.3.1	U4St_R8	High	The system shall use gripper to put documents near the product.
U4H_R2.3.2	U4St_R8	High	The system shall use gripper to put barcode labels near the product.

U4H_R2.3.3	U4St_R13	Medium	The gripper should interact with touch screen.
U4H_R2.3.4	U4St_R13	High	The gripper must be able to turn on and turn off screen.
U4H_R2.3.5	U4St_R20	High	The gripper should insert a paper or metal sheet inside the screen.
U4H_R2.3.6	U4St_R4.2, U4St_R11, U4St_R12	High	The gripper should be able to unplug power supply.
U4H_R2.3.7	U4St_R8 - U4St_R23	Medium	The gripper should be able to place a reference plate close to the screen.
U4H_R2.3.8	U4St_R3, U4St_R19	High	The gripper should stick power supply cable to the screen using tape.
U4H_R2.3.9	U4St_R2	High	The gripper should bend the power cable to the screen using tape.
U4H_R2.3.10	U4St_R8 - U4St_R23	Medium	The gripper shall scan the barcode written on a paper.
U4H_R2.3.11	U4St_R7	Low	The gripper shall open a plastic bag so that the screen is placed into the bag.
U4H_R3	Network Infrastructure		
U4H_R3.1	Derived	High	The robot shall be equipped with Ethernet switch for min. 1 ports
U4H_R3.2	Derived	High	The physical layer should have a minimum bandwidth of 512 Mbps

U4H_R3.3	Derived	High	The robot should be equipped with a router with GSM module
U4HR4	Perception Sensors		
U4H_R4.1	U4**S**t_R1, U4**St**_R9, U4**St**_R10	High	The system shall utilize industrial optic camera data of the product's surface in order to inspect defects in at most 12 seconds and in compliance to technical specifications.
U4H_R4.1.1	U4**St**_R1, U4**St**_R9, U4**St**_R10	High	The RGBD Camera in the system (static Camera System) shall provide images of the product's surface to the AI service that will perform inspection.
U4H_R4.1.2	U4**St**_R1, U4**St**_R9, U4**St**_R10	High	The system shall include one or more High Resolution Gray Scale Camera and lens (static Camera System)
U4H_R4.1.3	U4**St**_R1, U4**S**t_R9, U4**St**_R10	High	The system shall include an illumination pane, for controlled illumination.
U4H_R4.1.4	U4**St**_R1, U4**St**_R9, U4**St**_R10	Medium	The system may utilize cables to connect camera to the network.
U4H_R4.1.5	U4**St**_R1, U4**St**_R9, U4**St**_R10	Low	The system may need additional hardware equipment.
U4HR5	Human Monitoring		
U4St_R5.1	U4**St**_R24	Low	The human monitoring system may need two RGB cameras.

U4St_R5.2	U4**St**_R24	Low	The human monitoring system may need one or more wearable physiological sensor.
U4St_R5.3	U4**St**_R24	Low	The human monitoring system need computing hardware (PC).
U4St_R5.4	U4**St**_R24	Low	The human monitoring system needs Human Machine Interface (display).

Table 22: System-level requirements specification for hardware

4.4.3. System level requirements specification for Human-Robot Collaboration

Human-Robot Collaboration (corresponding to WP3 solutions),

ID	Requirement Source	Priority	Requirement
U4HR_R1	Human Robot Interactive Interfaces		
U4HR_R1.1	General		
U4HR_R1.1.1	U4St_R1	High	The system shall be capable of modelling and storing the series of actions taken by the operator during cobot training.
U4HR_R1.1.2	U4St_R1	Medium	User interfaces must respond to user input and change to fit various end user devices.
U4HR_R1.2	Human Visual Interface		
U4HR_R1.2.1	U4St_R9, U4St_R11, U4St_R13, U4St_R18, U4St_R19, U4St_R20, U4St_R22, U4St_R23	High	The system shall be work flawlessly by completing the tasks within the specified time constraints.
U4HR_R3	Robot Manipulation		

U4HR_R3.1	General		
U4HR_R3.1.1	U4St_R24, U4St_R25, U4St_R26, U4St_R1	High	The system shall plan and control to ensure robot operability.
U4HR_R3.2	Path Planning		
U4HR_R3.2.1	U4St_R6, U4St_R25, U4St_R27	High	The cobot(s) must calculate relative positions of the conveyor and workstations
U4HR_R3.3	Grasping		
U4HR_R3.3.1	U4St_R27, U4HR_R3.2.1	High	The robot shall grasp and hold the hood to move.

Table 23: System-level requirements specification for software

4.4.4. System level requirements specification for AI enhancing tools

AI enhancing tools (corresponding to WP4 solutions)

ID	Requirement Source	Priority	Requirement
U4AI_R1	Scene Perception		
U4AI_R1.1	U4St_R24	High	The cobot(s) must always be aware of their surroundings when passing through the working area
U4AI_R1.2	U4St_R24, U4St_R1	High	Inspection functionalities based on vision to determine the defect in proper position
U4AI_R1.3	U4St_R24, U4St_R1	High	The system must be able to detect the properties of the label, it's size, edges orientation, defects and dimensions
U+AI_R1.2	Object Detection		
U4AI_R1.2.1	U4St_R1, U4St_R9, U4St_R10, U4H_R4.1	High	The cobot shall learn to detect defects.

