Handling with AI-enhanced Robotic
Technologies for flexible ManUfacturing

D1.2
Initial setup of real world scenarios

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HARTU Consortium

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Executive Summary

In line with the user-centred and industrial driven approach followed by the HARTU project, the consortium has implemented an initial set of demonstrators as part of this strategy. The objectives are:

- To create the setups for an iterative and incremental integration-test-redesign process
- To have demonstrators where data acquisition campaigns can be carried out. This includes data for technical developments, but also to gather users feedback from the early stages of system building.

A total of 11 prototypes are available, corresponding to the 8 use cases defined by the project. The broad spectrum of demonstrators includes robots and vision cameras of different brands (i.e., KUKA, FANUC, UR, OMRON robots or Photoneo and Zed2i cameras), which will ensure that the solutions are not hardware specific.

The document includes also the methodology that is used for the User Research, as well as the initial insights on this topic which are the result of the literature review and the various workshops that have been held in the first 10 months of the project with different stakeholders from the 5 Industrial companies offering the validation scenarios. Finally, Legal and Ethical aspects that have to be considered are presented.

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1 Table of contents

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List of figures

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List of tables

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Acronyms

List of the acronyms	
HARTU	Handling with AI-enhanced Robotic Technologies for flexible manufactUring

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1 Introduction

HARTU intends to deploy new technologies in a number of relevant industrial use-cases. Deliverable 1.1 documented the following scenarios in detail:

Use-case	Industrial scenario	Sector
TOFAS: • UC1 – Spare parts delivery preparation • UC2 – Kitting and pre-assembly ○ UC2a - Kitting ○ UC2b – Pre-assembly	Manufacturing line Logistics operation	Automotive Automotive
PCL: • UC3 – Handling for mass customization in the consumer good sector	Manufacturing line	Household appliances
TCA: • UC4 – Packaging operation in food sector	Manufacturing line	Food processing
INFAR: • UC5 – Fixtureless assembly in hand tool manufacturing sector	Manufacturing line	Hand tool manufacturing
ULMA • UC6 – Pallet to pallet order preparation • UC7 – Box to box order preparation	Logistics operation Logistics operation	Logistics Logistics

This report provides an overview of the current state of the prototypes. At the time of writing, the initial prototypes are ready to start integrating HARTU results, implement a set of functionalities and enable data acquisition campaigns to begin.

In addition, the document includes an update on the results of the first 10 months of research on SSH related issues.

In the first part of this document, the use-case demonstrators will be described on a case-by-case basis. Each use case section will follow a similar structure:

- **Section x.1: Use case description** – First, a recap of the use case will be provided for this document to be self-contained.
- **Section x.2: Prototype setups** – An overview of the different systems being employed for data acquisition.

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Section 3: **Risk assessment** is an update of the Risk assessment introduced in D1.1

SSH aspects of HARTU use-cases are presented in sections 4 and 5.

- **Section 4** User research in HARTU's Use-cases
- **Section 5** Ethical and Legal aspects

2 Overview of the first prototypes overview

Initial prototypes have been built at the premises of different end-users and technology providers for data acquisition campaigns and to start integrating partial results.

	Prototypes:					
Use-cases:	TEK	DFKI	AIMEN	PCL	INFAR	ULMA
TOFAS						
UC1 – Spare parts delivery preparation						
UC2 – Kitting and pre-assembly						
PCL						
UC3 – Handling for mass customization in the consumer good sector						
TCA						
UC4 – Packaging operation in food sector						
INFAR						
UC5 – Fixtureless assembly in hand tool manufacturing sector						
ULMA						
UC6 – Pallet to pallet order preparation						
UC7 – Box to box order preparation						

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2.1 TOFAS – UC1 – Spare parts delivery preparation

2.1.1 Use case overview

The spare parts delivery preparation process is divided into two sub-processes. The first is the input box preparation in the warehouse (left picture in Figure 1) and second is the order preparation in the workshop (Figure 2).

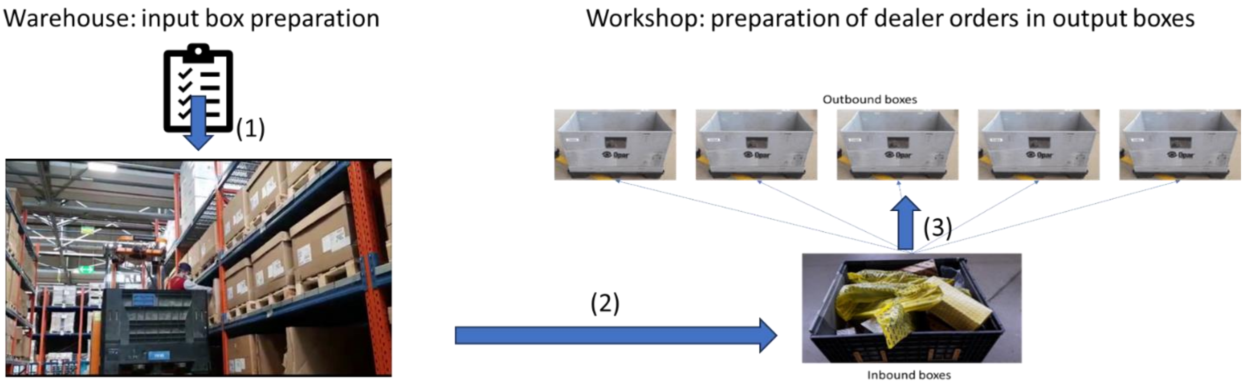

Figure 1. Input box preparation in the warehouse (1) and process overview (2)

Every day (Figure 1) (1) the warehouse operators receive a list of products that have to picked from the warehouse shelves to complete different orders for their dealers. The list consists of products of different sizes, shapes, and weights. The operators go through the warehouse on a fork-lift and an input box (2), take the products in the list and put them inside the box, without any particular order. Then, they go to the workshop and place the input boxes in front of the output boxes (3).

Once in the workshop (Figure 2), other operators (4) are in charge of taking the products one by one and identify them and the box with the barcode reader; then (5), they move to the corresponding output box as indicate by the barcode reader (connected to the Server through internal Wi-Fi system), identify the box with the reader and, finally, place them in the output box. They try to optimize the occupancy of the output box.

Figure 2. Order preparation at the workshop

Based on the experience gained in the Horizon 2020 PICKPLACE project this constraint is introduced:

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"Inbound boxes shall only contain products that come in cardboard boxes."

The current procedure includes the mixing of any kind of products in the same inbound box. This means that products in cardboard boxes, products in plastics bags and unpacked products are included in the same box. The presence of plastic bags of different characteristics represents a serious difficulty for grasping, either by vacuum or with 2-3 fingers, as there is no way of knowing the shape of the product inside and, depending on the plastic used, the vacuum doesn't work.

However, 60% of products come in carboard boxes. The conclusion in PICKPLACE was that by adapting the preparation procedure in the warehouse (carboard boxes in one inbound box and those coming in plastics bags and those unpacked in another), and creating a collaborative application on the preparation shopfloor, it was possible to achieve an efficient system.

Figure 3. Example of different plastic bags used for packaging

In this UC, it is proposed to use a mobile manipulator to handle the cardboard boxes and allow accessing multiple input and output boxes in a flexible way.

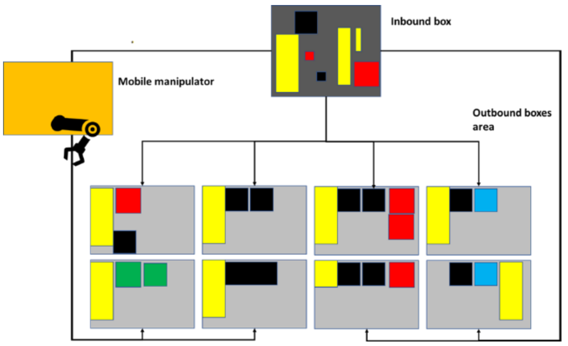

Figure 4. Layout of the proposed preparation area (TOFAS)

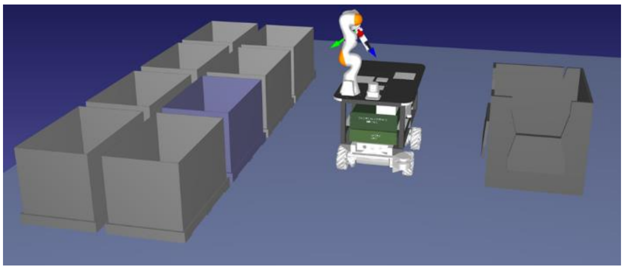

Figure 5. Simulation of TOFAS spare part order preparation scenario

The proposed approach will improve the working conditions for human operators, reduce the number of errors and increase the efficiency of the system.

A prototype will be created at TEK and, after integration and validation of the HARTU results, it will be delivered to the TOFAS plant in Bursa for final demonstration.

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2.1.2 Prototype at TEK

The demonstrator installed at TEK is a scaled-down version of the proposed overall system, due to the availability of physical space at the shopfloor.

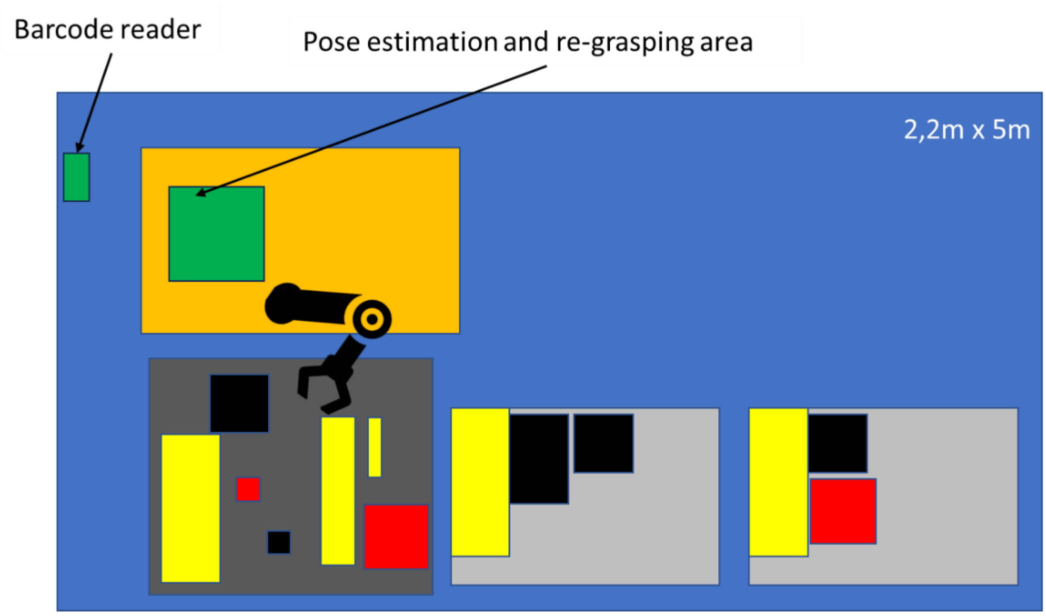

Figure 6. Scaled-down version of UC1 in TEK

Next picture shows the current UC1 prototype:

Figure 7. Initial UC1 prototype

The demonstrator consists of the following elements:

- Mobile platform: Segway RMP omnidirectional mobile + KUKA IIWA 14.
    - Dimensions of the base: (W x L x H) 788 X 1350 X 897.
- A ZED2i camera mounted on the end of arm.
- 2 Grippers.

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- One for small boxes.
- One for the biggest ones.

- Tool change station embarked on the robot for automatic tool change.
- Identification System.

All cardboard boxes have a barcode that has to be read to know the reference of the product inside the box and to be able to know which order it corresponds to. In addition, as it is requested to create a mosaic in the output box (it is not enough to drop the products), it is necessary to control the way the product has been grasped. To achieve these objectives:

- The robot will hold the carboard box 600mm above a barcode reader (model ZEBRA FS40-WA50F4-2100W) facing upwards.
- The robot will (1) leave the carboard box on the platform surface, (2) take a picture with the built-in camera, (3) estimate the pose and pick it up again.

Figure 8. Barcode reader

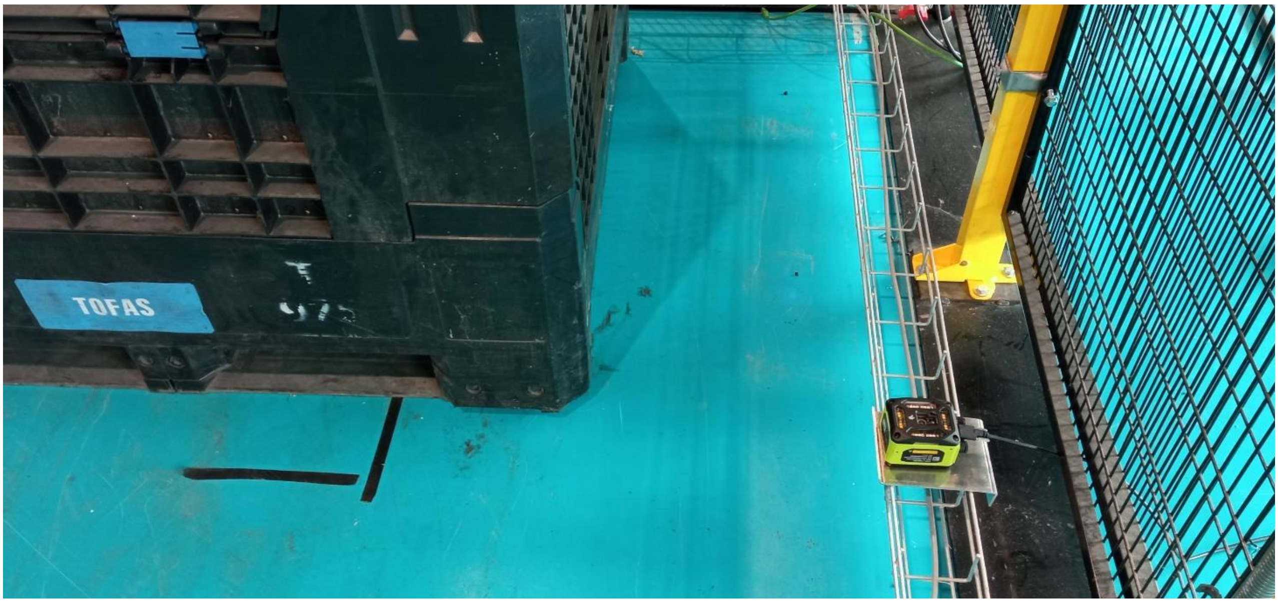

Figure 9. Barcode reader in the demonstrator

The sequence of actions in the demonstrator will be:

1. The robot generates an image of the input box (this is done only on the first iteration; for the rest, the image is taken in step 5).
2. Identifies the best candidate (based on the grasping points and the gripper on the arm).
3. If necessary, the robot changes the gripper.
4. Picks the object and places it 600 mm above the barcode reader.
5. The robot places the box on the platform surface and using the built-in camera, estimates the pose, and picks it up again. Before picking, it takes an image of the inbound box.

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6. The control system provides the destination box according to the order to which it corresponds, and the label read.
7. The robot picks the part and navigates to the destination output box.
8. The robot calculates the position inside the output box and executes the release.
9. The robot takes an image of the output box once the part has been released.
10. The robot navigates to the position of the input box.

(*) Step 5 can be executed during the navigation to the position of the output box.

(**) Steps 3 and 10 can be executed simultaneously.

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2.2 TOFAS – UC2a – Kitting in the automotive sector

2.2.1 Use case overview

This use case corresponds to the preparation of kits of components, an operation known as ‘kitting’ in the automotive sector. The subsequent pre-assembly step will be treated as a separate use case: UC2b pre-assembly at the corresponding assembly workstation.

In the kitting area, products are taken from containers/boxes in which they can be arranged in two main configurations: (1) Product-specific individual compartments (Figure 10); (2) Semi-structured configuration (Figure 11), forming layers that are separated by means of separators (cardboard or plastic); randomly distributed products (Figure 12) are not included in the kitting operation, but are managed by the operators at the assembly station.

Figure 10. Products in special compartments

Figure 11. Products in semi-structured configuration

Figure 12. Products randomly distributed

Components that must be included in the kit are placed in containers on one side of the preparation area, and the destination containers on the other side, as shown in the next pictures. The only exception is the discs, which are placed inside blue plastic boxes on a shelf near the conveyor belt.

