Handling with AI-enhanced Robotic Technologies for flexible ManUfacturing

D1.1
Real world scenarios and metrics for validation definition

Deliverable ID:	D1.1
Project Acronym:	HARTU
Grant:	101092100
Call:	HORIZON-CL4-2022-TWIN-TRANSITION-01
Project Coordinator:	TEKNIKER
Work Package:	WP1
Deliverable Type:	R-Document, report
Responsible Partner:	FMI
Contributors:	ALL
Edition date:	30 June 2023
Version:	07
Status:	Final
Classification:	[PU]

This project has received funding from the European Union's Horizon Europe - Research and Innovation program under the grant agreement No 101092100. This report reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

HARTU Consortium

HARTU "Handling with AI-enhanced Robotic Technologies for flexible manufactUring" (Contract No. 101092100) is a collaborative project within the Horizon Europe – Research and Innovation program (HORIZON-CL4-2022-TWIN-TRANSITION-01-04). The consortium members are:

1	Tekniker	FUNDACION TEKNIKER (TEK) 20600 Gipuzkoa | Spain	Contact: Iñaki Maurtua inaki.maurtua@tekniker.es
2	DFKI German Research Center for Artificial Intelligence	DEUTSCHES FORSCHUNGSZENTRUM FUER KUENSTLICHE INTELLIGENZ GMBH (DFKI) 67663 Kaiserslautern | Germany	Contact: Dennis Mronga dennis.mronga@dfki.de
3	aimen	ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE (AIMEN) 36418 Pontevedra| Spain	Contact: Jawad Masood jawad.masood@aimen.es
4	ENGINEERING	ENGINEERING INGEGNERIA INFORMATICA S.P.A. (ENG) 00144 Rome| Italy	Contact: Riccardo Zanetti riccardo.zanetti@eng.it
5	TOFAŞ	TOFAS TURK OTOMOBIL FABRIKASI ANONIM SIRKETI (TOFAS) 34394 Istanbul | Turkey	Contact: Nuri Ertekin nuri.ertekin@tofas.com.tr
6	PHILIPS	PHILIPS CONSUMER LIFESTYLE BV (PCL) 5656 AG Eindhoven | Netherlands	Contact: Erik Koehorst erik.koehorst@philips.com
7	ULMA	ULMA MANUTENCION S. COOP. (ULMA) 20560 Gipuzkoa | Spain	Contact: Leire Zubia lzubia@ulmahandling.com
8	deepblue	DEEP BLUE Srl (DBL) 00193 ROME | Italy	Contact: Erica Vannucci erica.vannucci@dblue.it
9	FMI ImProvia	FMI HTS DRACHTEN B.V. (FMI) NL-4622 RD Bergen Op Zoom, Netherlands	Contact: Floris Goet floris.goet@fmi-improvia.com
10	TECNOALIMENTI	TECNOALIMENTI S.C.p.A (TCA) 20124 Milano | Italy	Contact: Marianna Faraldi m.faraldi@tecnoalimenti.com
11	Politecnico di Bari	POLITECNICO DI BARI (POLIBA) 70126 Bari | Italy	Contact: Giuseppe Carbone giuseppe.carbone@poliba.it
12	OMNIGRASP	OMNIGRASP S.r.l. (OMNI) 70124 Bari | Italy	Contact: Vito Cacucciolo vito.cacucciolo@omnigrasp.com
13	ITRI Industrial Technology Research Institute	INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE INCORPORATED (ITRI)	Contact: Curtis Kuan curtis.kuan@itri.org.tw
14	INFAR INFAR INDUSTRIAL CO., LTD.	INFAR INDUSTRIAL Co., Ltd (INFAR) 504 Chang-hua County | Taiwan	Contact: Simon Chen simon@infar.com.tw

Funded by the European Union

Document history

Date	Version	Status	Author	Description
15/05/2023	01	Draft	FMI	Merged individual use case descriptions
15/06/2023	04	Draft	FMI	Reviewed all edits. Added company info from proposal to intro section of use cases.
21/06/2023	05	Draft	FMI	Reviewed structure for requirements and risks.
26/06/2023	06	Draft	TEK	Reviewed. Final contributions requested
30/06/2023	07	Draft	TEK	Final submitted

Funded by the European Union

Public Executive Summary

HARTU sets out to deploy new technologies in different relevant industrial use-cases. This document has been compiled based on input from each of the consortium members and describes the scenarios of 5 industrial partners in more detail:

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

Each use case is individually described in detail in chapters 2 to 8. A systems engineering approach was used to determine the requirements of the planned demonstrator for each use case. As such, each chapter is structured in a similar way.

- Section 1: Introduction
- Section 2: Use case description
- Section 3: Demonstrator design
- Section 4: Technical risks

The common and individual requirements are presented in Section 9. Finally, the result of a very preliminary Risk Assessment in presented Section 10.

.

Funded by the European Union

Table of contents

Funded by
the European Union

Funded by the European Union

List of figures

Funded by
the European Union

Funded by the European Union

List of tables

Acronyms

List of the acronyms	
WMS	Warehouse Management System
MFC	Material Flow Control
CAD	Computer Aided Design

Funded by
the European Union

1 Introduction

1.1 Industrial use-cases

HARTU sets out to deploy new technologies in different relevant industrial use-cases. This document describes the following scenarios in more detail:

Use-case	Industrial scenario	Sector
TOFAS: • UC1 – Spare parts delivery preparation • UC2 – Kitting and 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

1.2 Structure of the document

A systems engineering approach was used to determine the requirements of the planned demonstrators for each use case. As such, each use case will be structured in a similar way.

- **Section x.1: Use case description** – First, the initial (as-is) state is described, supplemented with key figures regarding the process, its inputs, and outputs. Second, a target state is described, emphasizing the relevance of the system to be developed for the use case provider.

Funded by
the European Union

- **Section x.2: Demonstrator design –** A system is proposed based on the described use case that tries to fulfil the posted requirements.
- **Section x.3**: **Technical risks** – Any risks associated with the development of the demonstrators should be signalled as early as possible.

Afterwards, there are two additional sections:

- **Section 9: Requirements –** Can be broken down into user requirements and system requirements.
    - **9.1: User requirements** – Describes what each potential user needs the system to do. Consists generally of non-technical statements written from a user perspective.
    - **System requirements**
        - **9.2: Functional requirements** – A description of the system's features. How should the system fulfil its intended purpose?
        - **9.3: Non-functional requirements** – How well should the system perform its actions?
- **Section 10: Preliminary Risk assessment –** A Preliminary risk assessment of the different use cases.

1.3 Ethics and human factors

In the first six months of the project, DBL carried out targeted field-work observations and interviews with the relevant roles involved in the analysed use cases. The purpose of these data collection activities was to investigate the Human Factors related to the different scenarios, aiming to gain a better understanding of the current processes, how the tasks are carried out, and the current end-user's needs and challenges.

The analysed aspects included both characteristics associated directly related to the interaction between the different roles, and those between the human and the currently used systems in the production processes in their daily tasks (at least for those ML/LLs that are already semi-automated in contingent production processes).The need to collaborate with other members of staff and operations, the skills and competencies currently required to work effectively with the provided systems, or the comfort of the working environment (analysed through the lens of Physical Ergonomics) are important elements that need to be considered when designing a new technological solution.

The definition of the current "context of use", which will be delivered in D1.2 (M10), aims to support the initial set-up of the real world scenarios, providing information to the designers and technology providers on the circumstances in which the designed solution will need to operate in relation to:

- **Roles, Procedures and responsibilities**: Actual/prescribed working methods, positions/functions in the organisation and expected tasks performed by relevant roles;
- **Working Layout and Environment:** The workspace, the general equipment and machinery used, and the physical environment;
- **Skills and Competencies:** The systematic development of competencies required by individuals to adequately perform their work;

Funded by the European Union

- **Human in the system:** The actions, reactions, and interactions between humans and other system components;
- **Teams and communication**: How people work and communicate with each other on shared goals and tasks.

The user needs are preliminary insights forming part of the broader working system that will be impacted by the integration of HARTU's solutions and that will need to be taken into account to ensure a smooth technological transition.

Moreover, a particular attention in the project will be devolved to the identification of ethical issues associated with the design, development and use of HARTU's AI-based solutions. Aligning with the great effort that the EU is making to promote the development and deployment of a trustworthy AI, DBL will adopt a Legal Use case methodology to analyse ethics and legal aspects related to the deployment of AI based handling systems. In this regard, the Legal Case will allow 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. In D1.2 a preliminary description of the ethics and protection methodology will be put in place to be then carried out during T1.3 and T.14 (of WP1). During T1.3 and T1.4 a living document will be generated and shared with the partners, in order to reinforce the ethical safeguards and allow the consortium to better explore the consequences (positive or negative), of the introduction of HARTU's solutions in the use cases. The document will be frequently updated to ensure compliance with the European Union's Ethical Guidelines for Trustworthy AI: (i) respect for human autonomy, (ii) prevention from harm, (iii) fairness and explicability.

As a result, the Ethical and Legal requirements will be tackled in future deliverables as a result of the work done in T1,3 and T1.4

Funded by the European Union

2 TOFAS-1: Spare parts delivery preparation

2.1 Introduction

TOFAS manages more than 63.000 different product references in its spare part warehouse. The preparation of spare parts order preparation for their dealers is done by operators and it is a source of ergonomic problems and is not error-free.

Automation of the process is challenging due to the huge number of references.

2.2 Use case description

2.2.1 Initial state

2.2.1.1 Process

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).