U4AI_R1.2.2	U4**St**_R1, U4**St**_R9, U4**St**_R10, U4**H**_R4.1.1	High	The AI shall utilize camera data.
U4AI_R3	Human Monitoring		
U4AI_R3.1	U4St_R24	Low	The system should be able to acquire the worker's face images by the camera.
U4AI_R3.1	U4St_R24	Low	The system should be able to acquire a full-body images of the back of the worker by the camera.

Table 24: System-level requirements specification for software

4.4.5. System level requirements specification for Social Collaboration

Social Collaboration (corresponding to WP5 solutions).

ID	Requirement Source	Priority	Requirement
U4SC_R4	Human Monitoring		
U4SC_R4.1	U4St_R24	Low	The system should be able to visualize and provide robot status information to the operator.
U4SC_R4.2	U4St_R24	Low	The system should be able to infer joint points from full-body images of the worker captured by the camera.
U4SC_R4.3	U4St_R24	Low	The system should be able to acquire the worker's physiological information in real-time.

Table 25: System-level requirements specification for software

4.5. Use Case 5: Generic Demonstrator

4.5.1. Stakeholder Requirements

ID	Category	Priority	Criterion	Specification
U5St_**R1**	Functional	Must have	Perception	System should recognize multiple PCBs.
U5St_**R2**	Functional	Should have	Perception	Some overlap with PCBs should be handled by the perception.
U5St_**R3**	Functional	Must Have	Grasping	Stable grasping of PCBs.

U5St_**R4**	Functional	Must Have	Interface	Interface for Non-expert to configure a grasping process to the robot.
U5St_**R5**	Functional	Must Have	Manipulation/ Perception	Manipulation correction of the grasped PCB so that the next step in the process can be achieved.
U5St_**R6**	Functional	Could Have	Manipulation / Perception	Efficient non-overlapping PCB placement (bin-packing).
U5St_**R7**	Functional	Must Have	Manipulation / Perception	Deposit the PCB into the testing adapter for testing the PCB.
U5St_**R8**	Functional	Must Have	Interface	Configuration of the process flow using interactive and natural interfaces.
U5St_**R9**	Functional	Must Have	Operational	Recovery Strategies for recovering from robot process failures or incomplete task execution.
U5St_**R10**	Functional	Could Have	Manipulation	The robot system, what is responsible for the PCB handling can be easily applied on similar locally separated workstations.
U5St_**R11**	Constraint	Must Have	Operational	The PCB size (maximum allowable) should allow stable manipulation with one flow gripper.
U5St_**R12**	Constraint	Must Have	Operational	The temperature in the use case facility should be constant (+- 2C)
U5St_**R13**	Normative	Could Have	Safety	The robot application should meet the normative requirements for collaborative robots according to ISO/TS 15066:2016.

Table 26 Stakeholder requirements

4.5.2. System level requirements specification for hardware

ID	Requirement Source	Priority	Requirement
U5H_R1	Robot System General		

U5H_R1.1	Operating environment and design		
U5H_R1.1.1	derived	High	The system shall work in the environmental temperatures between 20 and+35 deg C
U5H_R2	Manipulator		
U5H_R2.1	General		
U5H_R2.1.1	derived	High	6-axis collaborative manipulator robots with a minimum payload of XX kg and a minimum reach of XXXX mm. For PCB manipulation.
U5H_R2.1.2	U5St_R9	Medium	Autonomous Mobile Robot (AMRs).
U5H_R2.3	Gripper		
U5H_R2.3.1	U5St_R11	High	A gripper capable of holding printed circuit boards (PCBs) of various sizes and weights, whether or not they have components attached to them.
U5H_R3	Network Infrastructure		
U5H_R3.1	derived	High	The cobot shall be equipped with at least 1 communication port. (Ethernet, wifi)
U5H_R3.2	derived	High	The physical layer should have a bandwidth of 1 GB for wired network.
U5H_R3.2	derived	High	Router/Switch
U4HR4	Perception Sensors		
U4H_R4.1	U5St_R1, U5St_R2, U5St_R3, U5St_R4, U5St_R6	High	RGBD Camera on end effector, for Human cantered teach-in-process and grasping process.
U4H_R4.2	U5St_R6	High	A grayscale camera with a high resolution and a suitable lens for pose correction system.
U4H_R4.2	U5St_R6	High	RGBD Camera for pose correction system.
U4H_R4.3	U5St_R6	High	Illumination panel for pose correction system.