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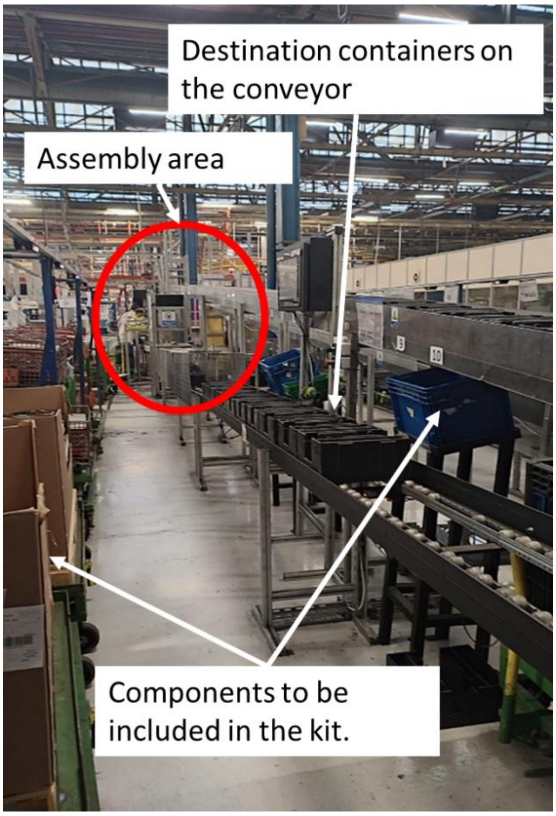

Figure 13. Kitting preparation area.

Figure 14. Destination containers on the conveyor. The blue boxes contain the discs

To start the preparation of kits, the operator presses the button in Figure 15 and 10 empty output containers arrive at the preparation area on the conveyor belt.

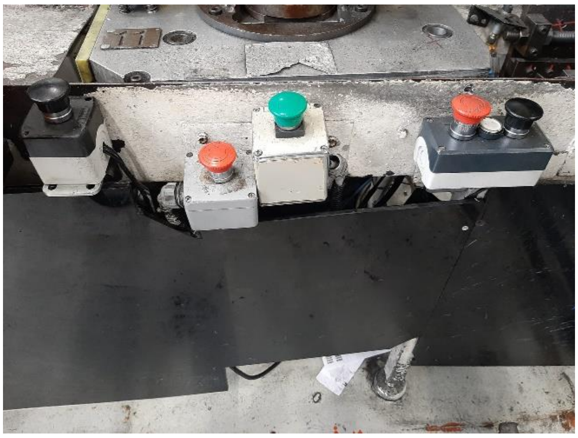

Figure 15. Push buttons to control the conveyor belt that transports the output containers

Figure 16. Pick to light device above each input container

Then, the operator starts the pick-and-place process: on top of each input container there is a pick-to-light device that shows the destination conveyor for each component (Figure 16). The operator takes the component, leaves it in the corresponding output box on the conveyor and acknowledges the action on the pick-to-light device.

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Finally, 10 paper forms are taken and introduced in each destination box, and the operator presses the button to transport the full containers on the conveyor belt to the assembly workstation (at the back of Figure 13).

Figure 17. Operator taking a component from the input container (left side). It will then put on the destination container (right side)

In this UC, it is proposed to use the same mobile manipulator as in UC1 to handle the products, as it provides a more flexible alternative to other solutions like a robot mounted on linear tracks.

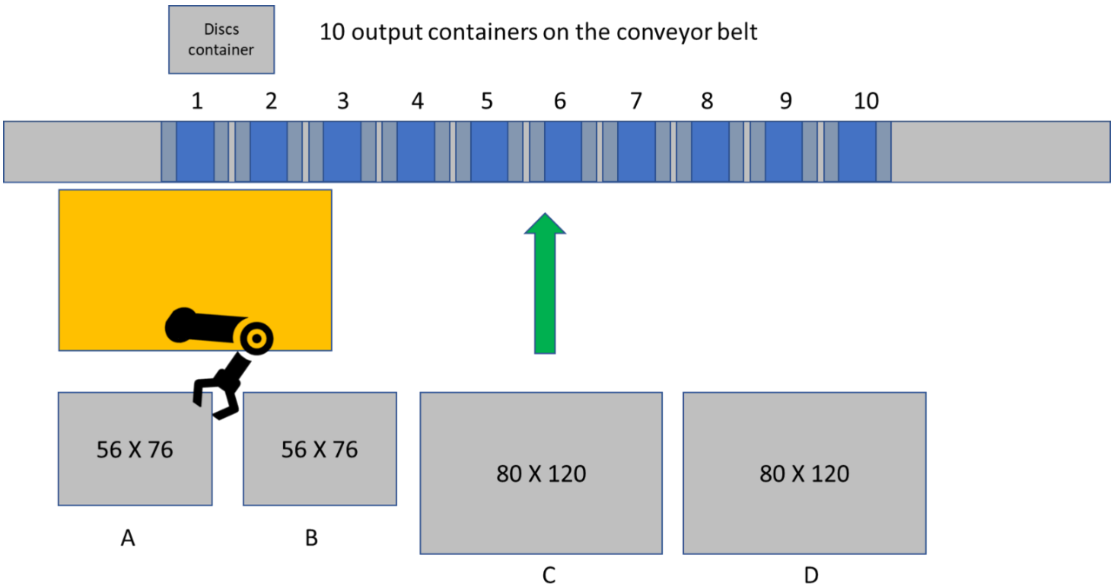

Figure 18. Design of the overall system

A prototype has been created at TEK and, after integration and validation of the HARTU results, it will be delivered to the TOFAS plant in Bursa for final demonstration.

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2.2.2 Prototype at TEK

The demonstrator installed at TEK is a scaled-down version of the proposed overall system, due to the availability of physical space at the shopfloor.

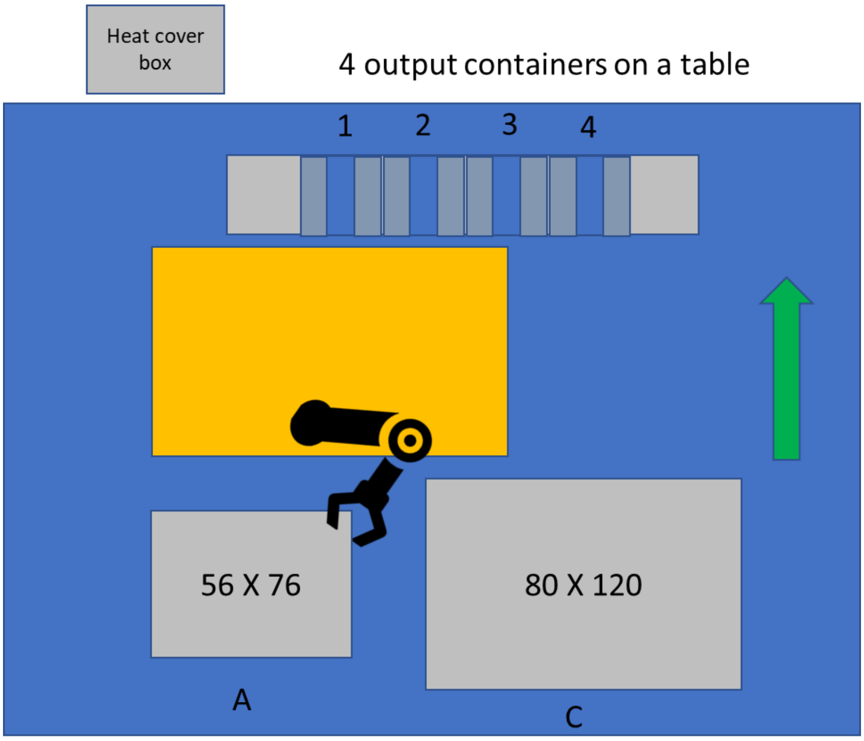

Figure 19. Scaled-down version of UC2a in TEK

TEK is waiting for the delivery of components and containers from TOFAS.

The demonstrator consists of the following elements:

- Mobile platform: Segway RMP omnidirectional mobile + KUKA IIWA 14.
  - Dimensions of the base: (W x L x H) 788 X 1350 X 897.
- A ZED2i camera mounted on the end of arm.
- A second ZED2i mounted on the platform to locate the output containers. Alternatively, an eye-in-hand camera configuration can be used for this purpose.
- 3 Grippers
  - One magnetic.
  - One 2-finger.
  - One 3-finger.
- Tool change station embarked on the robot.

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- Part repositioning station. Some parts are picked using a 3-finger gripper or magnetic gripper, but the placement in the output container requires to re-pick the part in a different way using a 2-finger griper. This operation is done in this station.

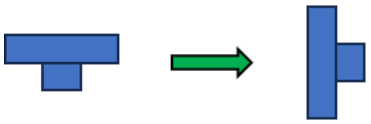

Figure 20. Parts are taken with a specific orientation but need to be re-picked to insert in the container

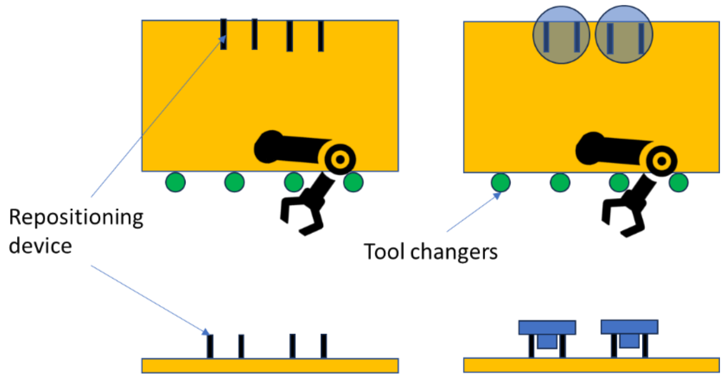

Figure 21. Initial tool re-picking stations

The sequence of actions in the demonstrator will be:

1. The robot receives the list of items to be placed in each output box. For each of them:
   a) It navigates to the input container.
   b) It takes an image and identifies the best candidate.
   c) It picks the object with the 3-finger or magnetic gripper and places it on the repositioning station.
2. The robot navigates to the destination container.
3. For each part
   a) It takes an image of the area and locates the container accurately.
   b) The robot picks the part from the repositioning station and places it on the corresponding output container.
   c) It moves to the next container position.

When necessary, the robot changes the gripper.

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2.3 TOFAS – UC2b – Pre-assembly in the automotive sector

2.3.1 Use case overview

This use case corresponds to the pre-assembly of components after the kitting operation described in UC2a. The use case to be considered is shown in Figure 22. It shows the pre-assembly of the real-wheel drum, which includes the following steps (from left to right): (1) Washer loading, (2) Nut loading, (3) Nut pre-screwing, (4) Drum loading, (5) Pre-screwing, (6) Screwing.

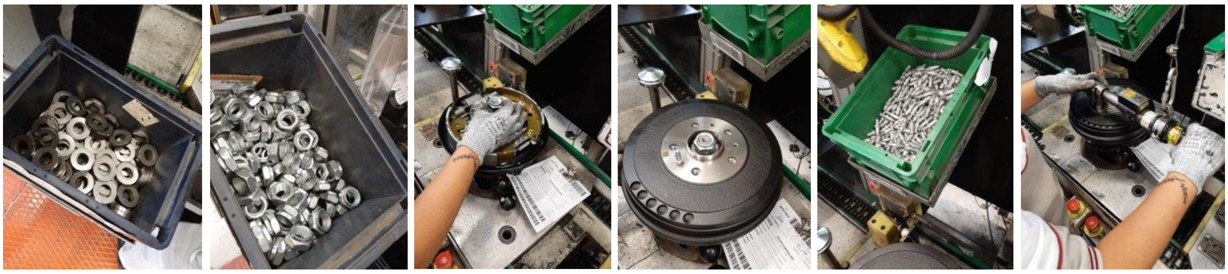

Figure 22 Use case UC2b, pre-assembly of real wheel in automotive sector

2.3.2 Prototype at DFKI

The laboratory prototype set up at DFKI Robotics Innovation Center comprises two rigidly mounted KUKA iiwa industrial manipulators equipped with Robotiq 3-Finger grippers, an Ensenso RGB-D Camera which provides high-resolution images and point clouds for object detection, 4x ASUS XTion RGB-D Cameras with low resolution to be used for collision detection, as well as two Sick Laserscanners for workspace monitoring. The robot will be controlled via ROS2. The table behind the robot can be used as assembly area and will be set up accordingly for the UC2b use case.

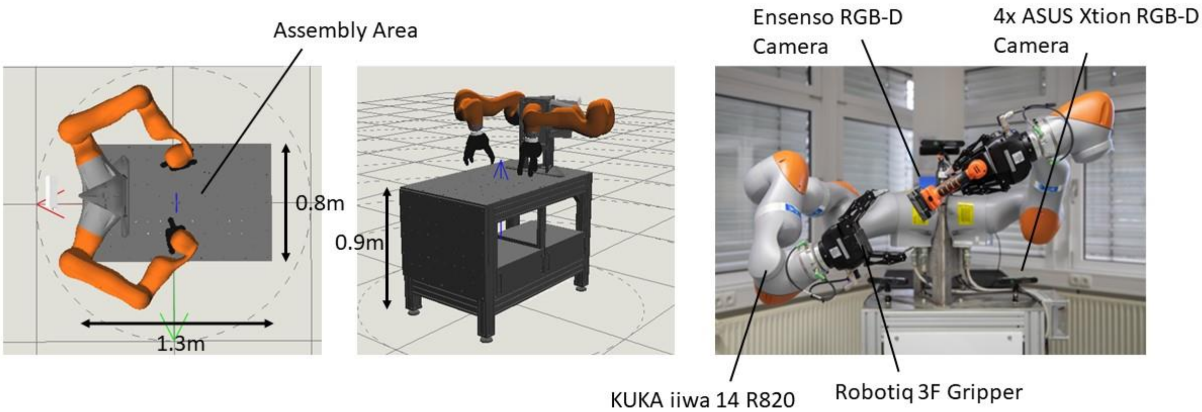

Figure 23 Dual-Arm KUKA iiwa as demonstrator for UC2b

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2.4 PCL – UC3 – Handling for mass customization in the consumer good sector

2.4.1 Use case overview

Philips is a world leader in mass production of consumer goods. To do this efficiently, the current processes are designed for high volumes with little product variation. Currently there is a trend towards more personalization. This results in more product variation within a given process, requiring the equipment to be more flexible and also easily reconfigurable.

A typical example of customization is the lacquering line, where parts are coated with a layer of lacquer to match the product design to the consumer's need. A wide range of products is fixtured manually by operators on the jigs that are going into the spray booths.

Image – fixturing at a loading/unloading station

Image – loading/unloading stations

The scope of the HARTU prototype is the automation of the insertion and removal of parts on/from the lacquering jigs.

This prototype will demonstrate flexibility, as it should be able to work with different product variants and colors (e.g., chest pieces and front panels). Furthermore, it should be easy to reconfigure or train the system for new product introductions.

Image – Chest panel

Image – Front panel

In addition, this prototype will show the adjustability of a complex fixturing motion to a changing environment (i.e a freely rotating jig). Placement of the parts on the jig is a complex wrist motion,

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that is different for each position on the jig. The parts are attached to the jig using a snap-fit connection. Correct placement can be checked by an audible click of the snap-fit joints.

Finally, the removal of parts from the jigs must always be done carefully to avoid scratching the newly applied surface finish.

2.4.2 Prototype at PCL

The demonstrator to be installed at PCL will focus on the placement and removal of products on the lacquering line. To demonstrate the repeatability of the action, this will be done in a continuous loop. Products are picked from a single tray and placed back in the same tray with the support of the perception system.

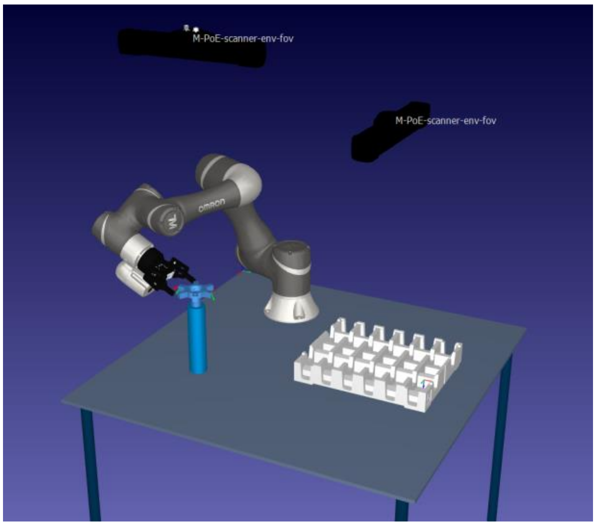

Figure 24. Side view proposed set-up

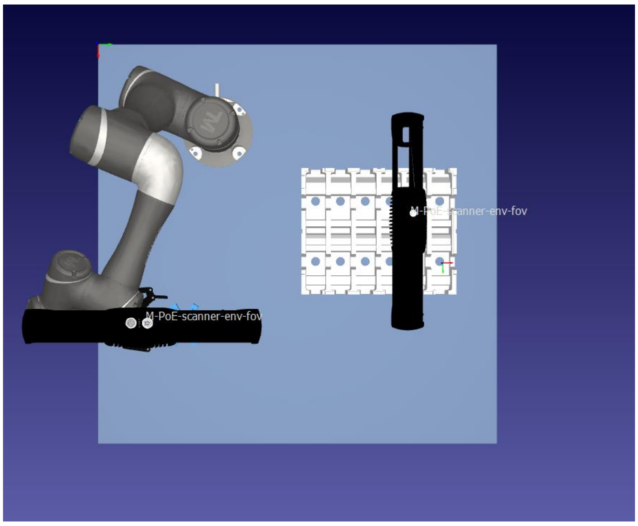

Figure 25. Top view

The state of the current set-up is as shown in Figure 26. This is an initial set-up that allows the start of the data acquisition campaign.