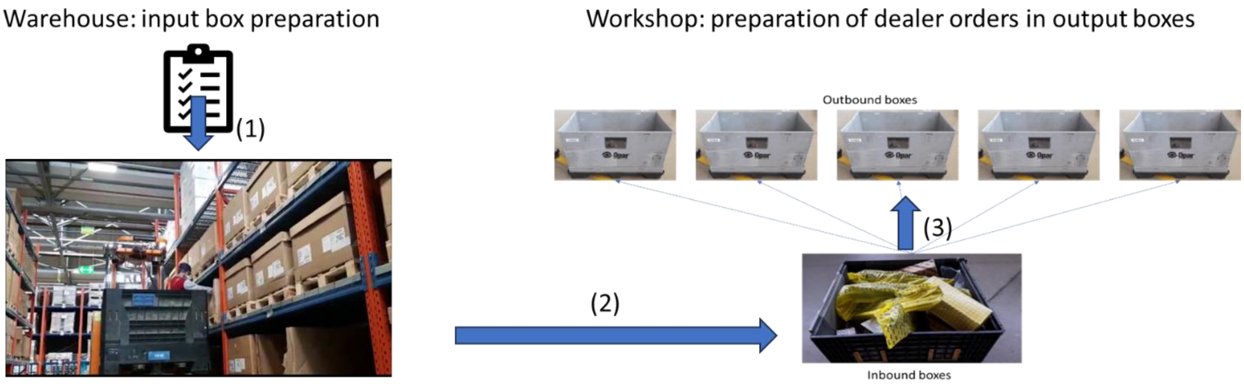


Figure 1. Input box preparation in the warehouse (1) and (2)

Everyday (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.

Funded by the European Union

(4)

(5)

Figure 2. Order preparation at the workshop

The process in the TOFAS warehouse can be seen in this video: HARTU-TOFAS-OrderPreparationArea-2-mute.mp4.

2.2.1.2 Inputs

- Environmental conditions
  - Temperature: Min 6 / Max 45 °C
  - Relative Humidity: Max 90%
- Personnel
  - 30 operators are required to carry out the process (in two shifts).
  - Operators receive one day training on how to perform their work.
- Materials
  - Spare parts: around 63.000 different spare parts are handled at the plant. They are packaged in cardboard boxes or plastic bags, or not packed at all.
  - Full inbound and empty outbound boxes.
  - Barcode reader.
  - For handing some heavy parts, they use manual forklifts.

2.2.1.3 Outputs

- Outbound boxes to be delivered to the dealers.
- No waste material is produced.
- Above 220 different dealers.
- As an average, 600 outbound boxes are prepared per day.

2.2.2 Product specifications

Most spare parts are delivered using the outbound boxes shown in Figure 3 and Figure 5.

However, in some cases the number of spare parts to be delivered is small and it does not justify the use of such a big container. In these cases, smaller carboard boxes are used, as shown in Figure 6. The dimensions of the most commonly used cardboard boxes are:

- 70x38cm h=37cm
- 36x20cm h=42cm
- 98x48mm h=50cm
- 18x52cm h=64cm

Funded by the European Union

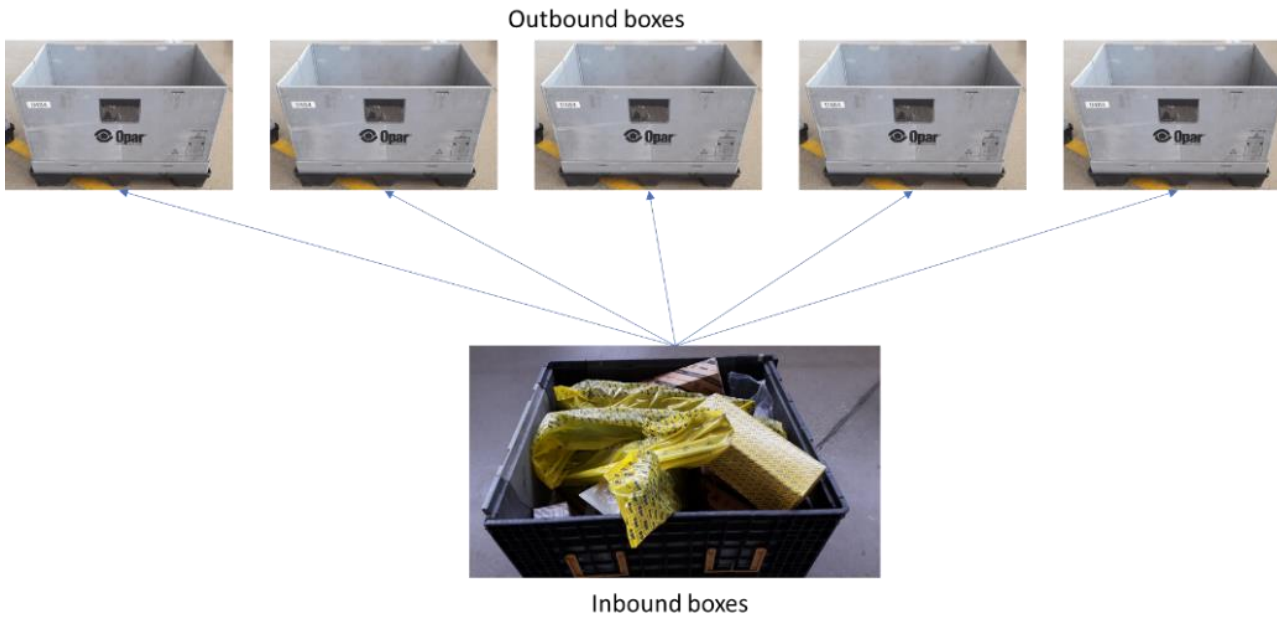


Figure 3. TOFAS order preparation overview

The two types of boxes (input and output) have the following dimensions:

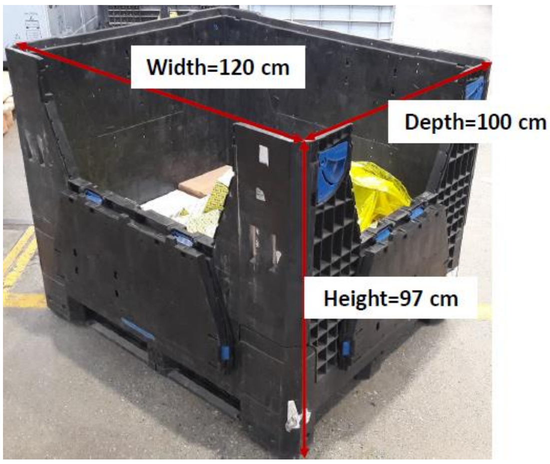


Figure 4. Inbound box dimensions (TOFAS)

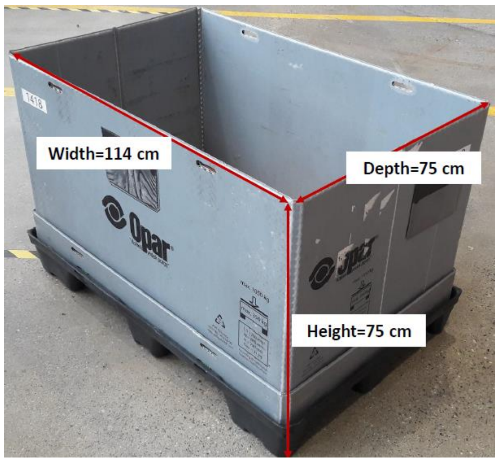


Figure 5. Standard outbound box dimensions (TOFAS)

Funded by
the European Union

Figure 6. Different outbound boxes, including small cardboard boxes

Figure 7. Spare parts inside cardboard output boxes

Figure 8. Spare parts inside big, standard output boxes

Funded by the European Union

2.2.3 Key figures

Key figures:

- 63.000 spare parts.
- Average cycle time: 45 seconds/part.
- The error rate is 0,03 % of the total (loading of an incorrect part into the output boxes).

2.2.4 Target state

Based on the experience gained in the Horizon 2020 PICKPLACE project these constraints are introduced:

1. 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 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.


Figure 9. Example of different plastic bags used for packaging

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.

2. To use a mobile manipulator to handle the cardboard boxes.

In PICKPLACE, a robotic arm mounted on a linear axis was used to deliver the products to the different outbound boxes. This was sufficient to validate the results on a lab scale, but is not suitable for a real industrial setting, due to (1) the lack of flexibility to manage many different configurations of input/outbound boxes, (2) creates physical barriers that hinder the movements of human workers, and (3) is a costly solution.

Instead, in HARTU, it is proposed to use a mobile platform with a robotic arm mounted on it

Funded by
the European Union

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

2.3 Demonstrator design

2.3.1 System description

As explained in previous section, in HARTU, it is proposed to use a mobile platform with a robotic arm mounted on it, which will be in charge of handling spare parts packaged in carboard boxes.

The proposed procedure is as follows:

1. The platform approaches the inbound box area.
2. It takes an image of the inside of the box and identifies the most suitable product to be picked up.
    - If needed, the platform will navigate to a different position to reach the product.
3. The arm movement is planned and executed to pick the target product.
4. The robot identifies the reference of the picked product by means of the bar code labelled on the carboard and sends the information to the WMS.
    - It may involve the robot presenting the different sides of the product to the bar-code reader device (depending on the position of the bar code label on the box)
    - The design of a workstation in charge of this identification will be considered.
5. The robot navigates to the position of the destination output box (this information is provided by the warehouse management system)
6. The robot calculates the trajectory to place the product in the right position (creating a mosaic to optimize occupancy)
7. Once the part has been placed, the robot takes an image of the inside of the box to monitor the status of the products inside. This information will be used for the placement of the next product (step 6).

The following pictures present the new concept.