U4H_R4.4	U5St_R7	High	Force Torque Sensor that can be attached to the flange of the robot.
U4H_R4.5	U5St_R8	High	A Microphone array for neural language module.
U4H_R4.6	derived	High	A visual sensor system designed for detecting human poses within the work area.
U4H_R4.7	derived	Medium	A DMC reader.
U4H_R5	Infrastructure		
U4H_R5.1	U5St_R8	High	Consumer Tablet
U4H_R5.2	derived	High	Multiple digital and analog I/O channels
U4H_R5.3	U5St_R5	High	Industrial vacuum
U4H_R5.4	derived	High	Edge device / Edge AI
U4H_R5.5	U5St_R8	High	Training platform

Table 27: System-level requirements specification for hardware

4.5.3. System level requirements specification for Human-Robot Collaboration

Human-Robot Collaboration (corresponding to WP3 solutions),

ID	Requirement Source	Priority	Requirement
U5HR_R1.1	General		
U5HR_R1.1.1	U5St_R8	High	Natural Human Robot Interfaces: e.g.: Hand guiding, joystick
U5HR_R1.2	Speech to Text functionalities		
U**5**HR_R1.2.1	U5St_R8	Medium	Natural language User Interfaces
U5HR_R1.3	Graphical User Interface		
U5HR_R1.3.1	U5St_R8	High	Intuitive UI for different Platforms

Table 28: System-level requirements specification for software

4.5.4. System level requirements specification for AI enhancing tools

AI enhancing tools (corresponding to WP4 solutions)

ID	Requirement Source	Priority	Requirement
U5AI_R1	Scene Perception		
U5AI_R1.1	General		

U5AI_R1.1.1	derived	Medium	Capabilities related to the detection of human poses within a workspace.
U5AI_R1.2	Object Detection		
U5AI_R1.2.1	U5St_R1, U5St_R2	High	Capabilities for detecting multiple printed circuit boards (PCBs) and algorithms that compute the gripping point, which is determined by the human-centered teach-in process.
U5AI_R1.2.2	U5St_R8	Medium	Capabilities for suggesting gripping points for a new PCB.
U5AI_R1.2.3	U5St_R5	High	Capabilities for computing an accurate correction transformation for the PCB that is currently being gripped.
U5AI_R1.2.4	U5St_R5	Medium	Virtual Twin of PCB
U5AI_R2	High Level Decision Maker		
U5AI_R2.1	General		
U5AI_R2.1.1	U5St_R9	Medium	Robot behavioural functionalities configuration and execution periods, which including recovery strategies.

Table 29: System-level requirements specification for software

4.5.5. System level requirements specification for Social Collaboration

Social Collaboration (corresponding to WP5 solutions).

ID	Requirement Source	Priority	Requirement
U5SC_**R1**	self-efficacy U5**St**_R1, U5**St**_R5, U5**St**_R7, U5**St**_R10	high	operators need to be the supervisors of the robotic processes, and be final decision-makers, ie. need to choose from several PCB handling suggestions
U5SC_**R2**	physical discomfort U5**St**_R4, U5**St**_R8	high	robot process and action planning should eliminate monotonous actions by human to reduce physical strain. The aspects of the task requiring expertise need to remain.
U5SC_**R3**	time pressure U5**St**_R9, U5**St**_R10, U5**St**_R13	medium	robot needs to indicate to the user where potential errors occurred. human must remain final decision maker deciding if the

			error/fault/defect is critical or within the tolerance limits

Table 30: System-level requirements specification for software

5. Conclusion

The present deliverable reports the efforts done in the scope of the T1.3 and T1.4 of the AI PRISM project toward the definition of the use cases and the requirement analysis specifications of the AI PRISM system. On the basis of the user requirements and use cases and, after clarifying the overall system purpose and perimeter, a functional analysis of the AI PRISM system was performed towards identifying the necessary requirements (Hardware, Human Robot Collaboration aspects, the required AI Enhancing tools and the social collaboration aspects) that should be established in respect to each use case and related user requirements. For each of these requirements, a preliminary analysis followed, which will be further improved upon in M12 in the D1.3 Use cases scenarios and requirements analysis (II).

This work allowed the consortium to elaborate the requirement, hardware, and software requirements on the basis of user requirements and foreseen use cases. It also enabled to prioritize the functional (and non-functional) requirements and subsequently the technical specifications (which will be dealt in detail in D2.2) that should be implemented, by building upon the prioritization of user requirements and use cases. On the basis of this set of prioritized functional specifications, the implementation plan of the AI PRISM project shall build upon (awaiting further improvements in D1.3), toward ensuring both that high priority use cases will be the first ones to be addressed from the project developments, as well as that project developments will maintain a clear orientation toward the most important user needs and expectations.

Finally, it should be stated that although the present deliverable has been drafted according to the AI PRISM DoA in the first six months of the project, the hardware components and their specifications will remain an open issue until all components and subsystems are built and all modules have been integrated to establish the final, AI PRISM robotic platform. In the following, the deliverable D1.2 will serve as the basis for further system developments. Specifically, the hardware development is starting with several feasibility studies in order to deliver the first version of the AI PRISM robotic platform according to the plan drafted within DoA. This deliverable will be further improved upon in its second version in the D1.3 Use cases scenarios and requirements analysis (II) in M12.

ANNEX A: Font and colours used in this document

- **Font**

  Arial

  Open Sans: https://fonts.google.com/specimen/Open+Sans

- **Colours**

  Dark blue: #01547E

  Light blue: #4CEEF2

  Light blue: #DEEBF1

  Grey: #606060

AI-PRISM