Figure 26. Current setup

The initial setup at PCL consists of the following parts:

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- 6-axis robot with 700mm reach. Type: Kuka kr6 R700 sixx
- 2 Structured-light 3D Scanners. Type: Photoneo PhoXi 3D scanner M
- Manual gripper change system. Type: Schunk SHS, size 50
- 2-Finger servo-electric gripper. Type: Weiss CRG 30-050
- Gripper fingers. Type: Custom 3D printed fingers

The sequence of steps for this prototype is as follows:

A. Place the pieces until the jig is full:
   1. Grab image of tray.
   2. Estimate pick pose.
   3. Pick product from tray.
   4. Grab image of jig.
   5. Estimate place pose.
   6. Place product on jig.
B. Remove the pieces until the jig is empty.
   1. Grab image of jig.
   2. Estimate pick pose.
   3. Remove product from jig.
   4. Grab image of tray.
   5. Estimate place pose.
   6. Place product in tray.

Upcoming and potential set-up changes:

- The system is controlled by a PLC and the robot is programmed using vendor specific software. In the next phase we will use the ROS based architecture integrating HARTU results. This might require changing the robot or using/developing an appropriate robot driver. The following robots are considered: Kuka Kr6 R700 six and TM5-700.
- Currently the jig is in a fixed position, therefore estimation of the jig position is not required for the placement of a part. This functionality is expected when implementing HARTU results.
- New gripper concepts can be tested in this setup. For mounting the gripper it is advised to comply with the specifications of the Kuka flange or the Schunk SHS 50 adapter plate.

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2.4.3 Prototype at DFKI

Figure 27 Prototype for UC3 at DFKI Robotics Innovation Center

The laboratory prototype set up at DFKI Robotics Innovation Center consists of a rotating jig, mounted on a table and a transport box with components. For robotic assembly, we investigate two options, (1) a fixed base industrial UR5 manipulator with 6 degrees of freedom, equipped with a Robotiq two-finger gripper, and force-torque sensor, (2) a mobile platform with Franka Emika Panda 7 degrees-of-freedom robot, including a 2-finger gripper. The former solution is closer to an actual industrial application, where position-controlled robots are usually preferred, while the latter solution provides the possibility to investigate more complex and dynamic interaction during the assembly task due to the use of torque-controlled robot joints.

Figure 28 Kinaesthetic Teaching of an assemby task

We use kinaesthetic teaching (hand guiding) to acquire end effector trajectories and allow the operator to teach new robot skills without explicit programming. The prototype is used to investigate different approaches for representing, learning, and controlling contact-rich assembly skills, as well as to develop generic robot software. Later, this software will be transferred to the actual use-case provided by PCL.

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2.5 TCA – UC4 – Packaging operation in food sector

2.5.1 Use case overview

This use case corresponds to the sorting and packaging of horticultural products. The products arrive in bulk boxes and bins of different sizes directly to the processing area from the field where they have been harvested. Then, in the production line, operators placed the products, in orderly order, into a box according to their size and shape (sorting based on other quality factors is out of scope of this project).

Figure 29. Current process for zucchini sorting

This use case will implement the robotized operation for three products: Zucchini, Eggplants and Tomatoes.

The use case will be carried out at Centrolazio facilities, a cooperative that produces a wide variety of vegetable products. It integrates the production of the associated farms, which cover a total area of more than 300 hectares cultivated between Anzio, Latina and Sabaudia.

The procedure to be followed is as follows:

- The line operator places the input and output boxes in the corresponding station of the demonstrator.
- An image is taken from the top of the input box. The most suitable product to be picked is identified using the grasping point identification component.
- The robot generates the trajectory to pick the selected product and, once picked, moves it to the size/shape inspection area, where a new image is acquired.
- The system classifies the product according to size and shape and asks the robot to place it in the corresponding output box.
- Once placed in the box, an image of the interior of the output box is acquired for the target position of the next product that goes to this box.

Two prototypes are created at TEK and AIMEN facilities. One of them will later be transferred to Centro Lazio.

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2.5.2 Prototype at TEK

The demonstrator concept and physical implementation is shown in next figures:

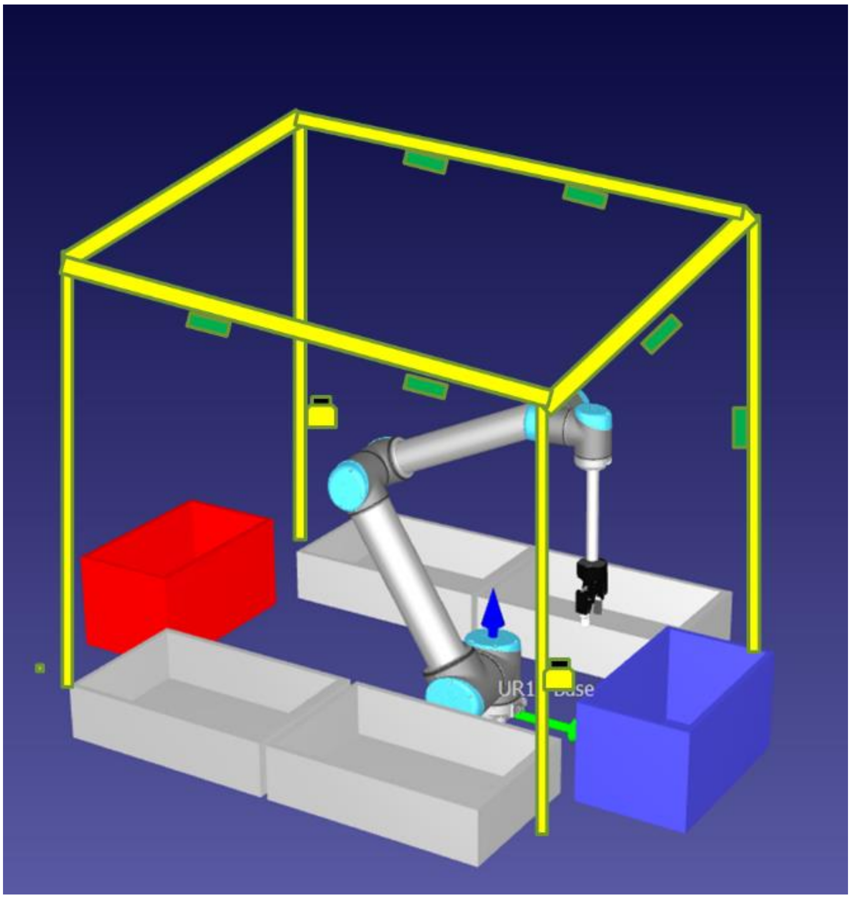

Figure 30. TCA Prototype concept

Figure 31. TCA Prototype concept implemented at TEKNIKER

The demonstrator consists of the following elements:

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- FANUC CR-14iA / L on a table. There is no specific requirement to apply for a collaborative robot. The chosen one is only a question of robot availability.
- 5 ZED2i cameras, one on top of each input-output box. No camera above the rejection box. There is one NVIDIA Jetson Nano connected to each camera through USB. These mini-pc's are connected to the central PC through ethernet.
- One central PC to control the system.
- A safety radar to stop the robot in case a human being enters the robot's working area of the robot. The final industrial implementation will require four radars (one on each side). Alternatively other mechanisms (safety lasers or safety photoelectric barriers can be used).
- A vacuum gripper, with different suction cups depending on the product to be handled. Once available, the new gripper concept developed by OMNI and POLIBA will be integrated.

Figure 32. PSEN rd1.2 safety radar sensor

Figure 33. Detail of 3 of the ZED2i

Figure 34. Vacuum gripper

The sequence of actions in the demonstrator will be:

1. The operator places an input box with bulk fruit.
2. An image of the input box is captured.
3. The system decides which fruit to pick.
4. The robot picks the fruit and places it in the position that allows an image to be taken from the side and from above.
5. The system measures the fruit and sends the destination box to the robot.
6. The robot drops the product into the destination box.
   a) Creating a mosaic in case of OK product

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b) Leaving it in case of NOT OK product

7. The process is repeated until the input box is empty. A message informs the operator to change the input box. Alternatively, a light can be switched on.
8. If somebody enters in the safety zone, the robot stops.

2.5.3 Prototype at AIMEN

The main objectives of the demonstrator are:

1. Provide the realistic/near representation of the TCA use-case in terms of the working heights, lighting conditions, container sizes and vegetables.
2. Provide the necessary infrastructure to mount the developing cameras, robots, grippers, lighting, etc. for the flowless development of the grasping technology.
3. Provide devices that can work as is to the real use-case with the actual capability and capacity to operate on end-user premises.
4. Provide platform to integrate the HARTU results on perception, grasping, and continuous monitoring related with TCA use-case.
5. Define accurate technology requirements for the TCA use-case. In terms of deployment space, human operator needs, equipment parameters, etc.
6. Provide ability to verify and validate the technology with the help of the pre-deployment performance indicators.

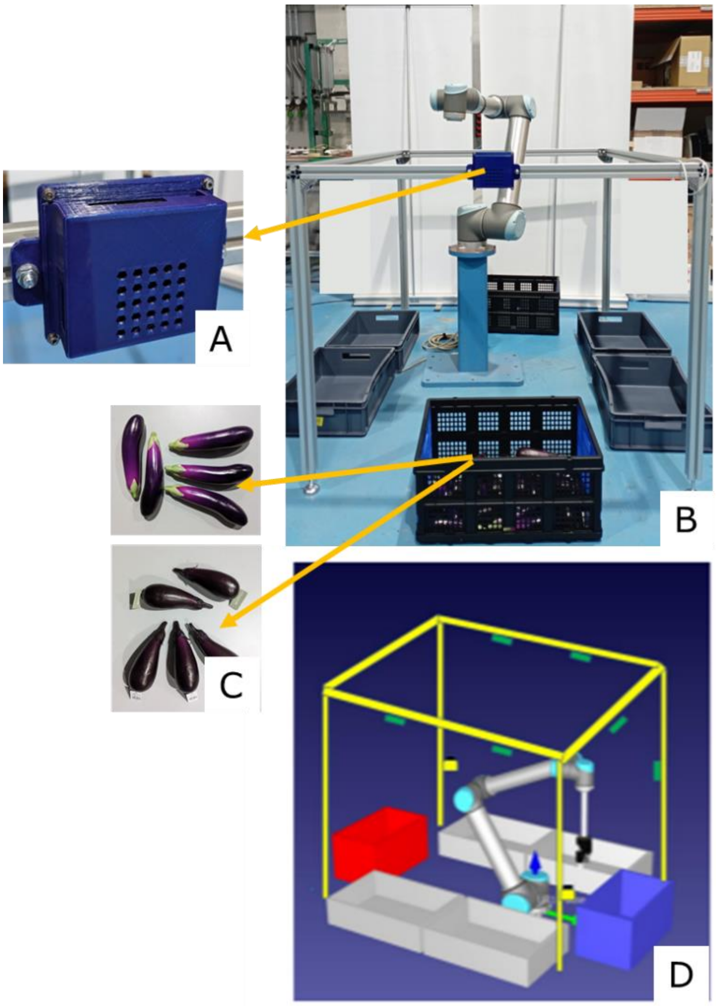

Figure 35. TCA demonstrator at AIMEN. A: Edge controller; B: Physical Demonstrator; C: Dummy Eggplants in container; D: Demonstrator concept from D1.1

The demonstrator at AIMEN is shown in Figure 35.

This demonstrator consists of the following elements:

- Collaborative Robot UR10e.
- Nvidia Jetson Nano with cover.

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- Inbound and outbound containers.
- Zed 2i camera above inbound box (perception database of inbound eggplants).
- Aluminium profile-based metal structure.
- Two types of eggplants (dummy).

It is expected to extend the height of the structure in the coming weeks to facilitate the work of operators.

In addition, it is expected to include:

- Six Zed2i cameras with their Nvidia Jetson Nano:
    - One above each inbound box and outbound box except the red one.
    - One for the shape and size check on the right column.
- A central PC for the processing of the information, connected to each jetson nano.
- Gripper/s integrated to the UR.
- Database information for the selected TCA vegetables.

These modifications are shown in Figure 36.

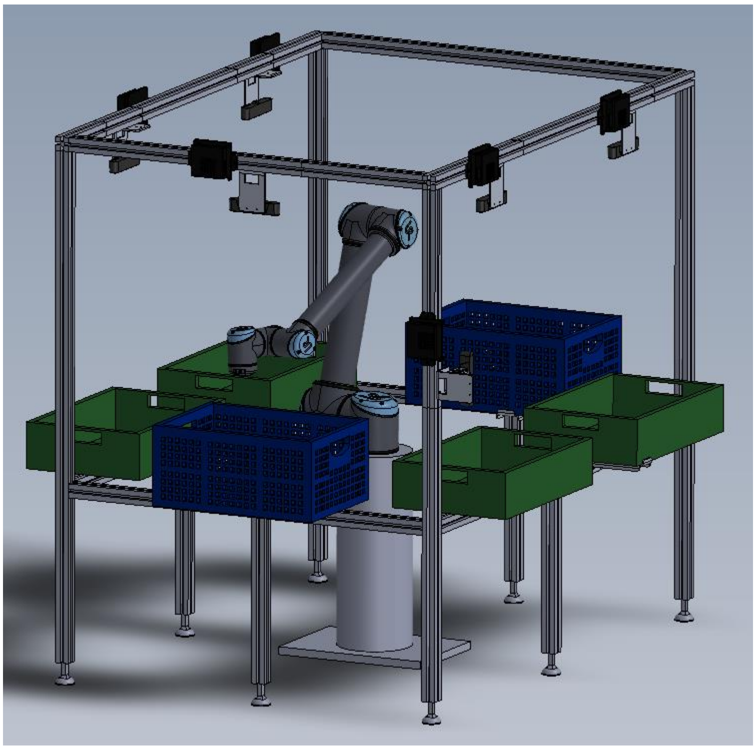

Figure 36: TCA demonstrator design with upgrades of perception, control and height.

Sequence of operations will be similar to that described for the TEK demonstrator.

This set-up at AIMEN will be used for the following activities:

- Demonstrator for integrating HARTU results (T1.5)
    - Computer vision setup -> acquiring images: Perception module.
        - To collect the data from the dummy eggplants to start the pose estimation module for the TCA use-case.

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    - The six Zed2i cameras work as the edge perception module and send the processed information to the central PC.
    - The Zed2i cameras can be moved along the infrastructure.
    - The height of the infrastructure can also be adjusted.
  - Robotics setup -> acquiring forces/trajectories/etc: Grasping module and Continuous monitoring module.
    - Universal robot is installed at the centre of the demonstrator.
    - The new gripper technology will be installed on the TCP.
    - The demonstrator will be connected to the pneumatic lines for the vacuum gripper technologies.

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2.6 INFAR – UC5 – Fixtureless assembly in hand tool manufacturing sector

2.6.1 Use case overview

The INFAR use-case will focus on the ratchet wrench assembly. The main components to be assembled in the ratchet wrench are shown in Figure 37.