Funded by
the European Union

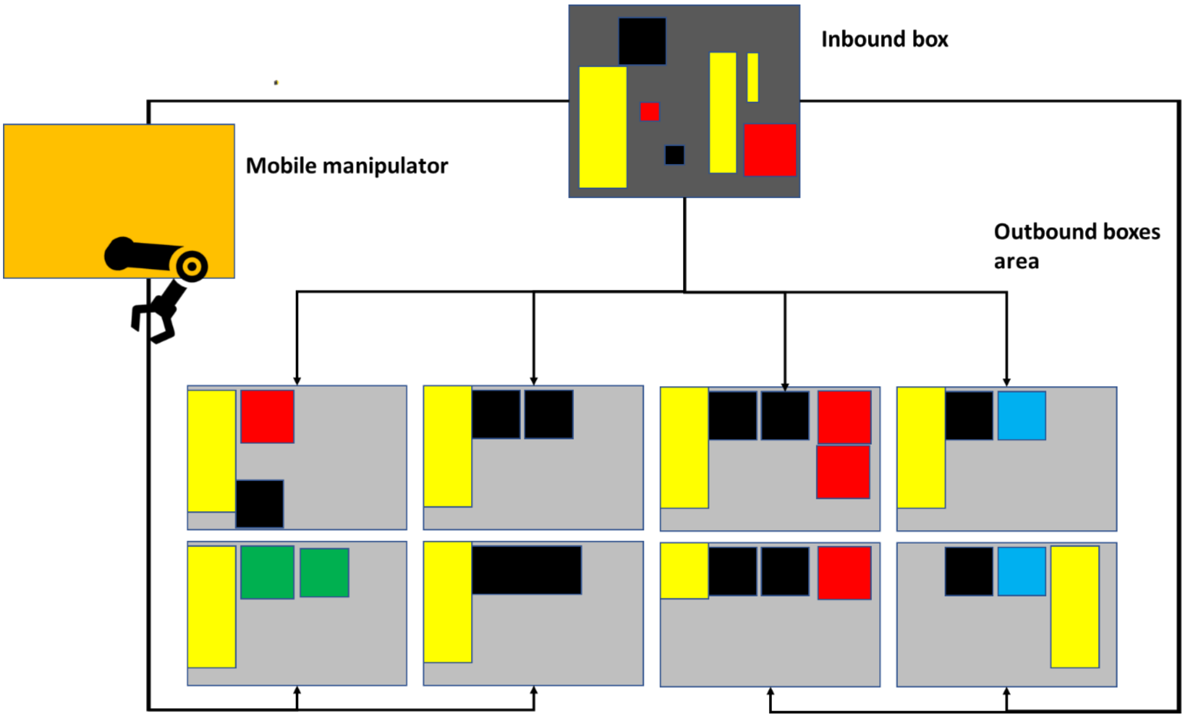


Figure 10. Layout of the proposed preparation area (TOFAS)

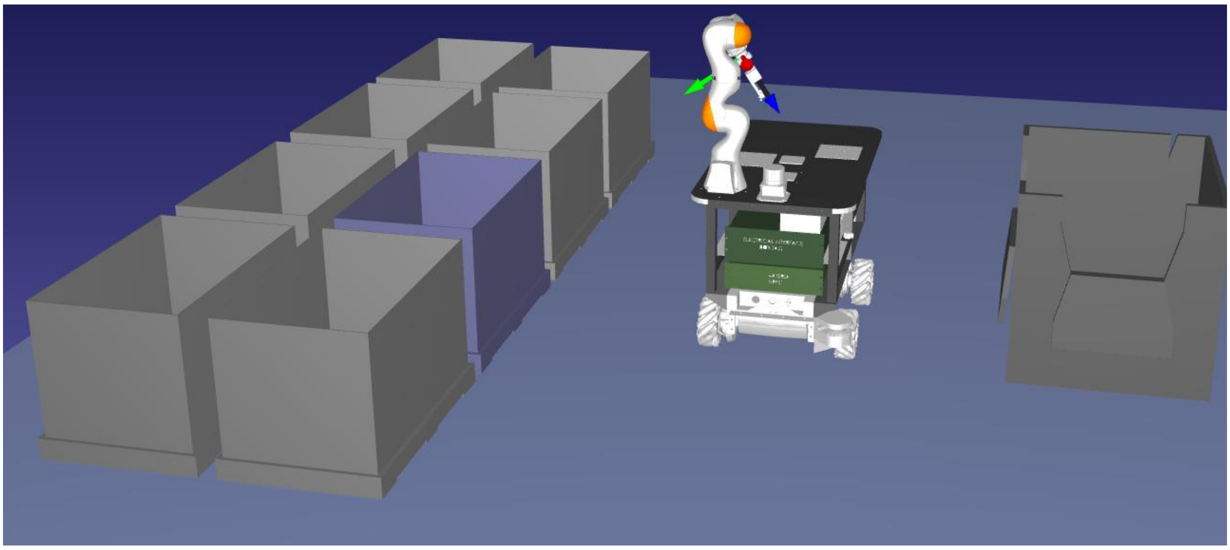


Figure 11. Simulation of TOFAS spare part order preparation scenario

2.3.2 Components of the system

- Mobile manipulator, consisting of:
  - Segway RMP omnidirectional mobile robot
  - 7-axis KUKA iiwa (14 kg payload)

  The dimensions of the base are: W = 788 mm, L =1350 mm, H = 897 mm.
- RGB-D or Photoneo Camera mounted on an eye-in-hand configuration on the robot.
- Gripper

Funded by
the European Union

- Based on suction principle. Due to the mobile platform we plan to use, the best option would be to use a gripper with an electrically powered gripper, so no external air supply is needed.
  A possible one is the VG10 from OnRobot, that has these dimensions:
  Folded: 146 x 146 x 102 mm.
  Unfolded: 390 x 390 x 102 mm

Figure 12. OnRobot VG vacuum gripper in its 3 possible manual configurations

  Other alternatives will be analysed, including some small form factor air supply tools, such as PIAB Kenos KCS, Coval CVGC150X150, or FORMHAND FH-R80.
- Dual gripper. Due to the different sizes of the boxes, it might be needed a tool exchange unit, or the use of a dual gripper (or both).
  The change of tool can be done in the way back from the release operation to the new picking (as far as the image of the input box is taken after each picking).
  An alternative can be to adapt the warehouse management, so the input boxes include references of similar sizes. In this case the operator in the preparation area will verify the appropriate gripper is on the robot each time a new input box arrives.

- Part identification (barcode). Two alternatives:
  - A bar code reader is placed on the mobile platform. As the label can be placed on any of the 6 sides of the box, the robot will move the box in front of it (to place the label in the reader's field of view.
  - To design a device that automatically identifies the box and includes a camera to identify the position of the part before regrasping it. This device can be used in ULMA box-to-box use case as well.

2.3.3 System deployment

The platform is provided by TEKNIKER, which will be in charge of system integration. The system will be tested in TEKNIKER's facilities and finally transported to Bursa to validate in the real TOFAS facilities.

The lab setup will include one inbound box and 1 to 3 outbound boxes, due to space limitations at TEK shopfloor.

Funded by
the European Union

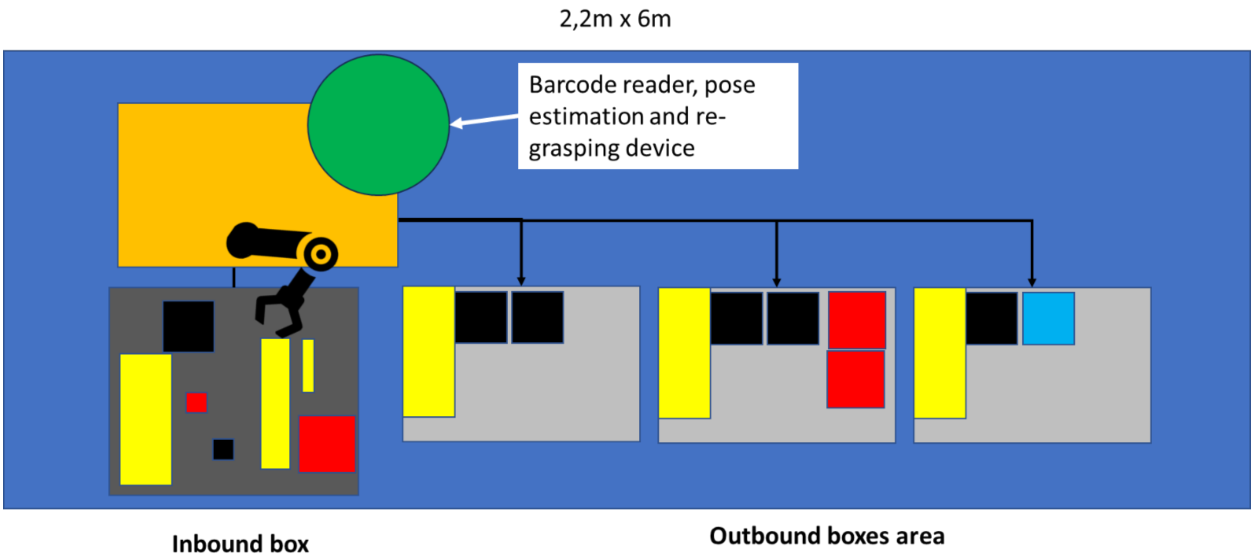


Figure 13. Order preparation Lab setup (V1) at TEK

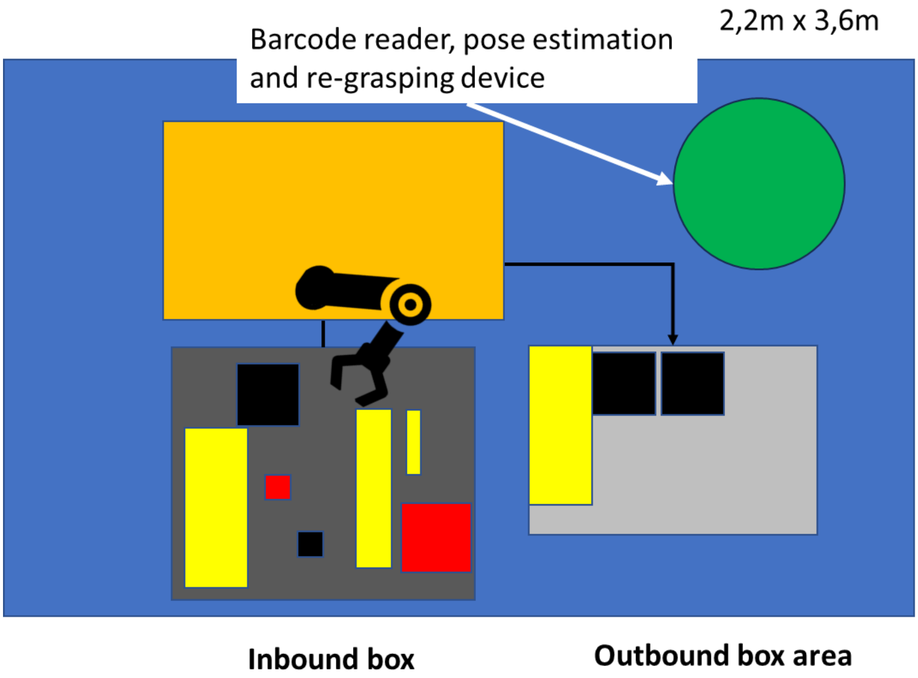


Figure 14. Order preparation Lab setup (V2) at TEK

The green circles in the figures above represent the possible barcode reading, pose estimation and re-grasping device to be designed. The two placement alternatives are presented: mounted on the robot or mounted on the workshop floor. The first option is the preferred, but space constraints need to be analysed.

2.4 Technical risks

.

Funded by
the European Union

CODE	Description	Probability	Impact
R.1	Carboard boxes flaps are not properly positioned. Mitigation measure: If the robot detects this situation, the operator will be informed, and the robot will stop the process until the problem is solved	Low (2)	Medium (3)

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Funded by
the European Union

3 TOFAS-2: Kitting and pre-assembly in the automotive sector

3.1 Introduction

This use case corresponds to the preparation of kits of components (operation known as 'kitting' in the automotive sector) ant their pre-assembly at the corresponding assembly workstation.

At TOFAS there are 120 kitting areas where human workers prepare kits of products that are then delivered to other areas of the factory to be assembled into sub-assemblies or into the final car.

In the kitting area, products are taken from containers/boxes in which they can be arranged in three main configurations: (1) Product-specific individual compartments (Figure 16); (2) Semi-structured configuration (Figure 17), forming layers that are separated by means of separators (cardboard or plastic); (3) randomly distributed (Figure 18).

Figure 15. Kit preparation, transport and assembly

The kits, composed of products with different geometries, materials and dimensions, are placed on carriers that are towed by conveyor belts and/or AGVs through the factory to the destination. The kits, once at the assembly workstation, are downloaded and the parts assembled manually, mainly using insertion and screwing techniques with the support of hand tools and devices.

Figure 16. Products in special compartments

Figure 17. Products in semi-structured configuration

Figure 18. Products randomly distributed

Funded by the European Union

3.2 Use case description

The use case selected in HARTU is the Real Wheel 356 kitting and assembly, internally identified at TOFAS as "Rear Wheel 356 - Drum - OP30" and "Rear Wheel 356 - Disc - OP30".

3.2.1 Initial state

3.2.1.1 Process

The production line consists of three workstations, where two operators assemble the rear wheels using mainly insertion and screwing techniques with the support of hand tools and devices. These workstations are identified as:

- Op 10: Rear wheel 356-Drum and Rear wheel 356-Disc
- Op 20: Rear wheel 356-Drum
- Op 30: Rear wheel 356-Drum and Rear wheel 356-Disc

The process workflow of the rear wheel production line and the schematic layout of the area can be seen in Figure 19. The current setup consists of 2 main areas: one for kitting (it is done in two sub-areas, one for OP10 components and the other one for OP20 and OP30), and one assembly area with three workstations (OP10, OP20 and OP30).

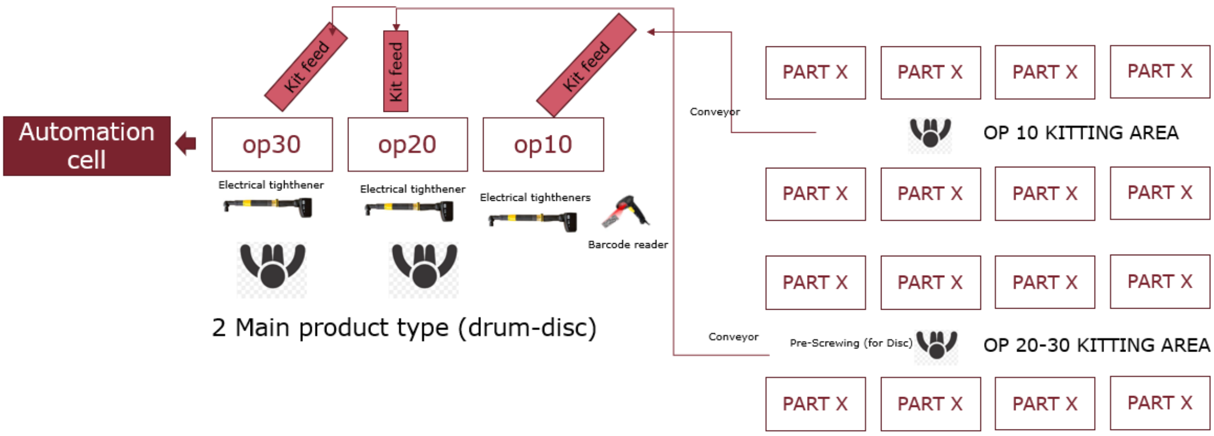


Figure 19. The Process Flow of The Rear Wheel Production Line

Funded by
the European Union

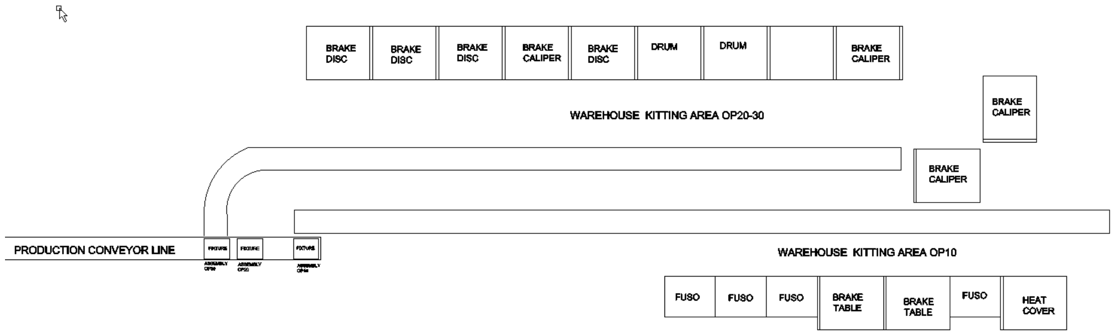


Figure 20. The Layout of kitting and assembly processes

3.2.1.1.1 Kitting preparation

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.

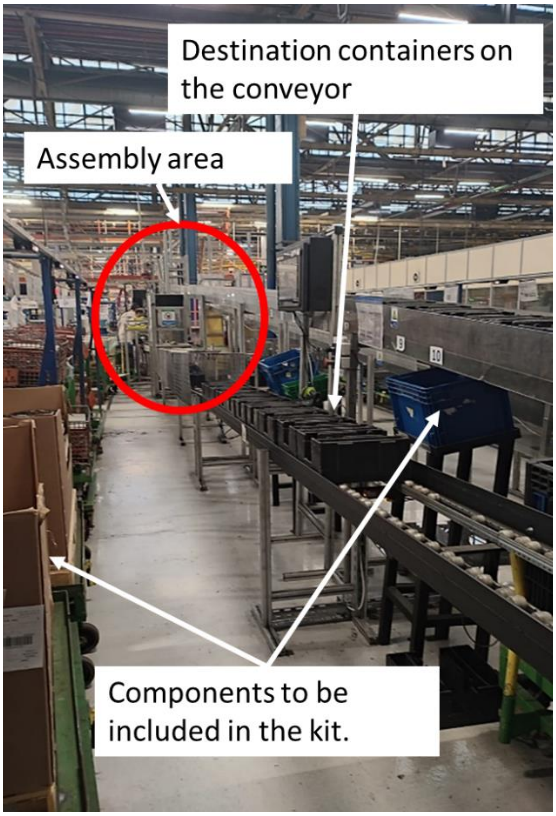


Figure 21. Kitting preparation area.

Figure 22. Destination containers on the conveyor. The blue boxes contain the discs

To start the preparation of kits, the operator presses the button in Figure 23 and 10 empty output containers arrive at the preparation area on the conveyor belt.

Funded by
the European Union

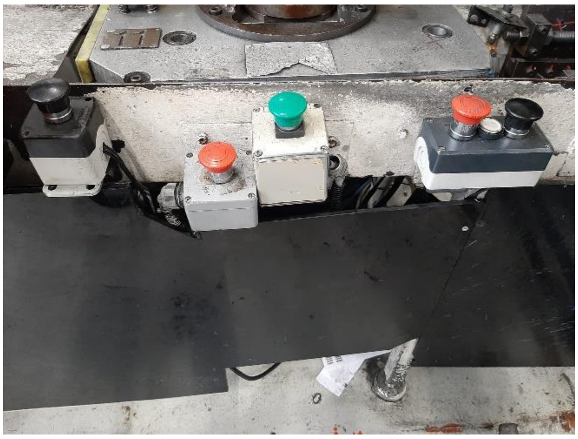


Figure 23. Push buttons to control the conveyor belt that transports the output containers

Figure 24. 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 24). 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.