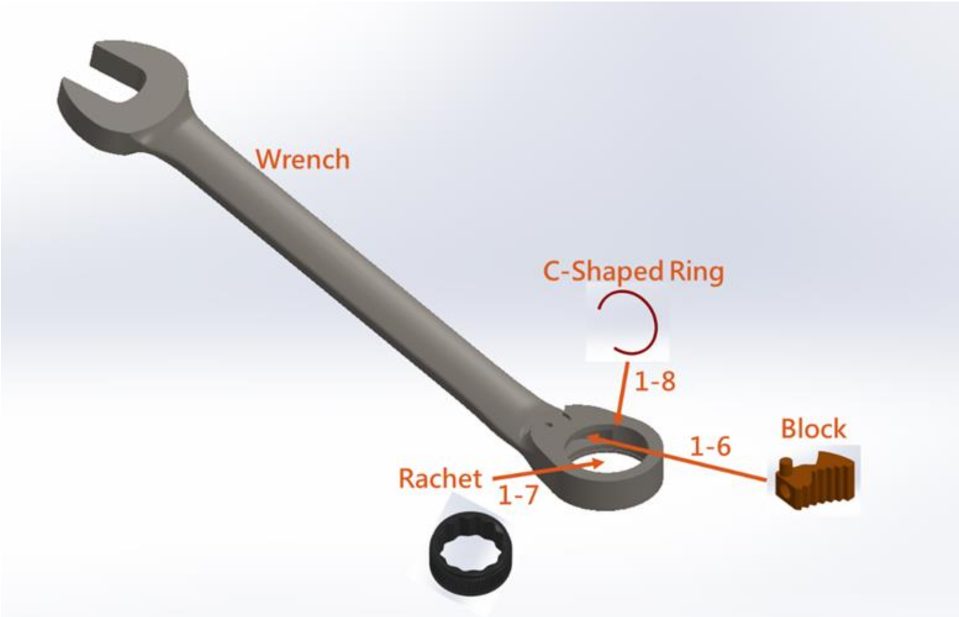

Figure 37. Main components of the wrench

Currently, operators assemble this ratchet wrench manually as shown in Figure 38.

Figure 38. Operators at the assembly tables

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HARTU will focus on three main steps of the assembly process, as shown in Figure 39.

- Assembly step 6 – Block insertion
- Assembly step 7 – Ratchet insertion
- Assembly step 8 – C-shaped ring insertion

Figure 39. Three main assembly steps: Step 6 (left), Step 7 (middle), Step 8 (right)

Automation of these assembly steps is challenging because of the small size of the parts that have to be manipulated.

2.6.2 Prototypes

A multi-robotic assembly system has been proposed for automating the assembly steps described in this use case. The demonstrator concept and the physical implementation is shown in next figures.

The main idea is to have the first robot arm to hold the main body of the ratchet wrench and the second robot to pick the components one by one following the assembly steps 6, 7, and 8. The assembly is performed via the coordination among the two robots. Before doing the assembly task, simulations on assembly steps are used to determine the best robot moving paths, configurations, coordination among robots, etc. as shown in Figure 40.

Figure 40. Simulated components for assembly steps

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The demonstrator will be implemented following the simulation set-up shown in Figure 41.

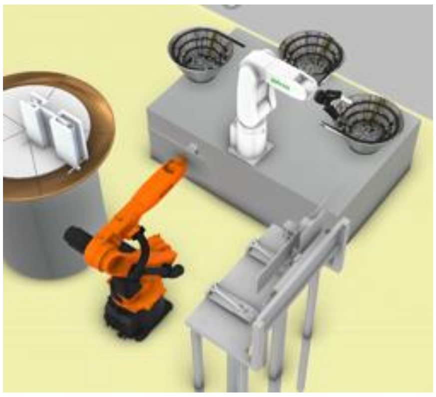

Figure 41. Simulated assembly process

The components included in the real demonstrator are the following:

- Two robots: AR605 or SJ605 (both are designed by ITRI)
- Specifically designed gripper to grasp the ratchet and the wrench. (Gripper is being designed by ITRI).
- Robot Cell Controller (eMIO designed by ITRI).
- Centralised robot coordination of the two robots with high-level commands, such as grasping points on the workpieces.
- Perception system, consisting of cameras at the ceiling or close to the robot end-effector to provide visual information for further object recognition, grasp planning, etc. FOVISION or SENSOPART products will be adopted.
- Multi-axis force/torque sensors mounted at the end-effectors to provide contact force information for assembly tasks.
- Workpiece loading/unloading mechanism for robot grasping of workpieces for next assembly movement. (designed by ITRI).

Figure 42 shows the 3D layout and the AR605 of the demonstrator.

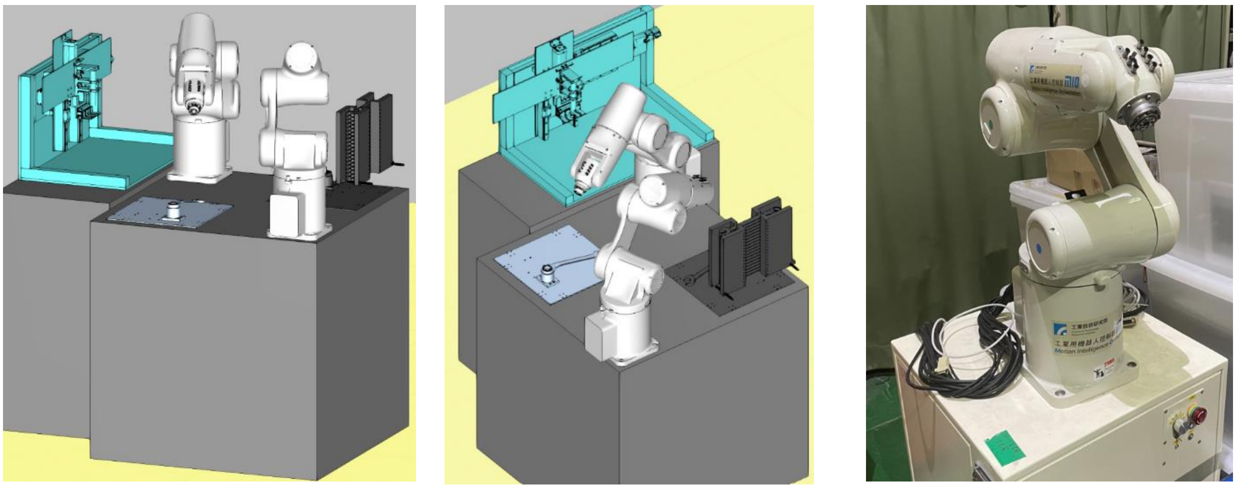

Figure 42. 3D layout (left) and the AR605 (right) of the demonstrator

Other HARTU results will be integrated as they become available.

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As described, currently simulation for this demonstrator has been used to verify possible solutions and designs, assembly procedures and algorithms. Since the specific designed gripper and the workpiece loading/unloading mechanism is under manufacturing by the contractor. The real implementation of the demonstrator is scheduled for Dec, 2023.

The sequence of actions in the demonstrator will be:

1. Placing the main bodies of the ratchet wrench, the C-shaped rings, ratchets, and block-modules into the loading mechanisms.
2. The first robot picks a main body of the ratchet from the loading mechanism.
3. The second robot picks the block-module from the loading mechanism.
4. The assembly step 6 is performed by the second robot to insert the block-module into the main body of the ratchet wrench held by the first robot.
5. The second robot picks the ratchet from the loading mechanism.
6. The assembly step 7 is performed by the second robot to place the ratchet into the main body of the wrench held by the first robot.
7. The second robot picks the C-shaped ring from the loading mechanism.
8. The assembly step 8 is performed by the second robot to place the C-shaped ring around the ratchet.
9. Then, the first robot will place the assembled ratchet wrench into a basket.

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2.7 ULMA – UC6 – Order preparation: pallet to pallet

2.7.1 Use case overview

In logistics, there are different types of order preparation procedures depending on how the products arrive at the preparation area and how the orders are delivered.

- Input
    - Products arrive on pallets, this is mainly the case of bulky products packaged in carboards, large cans and sacks.
    - Small size products arrive in boxes, sorted or randomly distributed.
- Output
    - Products are stacked on pallets, either of one or multiple references.
    - Products are placed in boxes, sorted or unstacked (randomly).

This use case corresponds to the case in which products arrive on mono-reference pallets and are delivered on multi-reference pallets.

In the order preparation area operators pick units from the incoming pallet (the one that has been transported from the warehouse) and place them on the pallets that will be finally delivered to the customer, as shown in Figure 43.

Some of the features of the use case are the following:

- The incoming pallets (Euro Pallet, EPAL) are always mono-reference and the output boxes are, usually, multi-reference.
- The warehouse management system informs the operator of the number of units that have to be picked from the incoming pallet. This information is available in a GUI and is displayed in a pick-to-light system.
- Operators manipulate the product by hand, and with the help of industrial manipulators for the heaviest products (they can weight up to 30 kg).
- In some few occasions, the incoming pallet transports a box with products inside, which must be manipulated individually to complete an order (e.g., to take a can from the box an put them on the output pallet).
- Operators use their own criteria to create the output pallet, trying to find the best combination to create stable pallets. For that, sometimes they move the already placed items and reposition them.
- .

Figure 43. Real example of output pallet at ULMA's customer

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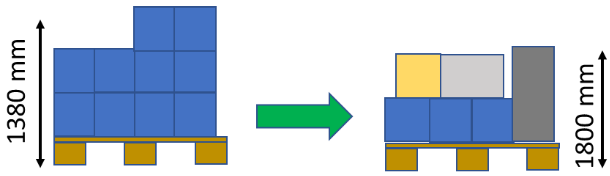

Figure 44. Pallet to pallet process

Figure 45. Example of multi-reference pallet

Two prototypes will be created: one at TEKNIKER for the validation of partial results and the final one at ULMA. The main two differences among them are:

- The type of robot used.
- The way the input pallets are transported to the picking station (using a conveyor in the case of ULMA and manually in the case of TEKNIKER).

Both prototypes are described in the following sections.

2.7.2 Prototype at ULMA

The demonstrator concept and the physical implementation is shown in Figure 46 and Figure 47:

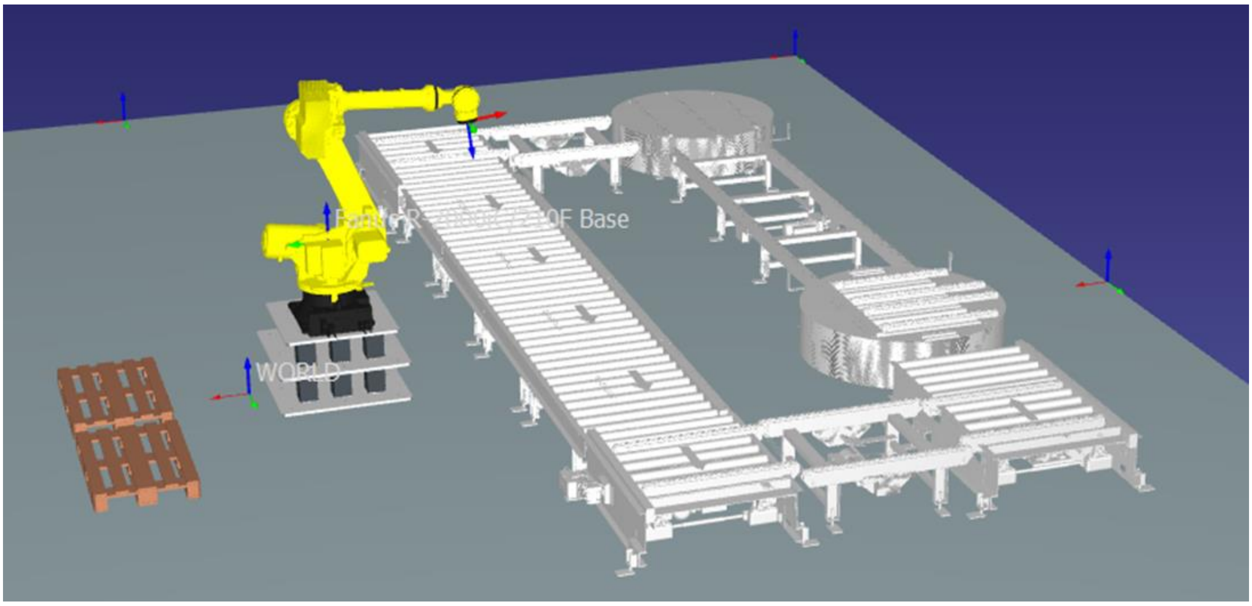

Figure 46. Design of the demonstrator at ULMA

The robot will pick products from the pallets transported on the conveyor and will create a new multi-reference pallet (an order).

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Figure 47. Initial setup at ULMA

The components included in the demonstrator are the following:

- Robot FANUC R-2000Ic/210F.
- Conveyor for transporting the input pallets (circular path).
- 1 Photoneo L above the picking station (input pallet).
- 1 ZED2i mounted on the robotic arm to monitor the status of the output pallet.
- 2 suction grippers of different sizes. The currently available grippers are:
    - JOULIN CG-VG 400x400-J-P20-3STx8
    - JOULIN EGV2-VG-125x400-J-4P30-3STx1
- Tool exchanger station and exchange system rsp P1804; Sn: 0108
- A control PC

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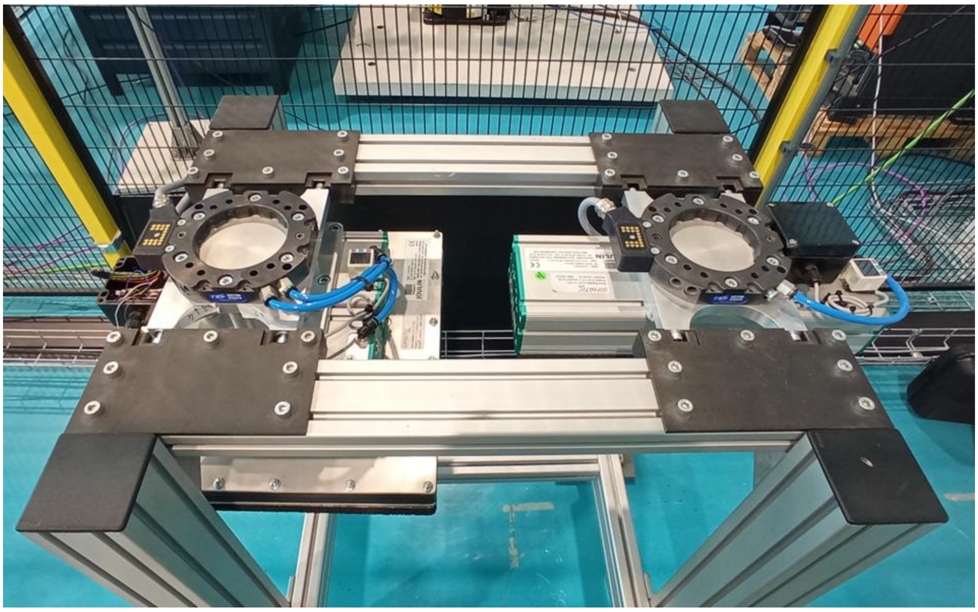

Figure 48. Tool changing station, with the two tools currently available

The sequence of actions in the demonstrator will be:

1. The system calculates the mosaic (position of each part) to be created for an order.
2. The warehouse management system delivers the input pallets based on the position of the products in the mosaic.
3. For each pallet arriving at the picking station:
    a) An image of the input pallet is captured with the fixed camera.
    b) The system decides which product has to be picked.
    c) The robot picks the product.
    d) The robot places the product in the corresponding position of the mosaic.
    e) The robot takes an image of the mosaic with the embedded camera.

       If there is a mismatch with respect to the proposed mosaic, it stops and an alarm is generated (light or message) to inform the operator.
    f) The sequence is repeated for the number of items to be picked. When finished, the pallet leaves the picking station and a new one arrives.

2.7.3 Prototype at TEK

The prototype at TEK is like the one at ULMA, with two main differences:

- Robot KUKA KR210 R2700-2 /FLR.
- There is not a conveyor to transport the input pallets. Instead, they will be moved by hand.

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The sequence of actions is similar to that of ULMA, except that the input pallets are moved by hand.

Figure 49. Initial setup at TEK during the preparation phase

2.8 ULMA – UC7 – Order preparation: box to box

2.8.1 Use case overview

These use case corresponds to order preparation in logistics centres, where products arrive in boxes, are picked manually by operators and placed in multi-reference boxes to complete an order.

The products are placed unstacked in the output box because they are then transported to a workstation to be packed in the final packaging in which they will be delivered to the customer.

Some of the features of the use case are the following:

- Products come in a huge variety of shapes, materials, and dimensions.
- Humans use their both hands and sometimes they pick more than one product at once.
- Operators are informed through the pick-to-light system on the number of items that have to be picked and the destination box.

Figure 50. Manual picking

Figure 51. Placing the products in the output box

The concept proposed is presented in the following figure. It consists of a robot picking items from one box and dropping them in the output box which is used to create an order. The boxes are automatically transported from/to the warehouse, an advanced perception system identifies the position of the parts, and the robot automatically generates the trajectory for both picking and releasing operations (HARTU results).

Depending on the production required, it is possible to have one or more robots, either in a fixed position or mounted on a linear track. Similarly, the number of input and output boxes managed can vary. The cameras on top of the input boxes can be fixed or mounted on a rail.