This is repeated for all kits; the discs are taken out of the blue box and placed on the corresponding conveyor.

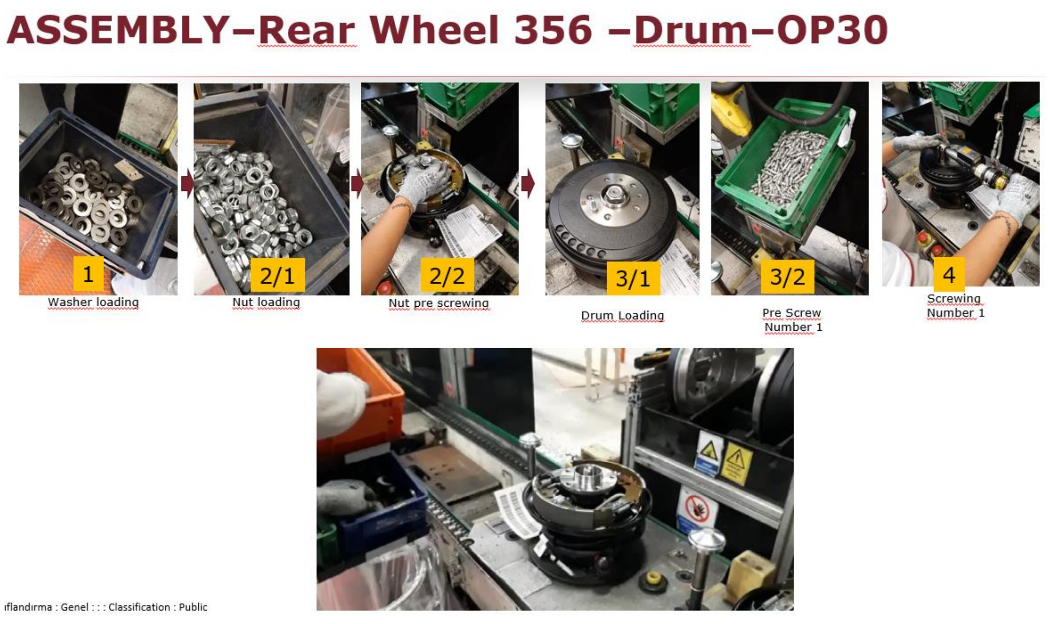
Finally, 10 paper forms are taken and introduced in each destination box, and the operator presses the button to transport the full containers on the conveyor belt to the assembly workstation (at the back of Figure 21) .

Figure 25. Operator taking a component from the input container (left side). It will then put on the destination container (right side)

The process can be seen in this video: [HARTU-TOFAS-OP20-OP30 Kitting.mp4]

Funded by the European Union

3.2.1.1.2 OP30 ASSEMBLY AREA-DRUM



Step 1. Takes one washer from the side of the line.

Step 2. Takes one nut from the line side of the line.

Step 3. Loads the washer and the nut on the part by hand, and pre-screws the nut by hand.

Step 4. Takes the drum from the kitting box and inserts it on the part.

Step 5. Takes one bolt from the side of the line and pre-screws it on the part.

Step 6. Screws the bolt using the screwdriver.

Step 7. Leaves the screwdriver at the side of the line.

Step 6. Pushes the start button and waits until a new kit container comes at the assembly workstation.

The process can be seen in this video: HARTU-TOFAS-OP20-OP30 Kitting.mp4

3.2.1.2 Inputs

- Environmental conditions
  - Temperature: Min 6 / Max 45 °C
  - Relative Humidity: Max 90%
- Personnel
  - 4 operators are required to carry out the assembly and kitting process. One of the 4 operators is responsible for periodically going to the kitting area and preparing the 10 kit containers. Then, she/he returns to the assembly area and continues the assembly work.
  - Operators receive one day training for the kitting operation.

Funded by
the European Union

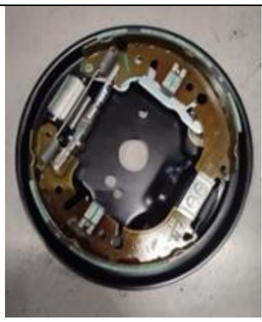
    - Operators are trained for one week for the assembly operations.
- Materials in
    - Spindle (Right/Left)
    - Brake Plate
    - Drum (Right/Left)
    - Heat Cover (Right/Left same geometry)
    - Flex assembled on brake calipper
    - Rear Hub (Right/Left)
    - Washer
    - Nut
    - Containers (input and output)
- Supplies In
    - Air for pneumatics: 5.5 bar
    - Electrical 24 V
- Information of the part that is produced, CAD data.

3.2.1.3 Outputs

- Rear wheel-disc (right/left), rear wheel-drum (right/left) preassembled (they go to the next automatic assembly workstation through an additional conveyor belt).
- There is no material waste.
- There are no quality metrics or reports/documents.

3.2.2 Product specifications

Funded by
the European Union

 *Figure 26. Hub*	Cylinder, Ferromagnetic, Grey, Shiny, 100g-500g Container dimensions: 560 x 760 x 350mm Part dimensions: Diameter: 120mm, h:60mm Machined through holes	 *Figure 27. Brake plate*	Cylinder, Ferromagnetic, Black, Very shiny, 1kg-5kg Container dimensions: 1200 x 800 x 700mm Part dimensions: Diameter: 270mm, h:55mm Pressed through holes
 *Figure 28. Spindle*	Irregular shape, Ferromagnetic, Grey, Shiny, 100g-500g Container dimensions: 780x560x450 mm Part dimensions: 120x90x110mm Machined through holes	 *Figure 29. Heat cover*	Planar, Ferromagnetic, Black, Shiny, 100g-500g Container dimensions: 290x400x290mm Part dimensions: Diameter: 300mm, h:20mm Pressed through holes
 *Figure 30. Brake disc*	Cylinder, Ferromagnetic, Grey, Shiny, 1kg-5kg Container dimensions: 1000x1200x600mm Part dimensions: Diameter: 265mm, h:45mm Machined through holes	 *Figure 31. Drum*	Cylinder, Ferromagnetic, Black, Matte, 5kg-10kg Container dimensions: 1000x1200x1000m Part dimensions: Diameter: 270mm, h:60mm Machined through holes

Funded by the European Union

 *Figure 32. Brake caliper*	Irregular shape, Ferromagnetic, Grey, Shiny, 1kg-5kg Container dimensions: 1000x1200x750mm Part dimensions: 140x170x110mm Machined through holes		

3.2.3 Key figures

Key figures:

- Cycle time: 90 seconds (40 cars/hour) per kit assembly
- All errors in the kitting area are detected in the assembly area
- Assembly defect rate: 0 (There is no possibility to make a mechanical mistake)

3.2.4 Target state

3.2.4.1 Kitting preparation

The kitting operation will be done by a robotic arm. Due to the number of containers to be reached, the robot must have an additional linear axis. This can be implemented by means of a robot mounted on a linear track, or by means of a robot mounted on a mobile platform. This latter is preferred as it is more flexible and in case the current manual procedure has to be used, does not interfere with human operators.

The human operators will perform four activities:

- To manipulate the discs (they are stacked in such a way that it is not feasible for a robot to manipulate them).
- To include the paper forms in each output container.
- To control the conveyor belt movements (to active the arrival of empty containers and the transport of the full ones to the assembly workstations).
- To remove the separators from the input containers once all the parts of the layer have been taken by the robot.

3.2.4.2 Assembly operation

The assembly operation considered is "Rear Wheel 356 - Drum - OP30". The operation involves similar assembly steps than for other operations, although the assembled parts vary in size and shape, for example a relatively small washer vs. a large and heavy metallic cylinder (drum). Furthermore, some parts are assembled manually, while others require tools, e.g., a pneumatic screwdriver.

Funded by the European Union

Given the diversity of assembly tasks, the operations are to be performed either by a human or by a robot. The concrete division of tasks between human and robot is still to be defined. It depends on the maximum robot speed, the workspace layout, and the complexity/ergonomics of the tasks. Ideally the robot takes over heavy and tedious tasks without disturbing the human or slowing down the overall workflow. Collaborative assembly is an option for heavy objects, e.g., metallic cylinder (drum). The robot is either mounted in a fixed position next to the assembly line or on a mobile base. The latter is preferred as it allows the robot to navigate between the assembly stations, increase its flexibility, and enlarges the reachable workspace.

3.3 Demonstrator design

3.3.1 System description

As mentioned above, the use case corresponds to a common activity in car manufacturing plants: the preparation of component kits of that need to be assembled prior to be fitted to the car, or that are assembled directly to the car.

In HARTU, the rear wheel assembly kit preparation and the rear wheel drum assembly (Rear Wheel 356 - Drum - OP30) have been selected.

3.3.2 Components of the system

3.3.2.1 Kitting preparation

The proposed system will use the same robotic platform as in the order preparation use case. It consists of:

- Mobile platform, consisting of:
    - Segway RMP omnidirectional mobile robot
    - 7-axis KUKA iiwa (14 kg payload)

  The dimensions of the base are: W = 788 mm, L =1350 mm, H = 897 mm.
  In case of need, we can adopt the MIR200+UR10 configuration.
- RGB-D or Photoneo Camera mounted on an eye-in-hand configuration on the robot.
- Gripper: Based on magnetic principle or fingers. In both cases, electrically actuated

The procedure to be followed is as follows:

- The operator press the conveyor belt control button to request the arrival of the 10 empty output containers.
- The robot receives the list of products and the order in which they have to be placed in the output containers from the WMS.
- The robot takes a picture of each box and starts feeding the part:
    - The platform approaches to the corresponding inbound box.
    - It takes an image of the interior and identifies the most suitable product to be picked.
    - It plans and executes the arm movement to pick up the target product.