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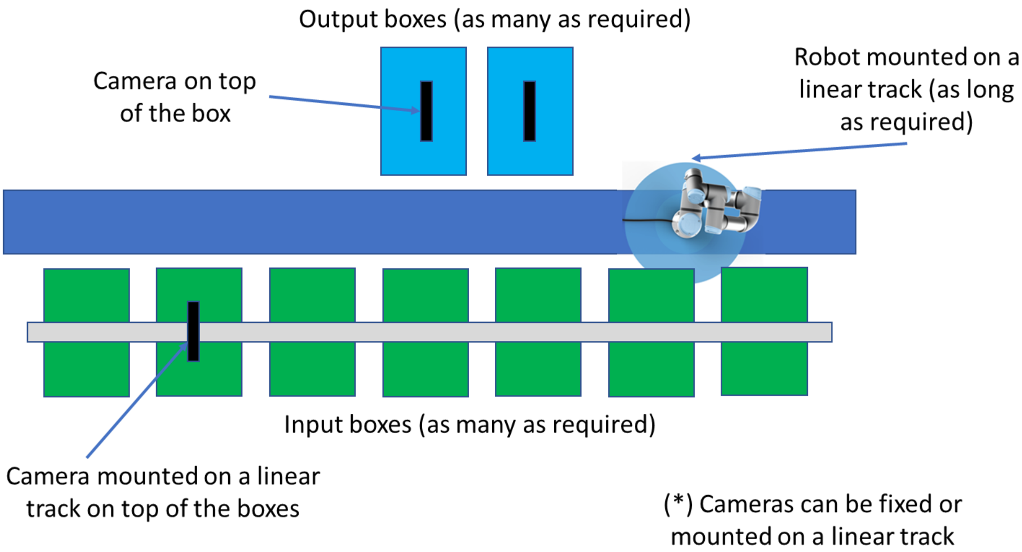

Figure 52. Design of the box to box order preparation

This prototype will be setup and validated at TEK.

2.8.2 Prototype at TEK

The concept of the demonstrator and the physical implementation are shown in the following figures. As a proof of concept only the preparation of one output box (one order) at a time will be implemented, and due to space limitations, up to 7 input boxes will be managed (this means that in this prototype an order can only be composed of a maximum of 7 different product references, but many items of each are possible).

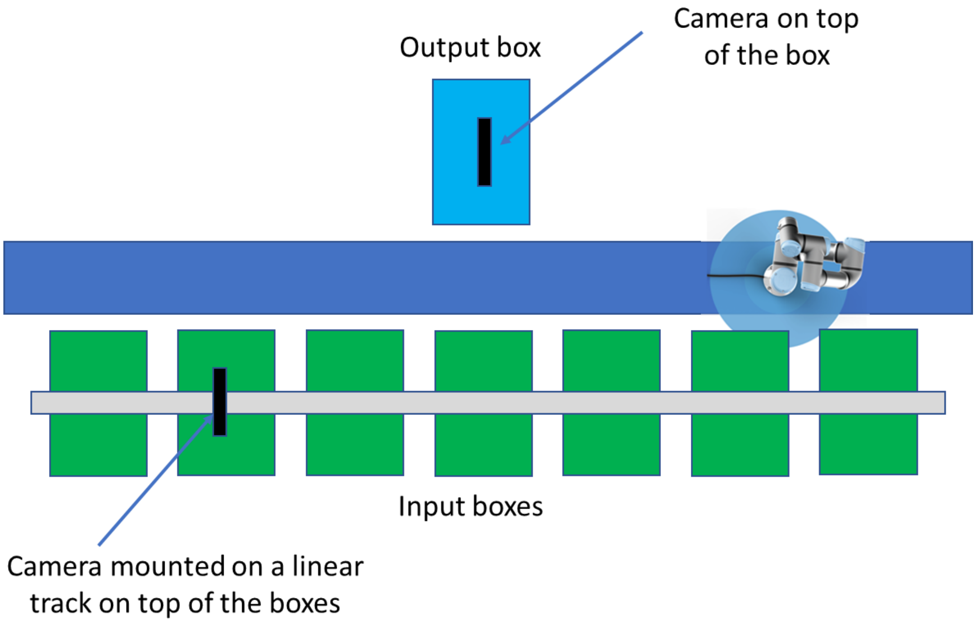

Figure 53. Design of the demonstrator at TEK

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Figure 54. Setup pf he demonstrator at TEK

The components included in the demonstrator are the following:

- Robot: UR 10 mounted on a 4 meters long linear axis.
- Plastic boxes for product delivery and order preparation.
  - Up to 7 input boxes (single reference): bulk products.
  - 1 output box (multi-reference) to prepare an order.
- Cameras
  - Photoneo XL mounted on a linear axis to monitor up to 7 the input boxes.
  - ZED2i camera to monitor the output box.
- Grippers
  - 3-finger gripper for products with cylindrical geometries that cannot be gripped by suction.
  - Suction gripper for products with a suitable surface, e.g., boxes.

  It will be considered the use of a combined 2-3-4 finger+suction gripper, for some special product shapes and configurations (see Figure 56 as an example).
- Tool change station
  - The tools will be equipped with quick-change devices.

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Figure 55. One of the 2 grippers with automatic quick-change mechanism

Figure 56. The combined finger + suction gripper under study

The sequence of actions in the demonstrator will be:

- The warehouse management system sends the list of items to complete an order
- The warehouse management system delivers the input boxes to complete the order
    - In the LAB version the boxes are placed on a table and their position is send to the robot
- For each product to complete the order:
    - In the LAB version, the robot moves to the input box position.
    - The robot changes the required tool.
    - An image of the input box is captured with the camera mounted on the linear axis.
    - The system decides which product is to be picked.
    - The robot picks the product.
    - The robot releases the product into the output box (order), trying not to create piles.

      Sometimes, linear translation of the robot to the position of the output box will be required.
    - An image of the output box is taken for the next iteration.

      This information will be used to ensure that products are not stacked.

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3 Updated risk assessment

A Preliminary risk assessment has been done in deliverable 1.1 based on the analysis of the use case descriptions. Here we present an updated version based on the current state of the prototypes. This risk assessment is to be updated per use case regularly, including the mitigation measures.

Risk-analysis												
No	Use Case	Occurrence	User phase	Cause	Effect	Remarks	Seriousness	Exposure	Probability	Danger avert	Risk level	Class
1	All	Robot moves to pick position	All	Moving part approaches Static part	Getting stuck	Use of cobots at cobot requirements (e.g. speed)	1	2	1	1	3	1: Low (possibly acceptable)
2	All	Robot picks product from pick positions	Automatic	Sharp parts	Cutting	Use of cobots at cobot requirements (e.g. speed)	1	2	1	2	4	1: Low (possibly acceptable)
3	All	Gripper picks product	All	Moving part approaches static part	Getting stuck, Cutting		1	3	3	1	5	2: Middle (improvement necessary)
4	All	Robot movement	All	Moving part approaches static part	Being hit by moving part	Use of cobots at cobot requirements (e.g. speed)	1	3	3	1	5	2: Middle (improvement necessary)
5	All	Robot moves to place positions	All	Moving part approaches	Getting stuck	Use of cobots at cobot requirements (e.g. speed)	1	2	1	1	3	1: Low (possibly acceptable)
6	All	Robot places product	Automatic	Sharp parts	Cutting	Use of cobots at cobot requirements (e.g. speed)	1	1	2	2	4	1: Low (possibly acceptable)
7	All	Robot moves from undefined positon	Maintenance, service, Manual	Sharp parts	Cutting	After maintenance the robot can be in undefined position	1	2	2	1	5	2: Middle (improvement necessary)
8	All	Working with electronics	Maintenance, installation	Live parts	Electrocution		2	1	1	2	4	1: Low (possibly acceptable)
9	All	Air hose lets loose	All	Bad installation	Being hit by moving part		1	1	1	1	1	1: Low (possibly acceptable)

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10	All	User can get into the blind spot of safety measures	All	Safety scanners cannot scan all area	Getting stuck, being hit		1	2	1	2	4	1: Low (possibly acceptable)
11	All	User can make unsafe robot program	All	Flexibility is target of systems	Getting stuck, being hit Damage to machine		1	1	2	2	4	1: Low (possibly acceptable)
12	TOFAS	Mobile manipulator moves	All	Moving manipulator	Getting stuck, being hit		1	1	2	2	4	1: Low (possibly acceptable)
13	ULMA_ 1	Product drops	All	Gripping force not enough Emergency shutdown, power down	Getting stuck, being hit		2	1	1	3	4	1: Low (possibly acceptable)
14	INFAR	Robots move towards each other	All	Moving part approaches moving part	Getting stuck		1	3	3	1	5	2: Middle (improvement necessary)
16	PCL	Movement of jig	All	Moving part approaches Static part	Getting stuck		1	2	1	1	3	1: Low (possibly acceptable)
17	TCA	(automated) supply of new box	All	Moving part approaches static part	Getting stuck, being hit	In demonstrator manual replacement of boxes	1	1	1	1	1	1: Low (possibly acceptable)

ISO/TS 15066:2016 specifies safety requirements for collaborative industrial robot systems and the work environment, and supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218-1 and ISO 10218-2.

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4 User research in HARTU's Use-cases

4.1 SSH: Methodology and data collection methods

User research is the practice of studying and understanding people's behaviours, needs, pain points and their motivation about their experiences in usage of technologies. The understanding of users' needs is essential to define effective requirements for the design of technologies and solutions.

In HARTU, user research has been used as a central process to study in a comprehensive way the five pilots so as to propose design recommendation, needs, and requirements centred on the users' perspective. This will ensure the design of solutions acceptable to users.

A four-phase process (Figure 57) has been defined at the beginning of the project to define the current AS-IS context and to support the partners involved in the initial set-up of the real-world scenarios (T1.2). The four phases of the user research approach (Explore, Understand, Analyse and Recommend) are described in the following paragraph, with the description of the main methods applied and the specific outcomes generated in each phase.

The outcomes of the process are directed to the designers and technology providers and are specific insights providing take home messages on the context, working layout and processes in which the designed solution will need to operate. User needs are preliminary insights that are part of the wider working system that will be impacted by the integration of HARTU results and that will need to be considered to ensure a smooth technological transition.

Figure 57. Different phases of the approach undertaken

4.1.1 Phase I: Discovery

In the discovery phase, a general introduction to each Industrial Use Case has been carried out. The main objective for this phase was to understand the relevant scenarios for HARTU in each Industrial Use Case and

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to define the possible logistics of field-studies.

A series of interviews with the Manufacturing Line / Logistic Line (ML/LL) representatives were conducted and relevant documentation from use cases was collected. Based on the analysis of the gathered data, a first version of the scope and objectives of each scenario was outlined. This exploratory phase clarified the key roles operating in the scenarios analysed, as well as their responsibilities and tasks.

4.1.2 Phase II: Understand

The main scope of phase II was the planning of field visits to the Industrial Use Cases to better understand the interactions between the key roles identified in Phase I and machines (both in its software and hardware components), as well as other related factors relevant to their tasks that might have indirectly affect interactions or be a result of these interactions (e.g., the need to collaborate with other members of staff, skills and competences needed to work effectively with the provided systems, or the comfort of the working environment).

Understanding the way that the work is organised in the ML/LL currently (e.g., different roles and responsibilities, or shift patterns), and identifying areas of opportunities where the impact of the new solution could positively influence the processes also at higher organisational levels (e.g., number of employees needed to conduct the work, redefinition of operators tasks and upskilling/reskilling of competencies) is very important when integrating a new system in the context. The overarching goal in this Phase was to delineate the current scenarios (AS-IS) in each use case taken into consideration, and to highlight all the socio-technical related aspects to be considered when designing HARTU's technological solution.

An in-depth evaluation of the context and the related production processes and environment was undertaken. To plan the data collection activity from a Human Factors perspective, a series of categories were considered as a lens to observe and analyse the scenarios. The categories chosen took inspiration from EUROCONTROL's Human-Factor Pie (EUROCONTROL, 2011) which is a framework that considers a series of Human-Factor related categories and sub-categories to be used in order to analyse a changing context. After a readaptation of the framework, six categories and sub-categories were identified as relevant to explore in HARTU's scenarios. The categories, illustrated in Figure 58 are namely:

- **Working Environment:** The workspace, the general equipment and machinery used, and the physical environment;
- **Organisation of work**: Organisational, production and people management within a work setting, consideration of personal and cultural factors and issues related to the management of organisational changes;
- **Skills and Training:** The systematic development of competencies required by individuals to adequately perform their work;
- **Roles, Procedures and responsibilities**: Actual/prescribed working methods, positions/functions in the organisation and expected tasks performed by relevant roles;
- **Teams and communication**: How people work and communicate with each other on shared goals and tasks.
- **Human-machine interaction:** The actions, reactions, and interactions between humans and other system components.

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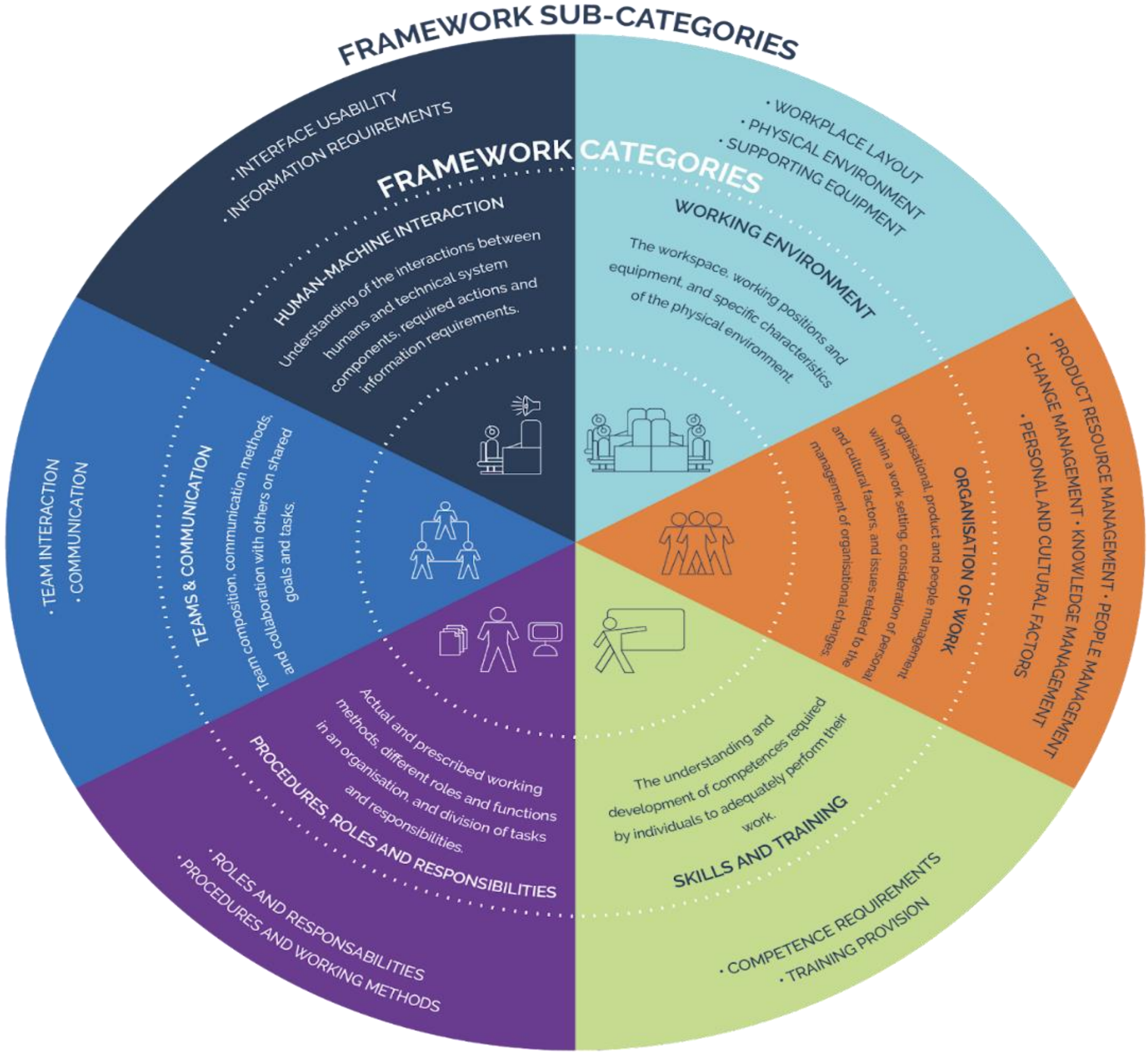

Figure 58. Human Factors Pie, readapted from EUROCONTROL

For each category, a rationale, a set of questions to pose and aspects to be observed in each pilot was developed accordingly. These points of inquiry were then selected prior to the field-visits in preparation of the interviews outlines for each key role and were used as prompts during the field-work helping in gathering useful information during the observations and in general in note taking during the visits. In the following the methods for data collection used during the field visits are better detailed but it should be noted that an overarching application of the Human Factor framework was applied to ensure a comprehensive methodology to be used across the different scenarios.