Funded by the European Union

- The robot navigates to the position of the destination container box on the. conveyor belt
- The robot calculates and executes the trajectory to place the product in the right position.

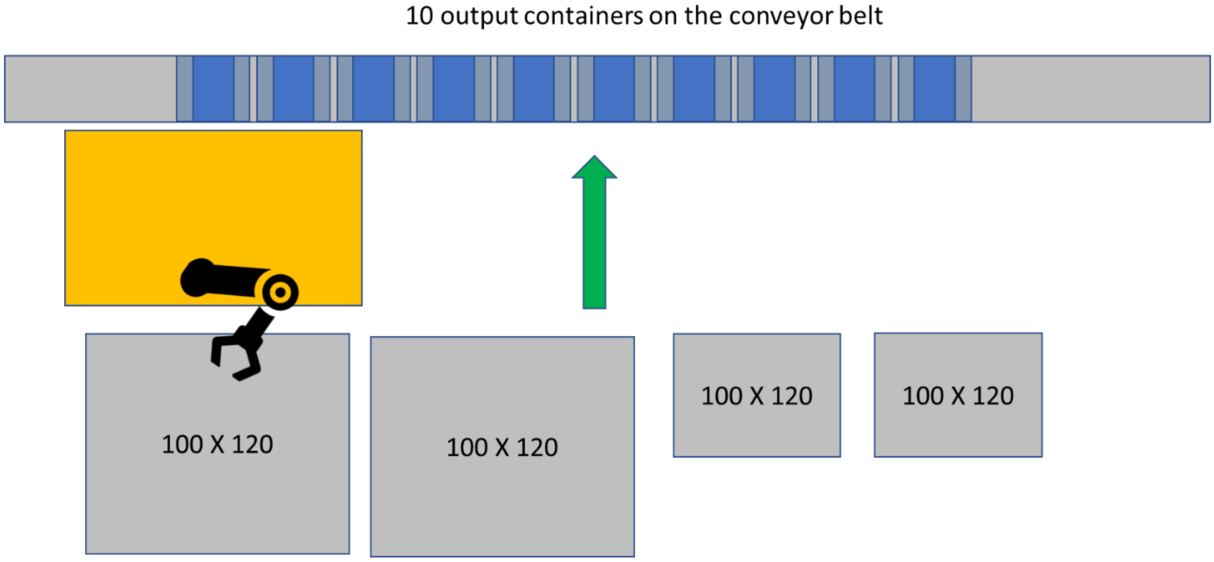


Figure 33. Proposed demonstrator for the kitting operation

- In case of having to remove a separator between layers, it requests the help of a human operator from the assembly area.
- These steps are repeated until all items in the list have been placed in the output containers.

- Once all parts are handled by the robot, it requests the presence of the human operator who introduces the discs and the 10 paper forms.
- Finally, the operator press the conveyor button to transport the filled boxes to the assembly area.

3.3.2.2 Assembly operation

The proposed demonstrator uses the same robotic platform as the kitting preparation. The platform is placed next to the assembly line (opposite to the human operator). Together with the human worker, the robot performs the assembly of the rear wheel (Rear Wheel 356 - Drum - OP30). Thereby, human and robot work in a shared workspace. Ideally the workflow is smooth and efficient, i.e., the robot should not disturb the human worked or slow down the assembly process.

3.3.3 System deployment

3.3.3.1 Kitting preparation

The platform is provided by TEKNIKER, which will be in charge of the integration. The platform will be tested in TEKNIKER's facilities and finally transported to Bursa to validate in the real TOFAS facilities.

The lab setup will include inbound boxes and outbound boxes on a table (instead of the conveyor).

Funded by the European Union

3.3.3.2 Assembly operation

An initial laboratory demonstrator will be prepared at DFKI Robotics Innovation Center in Bremen, Germany. The system will comprise an industrial robotic manipulator (Kuka iiwa) with 3-finger robotic gripper, as well as a mock-up of the assembly line.

The final setup will comprise a mobile platform with Kuka iiwa robot provided by TEK. It will be evaluated at the TOFAS assembly line, without interfering with actual production.

3.4 Technical risks

3.4.1 Kitting preparation

CODE	Description	Probability	Impact
R.1	Currently two containers are placed on top of each other (see Figure 34). the robot will not be able to reach the lower container. Mitigation measure: layout with containers in parallel.	High (4)	High (4)
R.2	The current output container is designed for manual placement of the objects (see Figure 35), but it will be too complex for robotic operation. The mitigation measure will be the redesign of the container (no problem for the rest of the line and the workstations)	Medium (3)	High (4)

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Figure 34. Spindle containers: one on top of each other

Figure 35. Current design of the output container

Funded by the European Union

3.4.2 Assembly operation

CODE	Description	Probability	Impact
R.1	The Parts are too diverse to be handled by a single robotic gripper. Mitigation measure: Introduce a tool changer or leave the parts that cannot be handled by the robot to the human worker.	High (4)	Low (2)
R.2	Precision (especially the positioning of the part inside the robot gripper) is too low for robotic assembly (e.g., pre-screwing). Mitigation measures: Use robot compliance to account for small inaccuracies, use sensor to estimate the position of the part inside the gripper, use object pose estimation to allow precise and repeatable grasping.	High (4)	Medium (3)
R.3	Parts are too heavy to handle with a single robot gripper. Mitigation measure: Handle large parts in collaboration with the human.	Low (2)	Low (2)

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Funded by
the European Union

4 PCL: Handling for mass customization in the consumer goods sector

4.1 Introduction

PHILIPS is world leader in mass production of consumer goods.

In the business of consumer goods there is more and more demand for personalized products. Traditionally, consumer products are mass-produced. Products which are mass-produced are optimized for efficient production, meaning limited product variance and high production volumes to keep the factory cost price low and the product available for everyone.

Personalization means an extra effort needed to personalize the product. Today, that would mean more manual labor in a lot of cases. This conflicts with the aim to keep products within reach of everyone.

4.2 Use case description

One area where diversity is added is the workpiece lacquering line, where parts are coated with a layer of lacquer to match the product design to the consumer's need. Up to now, this has been done by manual labor. There is a strong wish to automate this process and this production step will be the subject of this use-case.

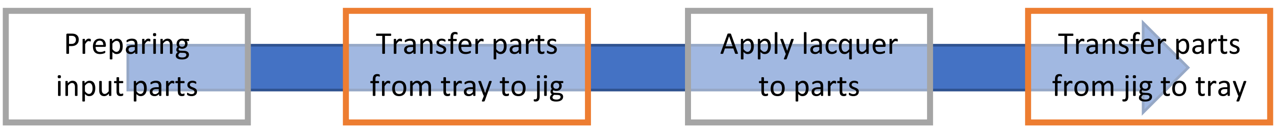
4.2.1 Initial state

Typical production line components which rely heavily on standardization are robotic arms and their grippers. Currently, robots need a highly structured workplace to be able to do their work. In a lot of situations, it is possible to comply with this need. In the lacquering line however, this is not possible due to the flexibility required (many different products).

Motions are now designed for the human hand and with current robot technology it will be very difficult to automate this process. The aim of the HARTU project is therefore to investigate new technologies to make the next step in robotization.

4.2.1.1 Process

A step-by-step description of the lacquering process is shown in figure:



Although the complete process of applying lacquer to shaver parts includes many steps, in HARTU we focus on the physical aspects of placing the parts on the jig and taking them off again after the lacquer is applied.

Figure 36. Step by step breakdown of the PCL lacquering process

Funded by the European Union

An overview of the lacquering line is given in next figures.

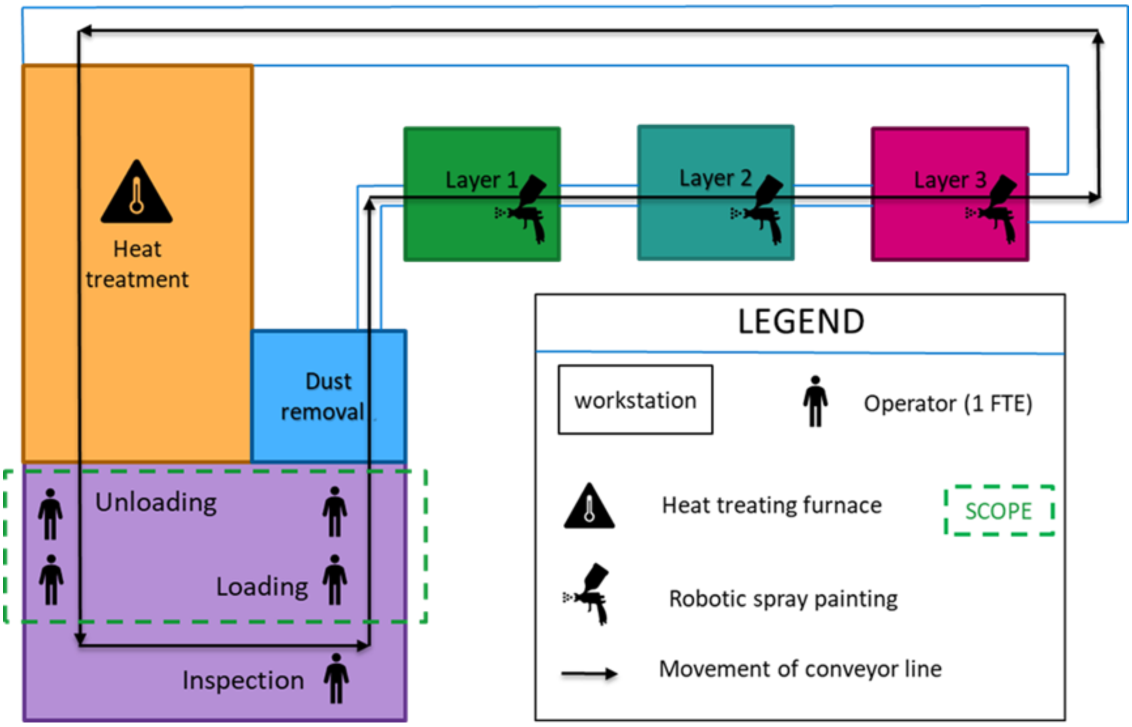


Figure 37. Lacquering process overview

Figure 38. Loading and unloading area

In this links: [HARTU-PCL-Chest-1.MP4](), [HARTU-PCL-Chest-2.MP4](), [HARTU-PCL-FrontPanel-1.MP4]() and [HARTU-PCL-FrontPanel-2.MP4]().