Investigations at the ML/LL plants were carried out using a mixed-method approach consisting of three main different activities aimed at gathering qualitative data, namely: semi-structured interviews, and observations. The methods used a focused-on approach offering diverse levels of interaction with study participants and considering a range of data sources (e.g., existing materials, internal and external documents sourced from the use-cases, individual knowledge, and experience of key roles). Table 1 shows the methods, followed by a brief description and their objectives.

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Table 1. Methods used for data collection

Methods	Description	Objectives
	Contextual interviews with different representatives of the current workforce	In-depth understanding of the wider organisational context in which employees are working (also including aspects such as organisation of work, training provision and communication), together with further exploration of HMI-related pain points identified during Observations and Physical Ergonomics Assessment, and related opportunities.
	Direct observation of the users while they are conducting the work. During the observation, a physical Ergonomics assessment can be performed through direct observation and direct measurements (e.g., light, noise).	Understanding the key tasks and points of interaction with interfaces and/or machines, the actual tasks performed and potential insights to discuss during interviews. The data collected provides an overview of potential improvement for the user, as well as informing the tech designers on ergonomics, organisational and technical aspects to consider.

The data collected during the field-studies visits to the ML/LL was the starting base for the analysis done in Phase III.

4.1.3 Phase III: Analyse

In this phase, the data collected in Phase II are analysed providing insights on the AS- IS scenarios. In this phase the use case context, tasks, challenges, opportunities, as well as a physical ergonomic assessment of the key roles observed and interviewed is provided. The analysis of the data was carried out using specific user research methods described in the following.

Personas

Personas are realistic representations of user types. They are created based on user research, collecting data about real users. Personas are a common tool used in human-centred design to represent users' goals, needs, skills and behaviours and are used for understanding users' expectations and help during the design phase of a solutions in making the right questions and taking into consideration the users' perspectives. Personas help the understanding of users' needs, goals, and behaviours.

The outputs outlined through personas are:

- Description of tasks
- Skills and Expertise

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- Workspace
- Typical interactions with tools
- Human- Human Interaction

User Journey Maps (UJ)

User Journey Maps represent the different steps a user does to reach a goal and/or to perform a task. User Journey Maps highlight interactions of the users with tools and systems, other people, and roles within the organisation. The User Journey Map makes it possible to briefly and visually describe a person's experience, highlighting also their thoughts, pain points, and emotions.

The challenges and opportunities for improvements related to the key activities are then identified in the applicable areas. This method is useful for understanding users' current challenges in reaching a goal and the identification of points of strength and weakness in it. It also provides information about the frequency of interactions at different steps of the process and the means in which these interactions take place with humans (e.g., email, face to face, phone call, document handling) and/or with tools (e.g., computers, software, machineries, forklifts etc.). The outputs outlined through a user journey map are:

- Workspace location
- Supporting roles
- Digital touchpoints
- Physical touchpoints
- Other supporting tools
- Challenges
- Opportunities

Hierarchical Task Analysis (HTA)

Hierarchical Task analysis describes a specific task by breaking it into specific smaller sub-tasks. It makes it possible to visualise all the different steps to complete a task. It maps the way in which users complete a task, and it is based on data collected and observations from the real world. The creation of a Hierarchical Task Analysis supports the identification of possible critical sub-tasks, which can be improved, simplified, or changed to smooth or improve the completion of the task. The critical sub-tasks are the ones where users can have the major struggles, or where specific difficulties (e.g., organisational, technical, contextual) can lead to suboptimal performances. Hierarchical Task Analysis help outline the following:

- Key tasks and sub-tasks
- Interactions with tools and other relevant roles.

Physical Ergonomics Assessment

The physical ergonomics assessment considers a number of factors that are currently involved in the pilot's role: workstation area, indoor lighting, use of tools, noise-related hazard, microclimate-related hazard: assessment of indoor temperature, considering also seasonal variations, pollutant-related hazard, vibration-related hazard, problems arising from the use of machineries, and biomechanical overload. The data collection is performed through direct observation and direct numerical measurements (e.g., light, noise). The analysis of the data of a Physical Ergonomics assessment identifies the physical factors that should be considered for the implementation of technology, focusing on the main problems identified during the observations. The assessment has been remodelled to better fit any pilot scenario, involving the usage of

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specific methods to investigate the case as the employ of RULA method for assessing postures. These analyses have been deployed to gain a better understanding of the main issues related to the physical ergonomics aspect of the work performed. This involves initially assessing the current state and then collecting data to determine what technology can achieve in order to reduce physical effort and redesign tasks. A physical ergonomic assessment provides the following information:

- Analysis of the current possibilities for improving the physical ergonomics state
- Considerations regarding how the redesigned tasks could mitigate the emerging issues.

The methods used to analyse the qualitative data collected, offered different ways of analysing, presenting, and identifying meaningful patterns within data. In Table 2 a mapping on how the methods used for data collection are linked to the methods used for data analysis and representation is done.

Table 2. Mapping of methods used for data collection with methods used for data analysis and representation

	Methods for data analysis and representation			
Methods for data collection	**Personas**	**User Journey Maps**	**Hierarchical Task Analysis**	**Physical Ergonomics Assessment**
Semi-structured Interviews	x	x		
Observations		x	x	x

4.1.4 Phase IV: Recommend

The results from the data analysis phase were used to create specific design recommendations for each Industrial Use Case. The form used for the recommendations are the "Take Home Messages" (THM). THMs include possible design opportunities and suggestions to consider while designing HARTU solutions to mitigate the challenges identified in each pilot. Analysing the data in the AS-IS scenario gives the opportunity to highlight relevant take-home-messages and considerations that might determine and advance the design of HARTU's technological solutions, including to a higher degree the end-user needs. Moreover, having a detailed overview of the AS-IS scenarios will help thinking through the possible changes in roles, responsibilities, procedures, tasks, that will need to happen through the adoption of HARTU's solutions.

4.2 Use-Cases and data analysis

The data collection conducted during the field work in the first six months of the project, was analysed for each pilot taking into account the different use cases of interest. The data gathered was analysed through the methods described in Section 1.2.3.

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The analysed data has been included in Annex 1. The results and key findings deriving from each Use Cases analysis are displayed in Section 4.3.

4.3 Findings

In Table 3 an overview of the main findings and a list of recommendations generated through the findings are outlined for each Use Case and scenario of interest. The findings and recommendations are to be considered as Take Home Messages (THM). These examples of preliminary user needs and requirements derived from the analysis of the data collected. The source codes and job-steps illustrated in the table refer to the specific use cases' analysis from which the finding was extracted (Section 1.2). The source code is formed by the pilots' name (e.g., **PILOT**), the use case analysed (e.g., PILOT-**1**), the output from which the finding was extrapolated (e.g., P as per "Personas"; HTA as per "Hierarchical Task Analysis", PEA as per "Physical Ergonomics Assessment", UJ as per "User Journey" etc.) and the key role to which the output is mapped on (e.g., OP as per "Operator", TL as per Team Leader etc.).

User requirements and needs will be finalised together with the partners in a joint effort that will be further discussed in Section 4.4. The results deriving from the data analysis will be updated at different stages throughout the evolution of HARTU's project.

Table 3. Take Home Messages for each analysed Use Case: an overview

UC1 – TOFAS – Spare parts delivery preparation				
Ref	**Source code**	**Job Step**	**Finding**	**Recommendation**
#1	TOFAS-1/P1_OP	3.1 Inserts order's related goods in the outbound boxes	The operators often need to grasp very heavy materials (boxes weight more than 14kg) that are sometimes also slippery (e.g., plastic bags). This causes discomfort and biomechanical overload of upper limbs.	Introducing a device/crane/machine to reduce the effort perceived by the operators during the picking, lifting, carrying, and positioning activities would significantly reduce their biomechanical overload of upper limbs. The device/crane/machine would support the operators in their daily workload.
#2	TOFAS-1/UJ1_OP	2.1 Area meeting and reallocation of resources	The daily reallocation of personnel into the different working areas impacts the operators' productivity and efficiency as they interact with machinery, tools and,	Machines, tools, interfaces should have a common and homogeneous designed visual interface across the working area to increase their learnability. The operators would be facilitated by the

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			eventually, interfaces, which do not always have the same structure and visual language across the plant.	same visual information and commands to be displayed and this would in turn allow for an efficient reallocation of personnel.
#3	TOFAS-1/UJ1_TL	5.3 Reallocate resources across the area	The daily reallocation of personnel into the different working areas impacts the operators' productivity and efficiency as they interact with machinery, tools and, eventually, interfaces, which do not always have the same structure and visual language across the plant.	Team Leaders should have the opportunity to choose among the different resources available considering a number of variables as the time a specific operators spend working in the different area or the familiarity they might have with the different machinery tools or interfaces. Those variables can be better studied in order to valorise this reallocation and increase efficiency and satisfactions of operators.
#4	TOFAS-1/UJ1_OP	3.1.1 Scans the inbound box and casually picks a part	To grasp parts in the inbound box the operator needs to bend in order to reach parts that are positioned in different depths of the box.	The parts to reach in the box should be higher placed and better angled, to ensure that the operators maintain a better posture. A platform could be placed under the inbound boxes to alleviate this issue.
#6	TOFAS-1/PEA1_OP	3.1.5 Position the part inside the outbound box	To correctly position the picked parts in the outbound boxes instead of throwing them the operators necessarily need to bend in order to gently releasing them and avoiding breakages. Although, the outbound boxes, differently from the inbound boxes, are not designed to facilitate this operation because the walls of the boxes are straight, this increases the vertical displacement of	Fixed postures imposed by the boxes could be alleviated by introducing angled or adjustable platforms where parts could be easily displayed, reducing operators' discomfort postures such as deep bending of their trunks.

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			loads.	
#7	TOFAS-1/UJ1_OP	3.1.4 Move to the outbound boxes area and searches for the correct outbound box	The usage of electrical and manual forklifts it is not always practical in tight spaces and implies the necessity of increasing spatial awareness to conduct technical actions to ensure safety moving of parts. When a forklift is used, the surroundings have to be free of obstacles, which means that operators' around must not carry out their tasks while it is being used.	Forklifts should be enhanced to operate safely within dynamic environments, and thorough studies are needed to ensure the system's safety and reliability. The addition of sensors capable of monitoring movements and automatically stopping the forklift to prevent potential collisions could significantly alleviate the operators' workload and enhance overall productivity efficiency. This would enable operators to use the machine while concurrently performing other tasks within the same working area, thereby expediting operations, and ensuring safe operation.
#8	TOFAS-1/UJ1_OP	3.1.2 Scan the label on the product with the barcode reader	The barcode reader is often carried in the operators' hands limiting the operators' capabilities to grasp slippery and heavy objects.	Finding a different way to carry the barcode reader would increase productivity and reduce the workload of the operator avoiding possible slips of the parts on the ground. The system could consider this issue and find another way to scan the parts and the inbound and outbound boxes, and/or could carry a barcode reader across areas in more efficient ways. As a result, the operator should be able to grasp objects with both hands when needed.
#9	TOFAS-1/UJ1_OP	3.1.7 Inserts the quantity needed in the box and confirms	Operators use gloves to carry out most of their activities although they need to interact with some interfaces throughout the process. The gloves that they wear are an impediment to the usage	The operators need to be able to interact with a system while wearing gloves, which means that if a new system to be implemented foresees the insertion of a touchscreen it should be designed enhancing the touch sensitivity feature to

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			of the touchscreen, as the fingertips of the gloves are not designed to use a touch interface. Instead, the area on the back of their gloves does work on screens, resulting on the operators' using their back side of the hand to unlock them.	increase operators' precision in the interaction with the interface, avoiding the use of the back side of their hands or the removal of the entire glove.
UC2 – TOFAS – Kitting and pre-assembly				
Ref	**Source code**	**Job Step**	**Finding**	**Recommendation**
#1	TOFAS-2/UJ1_TL	5.3 Reallocate resources across the area	The daily reallocation of personnel into the different working areas impacts the operators' productivity and efficiency as they interact with machinery, tools and, eventually, interfaces, which do not always have the same structure and visual language across the plant.	Machines, tools, interfaces should have a common and homogeneous designed visual interface across the working area to increase their learnability. The operators would be facilitated by the same visual information and commands to be displayed and this would in turn allow for an efficient reallocation of personnel.
#2	TOFAS-2/UJ1_OP & TOFAS-2/ PEA1_OP	1.Kitting	The human-machine interaction and the communication among colleagues (human-human interactions) is affected by 83dB of sound pressure.	The value of surrounding sound pressure should be considered during the design process of potential signals and/or alerts, in order to ensure a clear exchange of information between the system and the operators, and among the operators themselves.
#3	PEA_2 [AA]	2. Assembly	Biomechanical overload of upper limbs: the task is organized in cycles and characterized by similar working gestures for over 50% of the time. The force perceived for the task in a	To reduce/improve/ the biomechanical overload of upper limbs an assessment on OP30 using the OCRA method is recommended. The results deriving from the assessment will help establishing the best

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			CR10 Borg scale is moderate (max 3 or 4) and the pace is determined by the machine.	possible solution to understand the impact of the re-designed task on the role analysed. Reductions of the force perceived will decrease significantly the presence of risk.
#4	TOFAS-2/UJ1_OP & TOFAS-2/ PEA1_OP	1.Kitting	Currently, there are containers and output boxes that are placed far from each other's, which negatively affect the vertical displacement of loads that operators need to pick and place in boxes/containers and output boxes.	To complete the task the operator should work without assuming certain postures such as bending or deep bending and twisting. Reducing the delta value [Δ] (i.e., difference between the height of the picking location and the placing location) would significantly help the postures of the roles involved in these operations.
UC3 – PCL – Handling for mass customization in the consumer goods sector				
Ref	**Source code**	**Job Step**	**Finding**	**Recommendation**
#1	PCL/ P1_OP	2. 3. 4. 5.	Finding gloves that do not tear and don't give off dust or hair and are also comfortable is a challenge for operators and their colleagues.	When considering the re-design of the task and the amount of work that will still require operators to manipulate parts, further considerations on gloves should be made to support operators and increase efficiency and comfort.
#2	PCL/ P1_OP	5. Perform quality checks	Operators do not find the lights very suitable for the new products with Ultra Deep Shine (UDS) coating as they do not help spotting out the quality of the pieces to be analysed.	To increase efficiency during the quality check process, operators should be able to set and personalize the value of light required subjectively to perform the task. Considering the standard EN 12464-1:2021, a light range specific to the lacquering line working environment should be pre-set. However, due to the different coatings of the parts

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				to be analysed in the quality check process, giving to the operators the chance to add or diminish to the pre-set range a light-value more fit to their needs, would reduce their fatigue increasing overall efficiency.
#3	PCL/ P1_OP	5. Perform quality checks	Once the operator picks two parts from the jigs, they need to visually assess the colour and search for any impurity/contamination/scratch on the surface.	This process has two main variables, the first is the time spent for these operations that variate through operators/products and the second is the angle of the manipulated product to ensure perfect angle of vision and enhance the quality check. Those two variables are extremely subjective and during the design process should be considered.
#4	PCL/ P2_TL & PCL/ P3_PE	n/a	Currently the lacquering machine is not able to indicate its status and pace, and when it breaks down, it does not give any information about what is wrong. Therefore, it is challenging to understand the status (e.g., failure mode) of the lacquering machine and when/why there are quality issues.	Team Leaders/Process Engineers/Quality Engineers should be informed by the system when failures arise so as to promptly intervene. Redesign of the system should include a way to promptly alert team leaders when failures occur.
#5	PCL/UJ1_OP	2. Collects unlacquered parts	To increase efficiency, the operators stack up to 10 trays on top of each other. However, this creates a situation where the racker has to reach up to the last layer of trays to collect them.	The design of how operators handle trays from the trolley and position them should aim to minimize both horizontal and vertical displacement. It is essential to study the sequence and frequency of operations to streamline and minimize technical actions required during the process. The line that serves the trays

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				could be regulated in order to avoid wide differences in height. This adjustment would improve the task, reducing the biomechanical overload on operators.
#6	PCL/UJ1_OP	3.1 The operator picks two parts from the tray and places on the jigs.	When the jigs are covered by layers of lacquering, the interlocking between parts and jigs get stuck. The operators doing the racking to be able to correctly interlock the pieces need to first assess whether the jigs need to be replaced according to a specific norm.	Operators, when over lacquered jigs arrive, increase the number of technical actions needed to carry out the interlocking tasks. Reducing the cutoff for determining when to change or not change jigs could significantly reduce the difficulties to interlock parts to the jigs and facilitate the overall process.
UC4 – TCA – Packaging operation in food sector				
Ref	**Source code**	**Job Step**	**Finding**	**Recommendation**
#1	TCA/P1_OP	5.3 Sorts the vegetables	The operator during the sorting activities is able to rapidly assess if the vegetable under analysis reflects the number of variables (i.e. colours, shapes, moulds, size etc.) related to the choice required for the order. Moreover, while assessing if the vegetable can be sorted for that specific choice (i.e. first choice, second choice) the operator is able to add to the equation the client needs. For example: two different clients that require a second choice product might expect a different aesthetic level of the sorted vegetables.	The sorting operation conducted by the operators involves a set of variables including the client needs and it is performed in a short timeframe (less than 2 seconds) according to the supervisors' order and requires cognitive considerations. The algorithm should be designed to enable fine tuning of parameters to be considered while sorting**.** Those differences are fundamental to prevent waste, meaning that parameters that could be considered as not optimal for a specific choice level, could still be considered valid for the specific client's needs.

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#2	TCA/UJ_OP	5.3 Sorts the vegetables	The operators when placing the eggplants in the boxes, need to cut their petiole with a scissor up to a certain length. This step impacts the quality value of the vegetable as the eggplants' petioles appearances are judged depending on their petiole's appearance.	Eggplants petioles length and appearance are determining vegetables value, meaning that their cutting operations is important. We recommend considering the petiole cutting operation while designing an automated systems or to involve operators during this process.
#3	TCA/PEA_OP	5. Sorting vegetables	The operators completing the sorting task are experiencing frequent, moderate bending due to fixed work positions. working stations/environment calls for vertical and horizontal displacement of loads. Cushioned floor mats are not provided, and the task requires standing for extended periods of time.	The workstations have a crucial effect on the operators perceived fatigue. The workspace should be designed considering optimal height of workstations to reduce vertical and horizontal loads movements. The re-designed tasks could involve long standing positions, this could be alleviated introducing cushioned floor mats, to reduce the perceived fatigue or introducing a support system for the prolonged standing posture could help alleviate fatigue among the operators.
#4	TCA/UJ3_AS	8.2 Organizes the orders	Constructing a mental sequence of deliverables can prove challenging at times, particularly under high workload conditions. The effectiveness of this task relies on the area supervisor but has a significant impact on the entire team. The area supervisor at the beginning of the shift needs to construct a mental sequence of orders to be composed before initiating the sorting task, this is so to avoid changing	The technology has the potential to significantly enhance the efficiency of this process, thereby influencing the work of the entire team. Additionally, other factors that could be considered include the requirement to preserve certain vegetables in designated areas (such as fridge cells) and the feasibility of earlier deliveries. Algorithms could suggest a more efficient sequence of loading the line and sorting the vegetables depending on the different orders specificities, taking also

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			vegetables on the line each time. In other words, if multiple clients require zucchini in their orders, the area supervisor will give instructions to load zucchini on the line and will pace the sorting tasks considering the different clients that required zucchini in the order sequentially. The loaded boxes will be then piled up in different columns and the area supervisor will strategically chose the next type of vegetable to be loaded on the line and to be sorted for the different orders. Hence, it could happen that a couple of orders require a 1st choice and another couple a 2nd choice, which adds another level of complexity. The effectiveness of this task relies on the area supervisor management abilities but has a significant impact on the entire team especially under high workloads conditions.	into account a number of factors that could increase efficiency and support more sustainable behaviour (i.e., delivery time expectancy, temperature outside fridge cells, utilize of the line etc.).
#5	TCA/HTA2_OP	5. Sorting vegetables	Nowadays operators work in a sequence that is provided by the supervisor through vocal orders to operators. In the redesigned process the operators should assist the robots providing the correct boxes of vegetables to it. The way these operations will be performed is not yet decided but concerning the cognitive workload the	The robot should provide a clear signal once the sorting activity is completed, enabling the operator to proceed with the process. However, it is crucial to ensure that the signalling system is easy to understand and not congested with multiple buzzers or overlapping information within the working area.

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			way this system will provide the correct piece of information to the operators is strategically important.	
#6	TC\A/P1_OP	5.3 Sorting the vegetables.	The task requires the capability to identify anomalies in the sorted vegetables without a strong lighting system and through meticulous visual inspection.	Enhancing the lighting in the specific area could potentially improve the task's efficiency and it is fundamental for the camera recognitions. However, it is crucial to consider the possibility of reflections on the wet vegetables and take measures to avoid them.
#7	TCA/UJ_OP	5. Sorting vegetables 6.Piling empty boxes	Considering the implementation of technology and the operator's interaction with a robotic arm in a co-working setup are crucial factors to be considered.	The redesigned tasks involve the operators feeding the machines with the correct boxes, letting the robotic arms work until the process is completed to then collect the boxes and positioning them onto the conveyor line. This redesigned process should comply with the latest standards, and it will impact on the OSH specifically on the physical, psychosocial, and organizational side.
#8	TCA/PEA_OP	5. Sorting vegetables	Loading full boxes onto the line is a repetitive task that involves lifting, carrying, and positioning the loads from different heights. The weight of the boxes variates from 5kg up to 7 kg. Creates the order pallet requires loads lifting carrying and positioning. The operator piles boxes at different levels of height, above 175 cm for the last layers, lifting boxes weighting from 5kg up to 7 kg. Picking boxes full of waste	The warehouse assistant performs a physically demanding job, and especially for tasks 1. Loads full boxes on the conveyor line, 2. Creates order pallet, 3. Collects waste, it is recommended to proceed with further analysis based on the standard ISO 11228-1 ISO 11228-2 ISO 11228-3

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			from the conveyor line and through it to the wase box is a repetitive task that requires operators move boxes from the conveyor line (initial height) up to the highest point of the waste boxes (final height), weights vary.	
#9	TCA/UJ3_AS	8.4 Manages the creation of the outbound pallet.	The process of supervising is on the area supervisor. Different actions are performed throughout the shift and there is the possibility of making mistakes, especially in a period of high workload.	The technology has the potential to provide improved support for these operations by serving as a third eye on the tasks performed and assisting in error correction. It could enhance the accuracy and efficiency of tasks such as printing the right information to affix on boxes, counting operations, especially on the creations of pallets and weight registering and reporting, operations that nowadays are performed manually without any specific support or technology assistance.
UC5 – INFAR – Fixtureless assembly in hand tool manufacturing sector				
Ref	**Source code**	**Job Step**	**Finding**	**Recommendation**
#1	INFAR/UJ1_OP	3.Perform the assembly	Demanding tasks are assigned to specific operators who may develop specialized skills. However, the prolonged pinch posture required by these tasks can place significant strain on the operator, increasing the risk of injury or discomfort.	To mitigate the challenges that the nature of the operations requires, careful considerations on the workstation design should be given. The workstation design, with a specific attention to the desk layout, should minimize frequent handling or movement of wrenches and parts, especially those that imply the presence of the pinch grip. The repetitiveness of the tasks should be avoided in order to create sequences

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				where the operators can alternate the movements performed reducing stereotypies.
#2	INFAR/UJ1_OP	3.Perform the assembly	The operator works mainly seated upright without backrest. Bending forward and frequent twisting of trunk are required to finish the task.	Postures currently used are not recommended and require redesigning of the process. Biomechanical overload and awkward posture are to be considered when redesigning the work layout and implementing adjustable working desks and supports to reduce discomfort through operators.
#3	INFAR/UJ_OP	1 Receives information on the activity to perform from the MES.	The operators need to move across the area to receive the information provided from the MES.	The information could be displayed in a different way reducing the necessity for the operators to move across the area.
UC6/UC7 – ULMA – Order preparation				
Ref	**Source code**	**Job Step**	**Finding**	**Recommendation**
#1	ULMA_UJ1_OP	1.1. Check items to be added to the pallet	The system currently slows the operation as it signals the amount of items needed for the order in a small part of the computer display, highlighting the current orders and not considering upcoming orders.	The user should be provided with an interface where more detailed information about the orders are displayed (e.g., the type of items arriving, and the upcoming items after). This would significantly help the user to have a clear overview of current as well as upcoming orders to support the planning of his tasks and have a full supervision of the system.

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#2	ULMA_UJ1_OP	1.5. Moves to the pick-to-light area to extract items needed from light boxes	Operators are slow down in their process whenever they need to include only one or two light items into an order as currently items are boxed in triplets. When this happens, operators need to unbox the items needed, extract the number of items required in the order, re-box them to insert them in the pallet and write on the box with the remaining items the number of items that can be found in the box after the extraction of the ones needed.	The user should be provided with individually stored items to manage the handling of individual items. This would help the user in reducing time devoted to the unboxing of the items needed (if less than 3) and help the user in reducing possible errors counting items.
#3	ULMA_UJ1_OP	2. Picking rack re-stock	The operator in the picking of the light boxes does a repetitive movement, as well as a cognitive effort in reminding how many boxes (or items) he putted in the rack, and how many he still needs to put. The display and the computer do signal the number of items needed and not the number of boxes (each box usually contains three items). So it can happen that, especially when there are a higher number of items to count the operator makes mistakes placing the wrong number of items on the rack.	The user should be provided with external support to count the items loaded on the orders as well as those still missing. The system could help by making easier the retrieval of the right number of items and/or maintain the counting of the items while the operator is loading the order. This would reduce possible errors when counting items. If the operations were to be substituted by the new system, would still be significant for the operator to successfully monitor the process.
#4	ULMA /PEA1_OP	1. Pallet Forming	Operators often bend their trunk during pushing and pulling, and their hands are often held under 60cm during the forming of the pallet, and during the pushing and pulling of loads as it uses vertical	The operators should assume better postures in case of manual settings of the pallet, avoiding holding loads below the 60cm. The redesigned line should consider a different height according to the standard ISO 11228 -1 & ISO

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			force (partial lifting)	11228 - 2.
#5	ULMA /PEA1_OP	1. Pallet Forming	Operators currently use cranes implemented in the heavy weight picking area to help them handling heavy cans. However, the height of the prehensile handles is positioned above the elbows and higher than the maximum reached point for some operators whom, as a result, need to stretch the entire body to reach it.	The operator could be facilitated in the reaching of the crane if the system were designed in such way that it could recognise the operators' height and set and adjust its handling point to avoid scratches or jumps.
#6	UJ_WM	n/a	Whenever the operator finds in the line a damaged good to be replaced, he/she needs to contact the warehouse manager who will promptly and manually re-insert the order into the warehouse management software.	When a product is damaged or leaking, the new system should be able to: a) signal the problem to a monitoring operator that can intervene and call the warehouse manager as it is done now. b) automatically assess the damage and the number of items to be changed and communicate the information to the warehouse manager. c) automatically assess the damage and the number of items to be changed and replan the order from the warehouse. In the first case (a) the system should be provided with an alarm to recall the operator's attention.

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#7	UJ_WM	n/a	The warehouse manager needs to promptly know how many damaged items were replaced to ensure correct inbound orders and to always maintain an updated and organised inventory.	The warehouse manager should be always updated on the missing, damaged and/or replaced items to ensure an updated and organised inventory.

4.4 Co-designing workshops to delineate the TO-BE scenarios and next steps

The Take-home-messages played a crucial role in addressing a set of needs and outlining considerations for further exploration in terms of technology and its design, or human intervention and the way humans will need to interact with the technology to assist, cooperate, or collaborate with it in different tasks of the overall processes.

During the second face-to-face meeting of HARTU (23-25th October 2023), three workshops were conducted in order to explore, together with all the partners, the evolution of future TO-BE scenarios. The primary focus of the activity was to engage participants in reflecting on the role of humans in the imagined new scenarios and to imagine what is expected of them to support the system and intervene appropriately based on system requirements and needs. Understanding the system and delineating how the human role can get involved, being responsible for more cognitively engaging activities while also interacting with the technological system helps outline user requirements.

To initiate the co-designing sessions, a quick revision of the AS-IS Hierarchical Task Analysis was conducted, emphasising the current roles of operators and considering how and where they perform their tasks. Then, the most advanced version of the technological concepts derived from D1.1 was presented, highlighting what the robot can/cannot do at the moment considering its demonstrators' design, the associated risks identified by the technical partners as general limitations, and their possible mitigations.

Figure 59. One of the three co-design workshops carried out during the progress meeting

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At this point, the exercise revolved around a printed canvas representing 4 main areas of interest:

- Tasks (Operator)
- Tasks (Technology)
- Communication
- Risks
- Environment

The current tasks carried out described in D1.1 were printed out on cards that could be moved around the canvas. The moderator read the first task related to the technology and placed it onto the “Tasks (technology)” line. At this point, the moderator started asking whether any risks could be occurring and whether information as an input or output was expected to be delivered from the technology to the operators (and vice versa) in those cases the moderator collected the answer on a set of post-it and placed them on the corresponding task of the canvas. Depending on the type of information or communication exchange needed at the time, tasks that a human role might need to carry out could arise. These tasks were added to the Tasks (Operator) template row.

The purpose of the workshop exercise was to prompt reflection on the communication flows necessary between technology and humans to effectively support each other. This involved considering what kind of information is to be shared and when, and how humans can support the system in case of failures or unexpected situations. It also considered the surrounding environment and how it can affect the new task, sharing of information, and the associated risks. The development of a new task analysis focusing on the TO-BE scenarios and including two different actors (technology and humans) was the output of the workshops and can be found in Annex 2. The task analysis is to be considered a first step that should be repeated until the technological system comes to its completion and its final design. This essential exercise will be conducted individually in the different team groups, as well as jointly in the consortium to successfully design the new process. The interactions that emerged in the workshop will be used as input for T1.3 and T1.4. After this activity, and when the technological system is at a more mature stage it will be necessary a new set of reviewed HTA, User Journey, and Personas identifying user needs and setting parameters for the TO-BE context.

5 Ethical and Legal aspects

Alongside user requirements, Ethical and Legal aspects cannot be underestimated. These may affect the solutions' trustworthiness as well as their acceptability in the medium-long term. Therefore, it is advisable to take into account these aspects from the first phases of the project, when designing a technical solution. This will facilitate the innovation process, preventing the possibility that legal and ethical issues would act as showstoppers for the development and deployment of new technologies.

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It should be noted that the ethics assessment methodology has been developed by Deep Blue and previously implemented by Deep Blue in the XMANAI Research Project.

Similarly, the legal case methodology has been produced by Deep Blue and implemented in research projects in the aviation domain such as ARGON, AEON, and HAIKU."

5.1 Ethics model

5.1.1 AI ethics evaluation framework in manufacturing

The Ethics Guidelines for Trustworthy Artificial Intelligence (AI) is a document prepared by the High-Level Expert Group on Artificial Intelligence (AI HLEG), an independent expert group was set up by the European Commission in June 2018, as part of the AI strategy.

The AI HLEG presented a first draft of the Guidelines in December 2018. Following further deliberations by the group in light of discussions on the European AI Alliance, a stakeholder consultation and meetings with representatives from Member States, the Guidelines were revised and published in April 2019. Based on these specific Ethics Guidelines for Trustworthy AI, an AI system should have three main characteristics: be lawful, ethical and robust, to do so seven main requirements have been defined by the expert group.

While the document from the European Commission Expert Group is one of the most relevant addressing ethical issues for AI, many other contributions exist, and, as highlighted by Hagendorff (2020), there are some issues related to the implementation of the identified guidelines: there are not mechanisms to ensure the compliance with the various codes of ethics, there are no consequences in case of deviations. Also, there is the risk to use ethics as a marketing strategy. There is the need to bridge the abstract ethics values and the technical implementations, to have effective ethical AI systems. Thus, the implementation of ethical guidelines should be tailored accordingly to the specific context of AI application (Floridi, 2019) and starting from the design phase, with an AI ethics that look at individual situations and specific technical assemblages (Hagendorff, 2020).

As discussed, there are many recommendations for how to ethically design AI, but very few frameworks to support ethical AI evaluation and development. Moreover, when it comes to the failures of such systems, very little is documented on how their consequences can be contained. Most literature seems to simply warn of the risks of its failure, not on their mitigation and response. Furthermore, at the moment there is a lack toward specific framework for the manufacturing sector, while at the same time several studies highlight the ethical risks of introducing AI in the industrial sector such as in the case of loss of human skills (Torresen, 2018), and automated decision-making (Mpofu & Nicolaides, 2019). Another emergent risk, particularly relevant also in the manufacturing sector, is the liability and responsibility of AI activities (Coeckelbergh, 2020), which should be clearly defined. Explainability and transparency are a way to improve and answer liability concerns.