Funded by the European Union

4.2.1.2 Inputs

Process input definitions

Environmental conditions: ▪ No specific demands for temperature, humidity, etc. ▪ Any unexpected mechanical situation is handled by human operators, so **worst case mechanical conditions are not known.**
Personnel: ▪ The lacquering line is operated by a team leader and 5 operators. ▪ The skill level of operators is secondary school.
Materials in: ▪ Different geometries of molded plastic parts ▪ Lacquering jigs
Supplies in: ▪ Air for pneumatics ▪ Electrical (400 V)

4.2.1.3 Outputs

Process output definitions

Materials out: ▪ Lacquered and quality inspected parts ▪ Scrap parts ▪ Reusable jigs
Information out: ▪ Yield and scrap figure ▪ Batch info

4.2.2 Product specifications

Two plastic outer shell parts are identified for this use case:

- Chest
- Front panel

A detailed overview of the part properties is given in HARTU-PartsCharacterization.xlsx.

The plain plastic input parts and the jigs used for fixturing the parts are shown in next figures.

Figure 39. Chest panel

Figure 40. Front panel

Funded by the European Union

Figure 41. Chest jig

Figure 42. Front panel jig

The pictures show an intermediate stage of the process when the parts are placed on the jigs. After the entire process is completed, the parts are again in the trays, as shown in next picture.

4.2.3 Key figures

- 6 parts per spindle
- 500 spindles on the chain
- 8 seconds cycle time for each advancement of the chain
- 3 loading positions
- 2 unloading positions
- 2 products are (un)loaded to or from tray in one cycle

Funded by
the European Union

4.2.4 Target state

As already mentioned, the use of manual labor to achieve the required degree of production flexibility is relatively expensive, and it is an opportunity to have robots to do this work. The ideal outcome would be that a robot with a universal gripper is able to take the parts from the tray and put them on the jig and vice versa.

This will result in a reduction of the human labor force engaged in repetitive and low value-added tasks, as seen in the videos cited at the end of section 4.2.1.1, while allowing for flexible production systems. This is particularly important in countries suffering from labor shortages.

4.3 Demonstrator design.

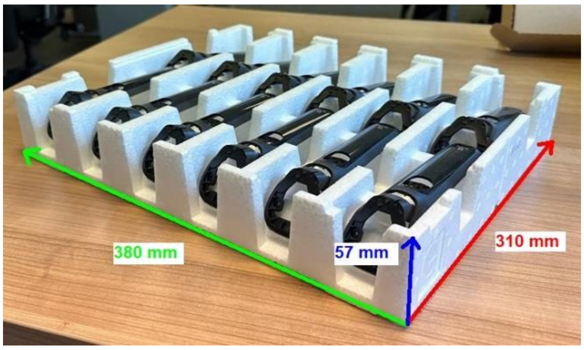
4.3.1 System description

The scope of the intended system is to demonstrate the placement and removal of products on the lacquering jig.

The system shall be designed and validated for the two described product ranges, but not be limited to it. Furthermore, the perception system used for product pose estimation shall cope with color variations.

The system will be commissioned in a relevant environment, but not on the actual lacquering line. Therefore, a continuously looping demonstrator can be achieved by using a single tray from which products are picked and to which products are placed back.

The supplied tray contains a single type of outer-shell part in a structured way. The parts lay loose within the tray resulting in a positional uncertainty that must be resolved before fixturing. The 3D models of all parts are known and can be used by the grasping point estimator and the vision algorithm for pose estimation.



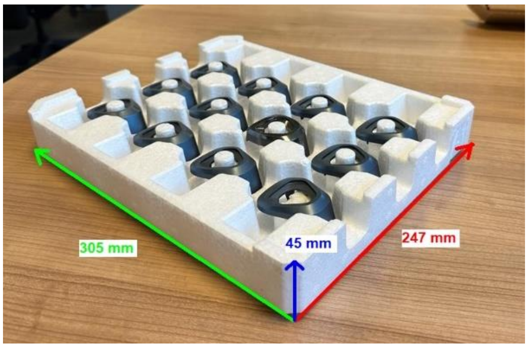


Figure 43. Trays dimensions

The parts can be gripped using a regular two-finger gripper, either from the inside or from the outside, depending on the part type and tray type.

Funded by
the European Union

Figure 44. Different gripping alternatives

However, the smaller tray used for chest parts has two variants: one with a support at the center and one without (see Figure 45). Therefore, some chest pieces cannot be gripped from the inside.

Figure 45. Example of a tray that does not allow gripping from the inside of the workpiece (left)

The expected process flow will be:

1. Set-up

1. Operator supplies filled tray
2. Operator places jig for selected product type on spindle.
3. Operator presses start button on HMI

2. Fixturing

Funded by the European Union

1. Perception system detects available parts in a tray, and the grasping point estimator proposes a pick position.
2. Robot performs the picking action.
3. The system determines free jig positions, resulting in a place position.
4. The robot performs fixturing action.

The process is repeated until all empty jig positions are filled, then continue with 3. Removal

3. Removal

1. Perception system detects the part on the jig, an propose the pick position.
2. The robot performs the picking action.
3. The system determines free tray position and proposes the place position.
4. The robot performs removing action.

The process is repeated until all jig positions are empty, then continue with 2. Fixturing

4. **Stopping**

1. Operator presses the stop button on HMI.
2. Robot completes either its current fixturing or removal task. Then it moves to a home position.

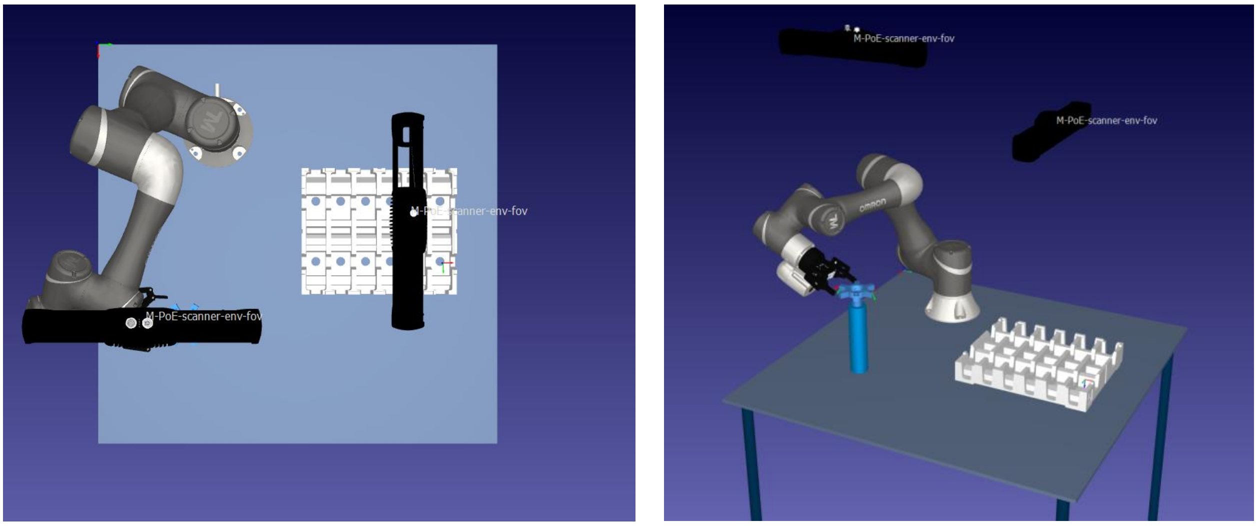


Figure 46. Proposed layout for PCL use case

In the proposed configuration, a robot with a minimum reach of 700 mm is required to pick objects both at the closest and the furthest tray positions from the robot.

The positions of the spindle and tray are chosen in a way that ensures the robot does not block the camera above the tray during fixturing, as well as the camera above the jig during picking and/or placing.

The process described above will be utilized to evaluate the system's performance. In addition to meeting the performance metrics, it is important for the system to demonstrate flexibility in accommodating new product introductions. The teaching of new products through demonstration

Funded by
the European Union

is expected to be possible either from the HMI (Human-Machine Interface) or offline, using the results provided by HARTU.