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5.1.2 Ethics framework

The AI ethics evaluation framework is applicable to any AI technology and solution, already existing or to be designed. The approach, that it is explained in the next section, wants to be a holistic approach, that considers both the AI technology to be implemented and the context where it is implemented (see Figure 60).

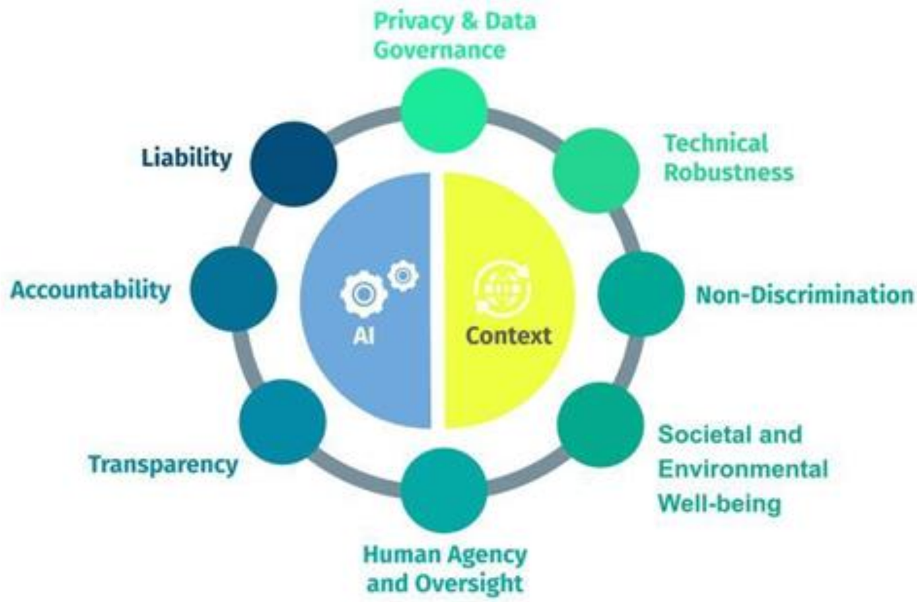

Figure 60. Framework dimensions and concept

A set of dimensions covering different ethical aspects have been defined starting from the proposal of the European Commission High-Level Expert Group on AI, with the addition of a specific dimension added to evaluate specifically the risks regarding the liability of AI.

The framework is designed to be applied with an iterative approach along the duration of the project to evaluate and monitor, during the different stage of HARTUs implementation, the ethical risks, and understand if the mitigation measures identified during the first iteration are effective. In the next section is presented the implementation process of the framework.

The framework dimensions are presented and described in Table 3 . Description of dimension and sub-dimensions of the framework.

Table 4. Description of dimension and sub-dimensions of the framework

Dimension	Description	Sub-dimensions
Privacy and Data Governance	Only essential data for achieving the process is to be used for processing by the AI system. Suitable anonymity is to be kept at the time of algorithm supervision.	Respect for privacy – Full GDPR compliance at all stages Quality and integrity of data – Checks in place to ensure truthful inputs and outputs

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Dimension	Description	Sub-dimensions
		Legitimised access to data – Protection measures in place for users when accessing their data
Technical Robustness and Safety	AI algorithms should include security measures protecting the parties whose data is being processed by the AI. The integrity of the data needs to be protected by breaches and system failures.	Resilience to attack and security – Security measures put in place to protect data Fault tolerance and general safety – Emergency measures in case of system failure Accuracy – Measures in place to maintain accuracy and avoid misinputs or human error Reliability – Tested for consistency before deployment Reproducibility – Sufficiently documented for easy reproduction in case of failure
Diversity, Non-discrimination and Fairness	Inclusion and diversity must be considered, to avoid biases that could be included in the models due to data used. Biases could lead to discrimination and harm to certain groups of people. Consequently, action must be taken to avoid said biases.	Avoidance of unfair bias – Checks on the algorithm preventing marginalisation of groups Accessibility – The system must be accessible to stakeholders with disabilities and impairments Universal design – Stakeholders involved throughout design and operational lifecycle
Societal and Environmental Well-being	Clear system documentation for the upskilling and reskilling of upcoming AI system operators. Environment variables taken into account for environmentally-conscious system design and operation.	Adaptability – Impact on workers (reskilling/upskilling) Environmental impact – Monitoring for environmentally friendly decision-making Social impact – Monitored effect on communities affected by the AI decision-making Fundamental rights – Sustaining human rights
Human Agency and Oversight	AI algorithms should be accessible for oversight from all stakeholders. Human supervision is required to re-establish agency to human supervisors and regain control over decision making processes involving AI.	Human oversight – human supervision for every stage of the algorithm Human agency – The ability for human modification of AI at any point
Transparency	AI should have systems in place to make the algorithm traceable and explainable at every stage of the process. Model weights should be accessible and	Traceability – Full operational traceability ensuring correct operations at each stage of the AI process

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Dimension	Description	Sub-dimensions
	understandable through component analysis. Inputs and outputs need to be clearly outlined.	Explainability – Each stage of the process should be explainable to stakeholders Awareness – Humans need to be aware of the AI system and its capabilities/limitations
Accountability	Automatic auditing measures should be put in place to easily identify and highlight flaws in the system. Version control must be used to revert harmful changes and identify failing areas for easier and faster modification.	Auditability – Measures in place to make the system easy to examine and evaluate Impact – Negative impacts considered and reported, measures in place to minimise it Redress – Easy modification of failing areas/systems
Liability	All parties involved with the AI system and products of its operation need to be made aware of the possible hazards and failures and how reliability can be traced back to each party.	Liability clarity – It is clear where the liability of the systems can be traced back to each actors involved

5.1.3 Implementation of AI ethics evaluation framework

The AI ethics evaluation framework aims to facilitate a systemic and contextual approach to the ethical issues related to the design, development, and implementation of these new technological solutions. In particular, the main three goals of this tool are:

1. promoting a user-friendly approach from a fair reading of contextual ethical issues;
2. facilitating a dynamic and ongoing understanding of ethical principles in practice;
3. introducing a consistent assessment methodology for a handy and fair trade-off of the competing interests at stake, also considering each new technological solution that could be implemented.

The AI ethics evaluation framework implementation is based on a four steps iterative process (see Figure 61).

Figure 61. Ethical framework implementation process.

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The general implementation of the framework, which will be used in each project demonstrator during tasks T1.3 and T1.4, is presented below.

STEP 1: MAPPING

At first, the evaluator shall map the ethical dimensions of the technological solution at issue. The referral ethical dimensions are those previously defined in the AI ethics evaluation framework description (see Table 4).

For each of these dimensions, the evaluator shall use the additional subsets of ethical benchmarks to obtain a granular representation of the performance of the technology assessed (i.e., technical robustness: resilience to attack and security, fallback plan and general safety, accuracy, reliability, reproducibility, etc). This procedure aims at defining qualitative and quantitative indicators for the precise evaluation of every single dimension considering the specific performance of each subset of principles.

For the sake of consistency and to ensure a systemic approach to ethics, it is advisable to keep the integrity of the ethical framework. In particular, it is important to define this further consequential subset into only one consolidated and shared matrix, then available to all the stakeholders involved in the project. A similar approach is suggested in all industrial branches, even with the mediation and support of specific ethics committees and sectoral representative entities. A specific data collection tool will be prepared where all the dimensions and the related sub-dimensions will be evaluated with a specific statement, each statement will be evaluated from 1 to 5 (1 very low – 5 very high).

Once these points are defined, the collection of data and insights for the assessment should be tailored according to the maturity and scalability of the technologies considered, and for the different industrial contexts. A responsible for each demonstrator should be identified, that can have access to the information needed, and follow the process during the time of the implementation of XAI (eXplainable AI) solution in the project's timeframe.

STEP 2: ANALYSIS

Secondly, in light of the evidence obtained, the evaluator shall analyse the overall ethical performance of the XAI solutions evaluated. Spidergrams or other visual representations may facilitate a systematic visualization since these tools allow us to consider the results obtained in all the different ethical dimensions in a unitary context (see Figure 62).

The ethical performance of the technological solutions should be approached according to the priorities of the reference manufacturing domains, taking care of the positions of the human actors and addressees directly and indirectly involved.

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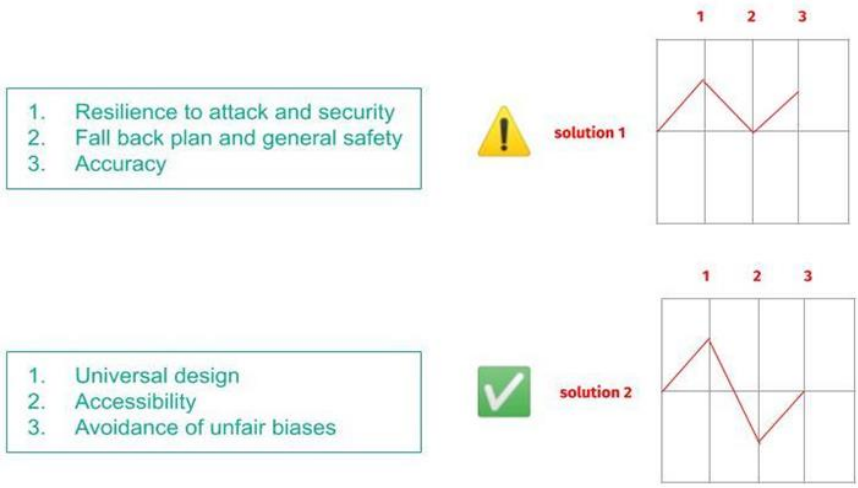

Figure 62. Example of possible results emerging from the analysis conducted in step 2 analysis

The analysis will provide a clear picture of the risks associated with the ethics of XAI and have the goal of informing demonstrators about the status related to ethics of the XAI implementation and development.

STEP 3: MITIGATIONS

Thirdly, where required by the results obtained, the evaluator shall consider the design of appropriate mitigations.

The comprehensive vision provided by the framework allows easy comparisons among the possible different solutions (e.g., by considering different XAI models, and explainability tools associated with the demonstrator). The analysis can cover existing competing solutions as well as the improvement of the new ones in light of the adjustments that occurred after the implementation of the suggested mitigations.

STEP 4: MONITORING

The implementation of the framework should culminate with the creation of an interactive dashboard aimed at monitoring the results of the different solutions over time (see Figure 63).

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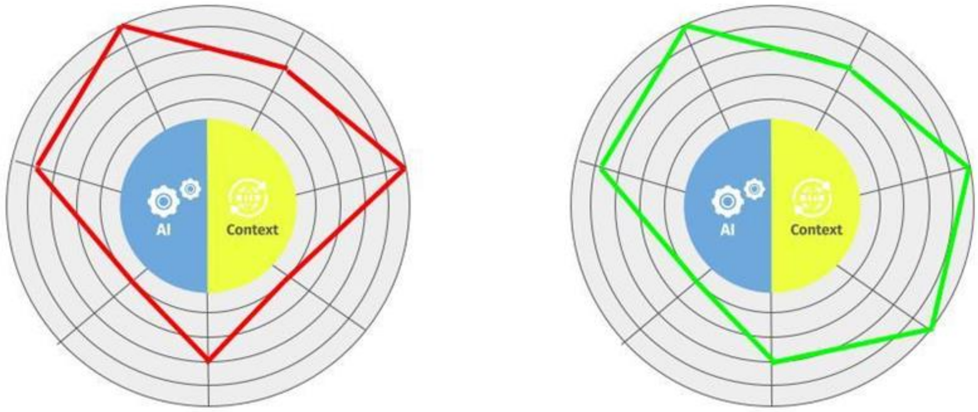

Figure 63. Example of possible dashboard of final results of ethical assessment

In particular, the proposed approach aims to promote a diachronic and scalable reading among the results for the single algorithms and process or procedure considered as a whole. Once implemented, the dashboard shall facilitate the introduction of new forms of automation in the framework for bias-suspect reporting, allowing a dynamic, real-time and participatory assessment of ethics. An iterative approach is envisaged in the periodic application of the process.

5.2 Legal Case

The Legal Case is a methodology with an associated tool intended to support the integration of automated technologies into complex organisations. Its purpose is to address liability issues arising from the interaction between humans and automated tools, ensuring that these issues are clearly identified and dealt with at the right stage in the design, development, and deployment process. This section introduces the method, showing its purpose, the way it is structured, and the process specifically applied in the reported project.

5.2.1 Purpose and scope of the method

The Legal Case (Contissa, et al., 2013) can be applied to any concept involving automation, i.e., the use of automated technology, including those based on AI. By automated technology, we mean any "device or system that accomplishes (partially or fully) a function that was previously carried out (partially or fully) by a human operator". Two key elements are implicit in our characterization of automation:

1. Automation is not all-or-nothing. In most cases, automated systems do not fully replace human activity but rather change it, in a way that depends on what tasks are supported by automation, on the extent to which human performance is involved, and on the impact on that performance.
2. Automation is not tantamount to modernization or technological innovation as such. It covers only those cases where technology has an impact on human activities, and in particular on the interaction between humans and machines. For example, updating a

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computer with a more powerful system does not necessarily amount to increased automation, nor does an improvement in multi-radar tracking performance, which only implies a reduced radar-update time or more-accurate surveillance data. Our analysis is focused on the cooperation or co-agency between the human and machine when performing certain tasks and on the ensuing changes in the human operator's roles and responsibilities.

The Legal Case has been designed to be flexibly applied across all the phases of maturity in a system's life cycle. The methodology can be applied both proactively and retroactively, depending on the maturity phase of the technology; the Legal Case analysis will rely on different types of background information, hence, it can be used for different purposes, and will provide different sorts of output.

The Legal Case is primarily intended for use in a proactive way during the design phase of a new operational concept/system, the point is to be able to address possible legal issues arising in the future from Development of safety, HF and security approaches for Human Intelligent Assistance Systems potential accidents or malfunctions. Indeed, the Legal Case is expected to provide important benefits if used early in the design phase, when remedies can be implemented in a cost-effective way. The application of a proactive process is expected to be systematically and periodically applied during the design process in order to assess at different levels of concept maturity, the legal issues of the systems being developed in HARTU.

It is worth noticing that in none of these cases the Legal Case is intended to apportion liability and blame people or the organisation, conversely it is intended to enforce the safety culture of the organisation making all the actors involved aware of the liability risks associated with their roles, tasks and activities and proactively identify suitable mitigations.

5.2.2 The process

The Legal Case process consists of the following four steps:

- **Understand context and concept**: This step involves collecting and elaborating background information about the object of the study so as to understand its socio-technical and normative aspects. The information collected concerns the operational concept itself, the context of its deployment, and the legal and regulatory aspects. This step includes the identification of the level of automation of the concerned ATM system, its impact on roles, tasks and responsibilities and a set of UCs considered relevant for the following legal analysis. Where available, the solutions adopted according to the LbD approach may inform and feed this analysis.

- **Identify liability issue**s: This step involves identifying the possible liabilities related to the object of the study and determining the associated liability risks.

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- **Address the liability allocation**: This step involves analysing the acceptability of liability risks for all stakeholders, proposing mitigations that may improve liability allocation, and making design recommendations accordingly.
- **Collect findings and Systemic Analysis**: This step presents the results of the study, highlighting the liability issues associated with the object of study and the ways to deal with legal risks, as well as making further recommendations.

The application of this methodology requires the use of special tools, also known as argumentation maps. These means are based on the applicable legal requirements to each of the actors involved in the development and deployment of new technology, providing relevant insights about the legal regime applicable to producers, deploying organisations and end-users. More specifically, the maps provide the logical representation of the factual conditions that may confirm a liability hypothesis according to a cause-effect approach (i.e., if these factual conditions may be true, this actor is exposed to liability risks in using this technology).

Comparing the results obtained for each subject, the Legal Case allows for identification by design and by default mitigations to improve the liability risk exposure of the subjects more impacted by the introduction of a modern technology.

5.3 Next steps

Against this background, the next step will be the definition of state-of-the-arts about AI ethics and legal framework in manufacturing. The study will provide an overview on the specific legal and ethical issues that may affect the development and implementation of AI-based solutions in this sector. In light of the results obtained from the user research workshop, this framework will be used for the ethics and liability assessment of each use case. The outcomes will help teams how to design a technology able to support roles throughout their changing task and workflows, mitigating possible legal and ethical risks. These recommendations can be seen as preliminary requirements for the case specific scenarios. Such insights should be considered to design a better technological solution.

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7 Annexes

8 Annex 1: User research data collection

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