4.3.2 Components of the system

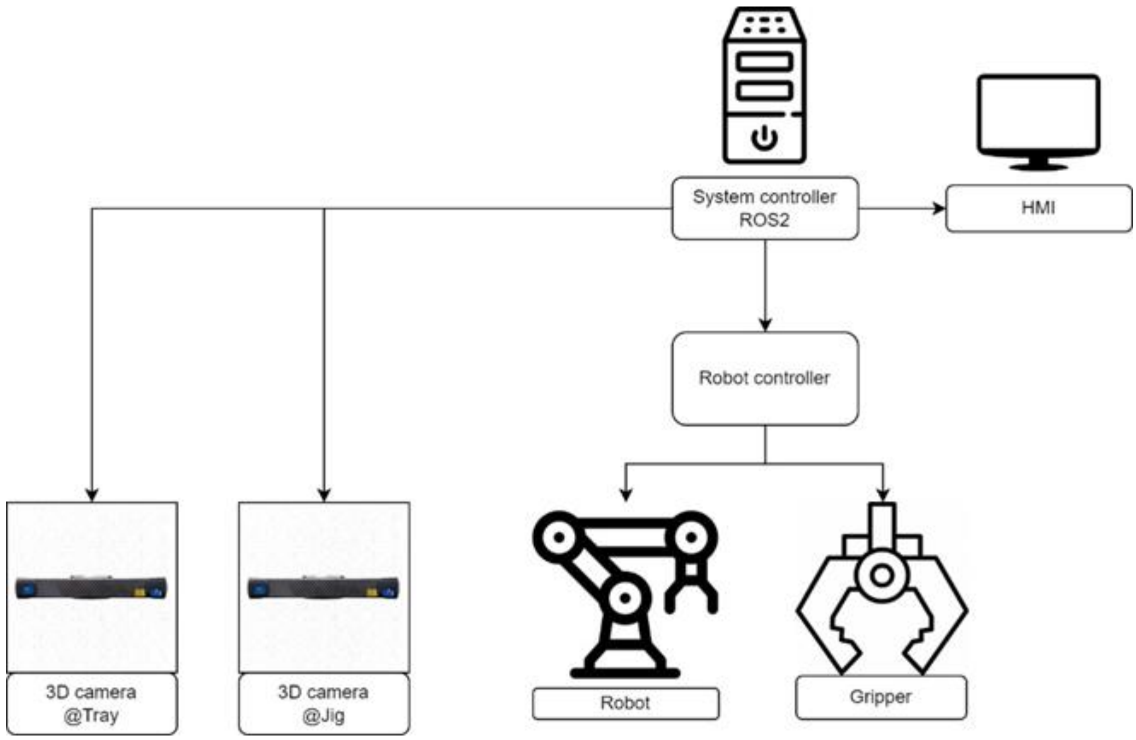


Figure 47. Component in the proposed system for PCL use case

HMI

- Any display can be used, and the input device can be a mouse + keyboard or touchscreen.
- E.g., 24 inch pc monitor with mouse and keyboard

Vision @Tray

- RGB-D camera or 3D scanner
- E.g. Photoneo PhoXi 3D scanner M

Vision @Jig

- RGBD camera or 3D scanner
- E.g. Photoneo PhoXi 3D scanner M

Robot

- Reach of at least 700mm
- Omron TM5-700 (for initial cobot set-up)
- Kuka KR6 R700 sixx (optional for testing HARTU outcomes on industrial robot)

Gripper

Funded by
the European Union

- Any two-finger gripper that allows for custom made fingers is sufficient, e.g., Weiss CRG 30-050. Servo-electric gripper module for collaborative applications, gripping force 30 N, stroke 50 mm

System controller

- Consumer grade pc
- Ubuntu 22.04
- ROS2 - Humble

Safety

- Emergency stop push buttons
- Users should be kept out of reach, either via lockable doors or a safety scanner

4.3.3 System deployment

The system described above will be deployed at the Philips location in Drachten by FMI-ImProvia. Philips already has the proposed equipment in HARTU.

Copies of the system or a subset thereof can be set up at the sites of other partners for testing and development purposes. Therefore, the component overview can be considered as a guideline, and other equivalent equipment can be used.

A lab setup will be implemented at DFKI facilities.

4.4 Technical Risks

CODE	Description	Probability	Impact
R.1	Damaging the products with robotized grasping and placing	Medium (3)	Very High (5)
R.2	Robotic system unable to place part on the jig due to inaccuracies/unmodeled effects	Medium (3)	High (4)
R.3	Damaged products are no longer detected as the products are no longer handled by human who includes inspection	High (4)	High (4)
R.4	Demonstrator at various partners is not compatible due to hardware differences	Low (2)	Low (2)

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Funded by
the European Union

5 TCA: Sorting operations in agri-food sector

5.1 Introduction

The pilot will be led by TCA in Italy, supported by a food company of its network, Centrolazio cooperative, which produces a wide range of vegetables.

To define the scenario, different product production lines and the corresponding operations have been analyzed. In summary, the general overview of the activities in the sector are presented in next scheme.

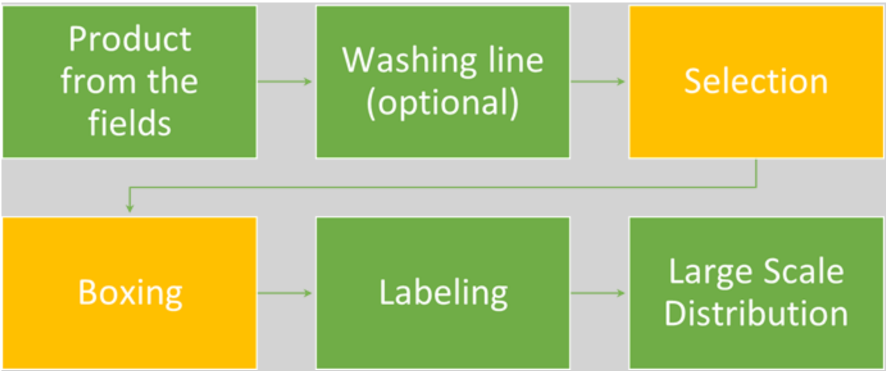


Figure 48. Agri-food sector: scheme of activities

In HARTU we will focus only on the two in yellow, i.e., selection and boxing.

5.2 Use case description

Location of the use case:

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 (741 acres), making Centro Lazio one of the largest and top producers among all the farms in the Agro Pontino area (**80 kilometers from Rome, in central Italy)**. All the cultivated areas are situated between Anzio, Latina and **Sabaudia** where the central office is located (Figure 49 on the left). The processing plant is placed close to the harvest sites, within a radius of 40Km (Figure 50 on the right).

Funded by
the European Union

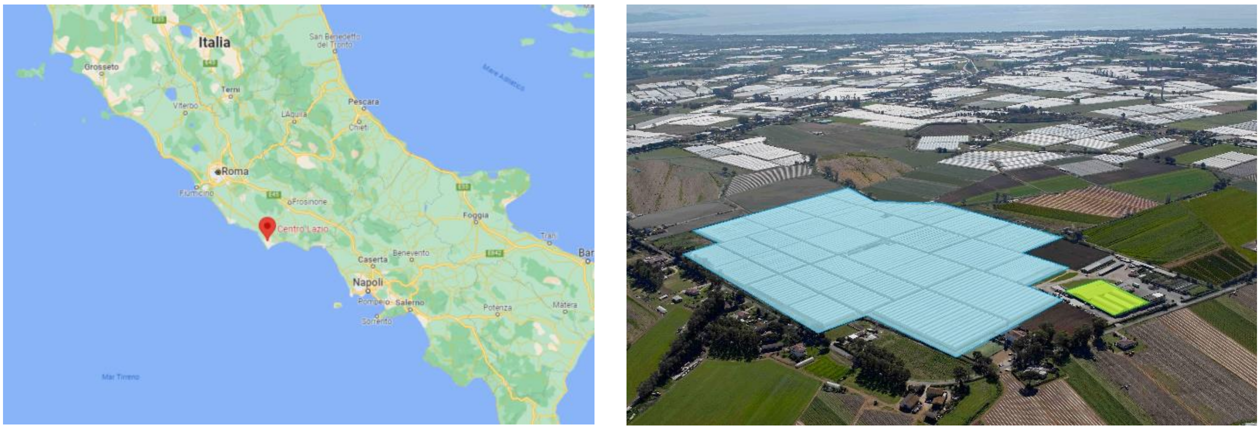


Figure 49. Location and production area of Centrolazio: (left) Map of *Central Italy*, (right) in *light blue the greenhouses, in green the processing area.*

Seasonality of products:

Some products, such as zucchinis, are cultivated all year-round, while others (such as eggplants and tomatoes) have a more limited seasonality, so the workload could be different throughout the year.

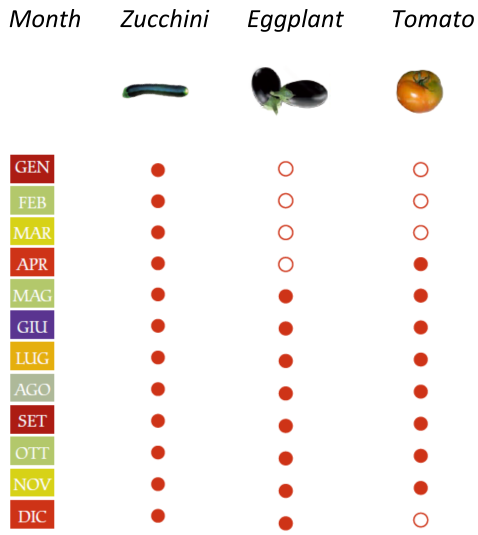


Figure 50. Seasonality of zucchini, eggplant and tomato

5.2.1 Initial state

5.2.1.1 Process

Brief description of the current process (valid for all products):

All the products arrive in boxes and bins of different sizes directly to the processing area from the field where they have been harvested. Products are harvested several times during the agronomic campaign based on their stage of maturation. The aim of the process is to sort the products coming from the fields (based on their dimension, quality and defects) and box them homogenously to meet market needs. The selection and manipulation of products is done by people operating on an industrial line (different for each type of product).

Funded by
the European Union

In some cases, the product needs to be processed as it is (without treatments which could compromise its quality), in other cases the product is washed and preselected automatically on one line and distributed via conveyor belts to a second line where operators pick the products from the belt, asses the size and quality of the products and place them in the final boxes (output). Once the boxes are full, the operators place them in the logistics area.

In Centrolazio there are two types of process lines:

- Line 1 for zucchinis and some type of tomatoes
- Line 2 for eggplant and salad tomatoes

The sorting process of zucchinis is presented in these two videos HARTU-ZUCCHINI-SORTING-1.MOV and HARTU-ZUCCHINI-SORTING-2.MOV.

Line 1 (Zucchinis or tomatoes)

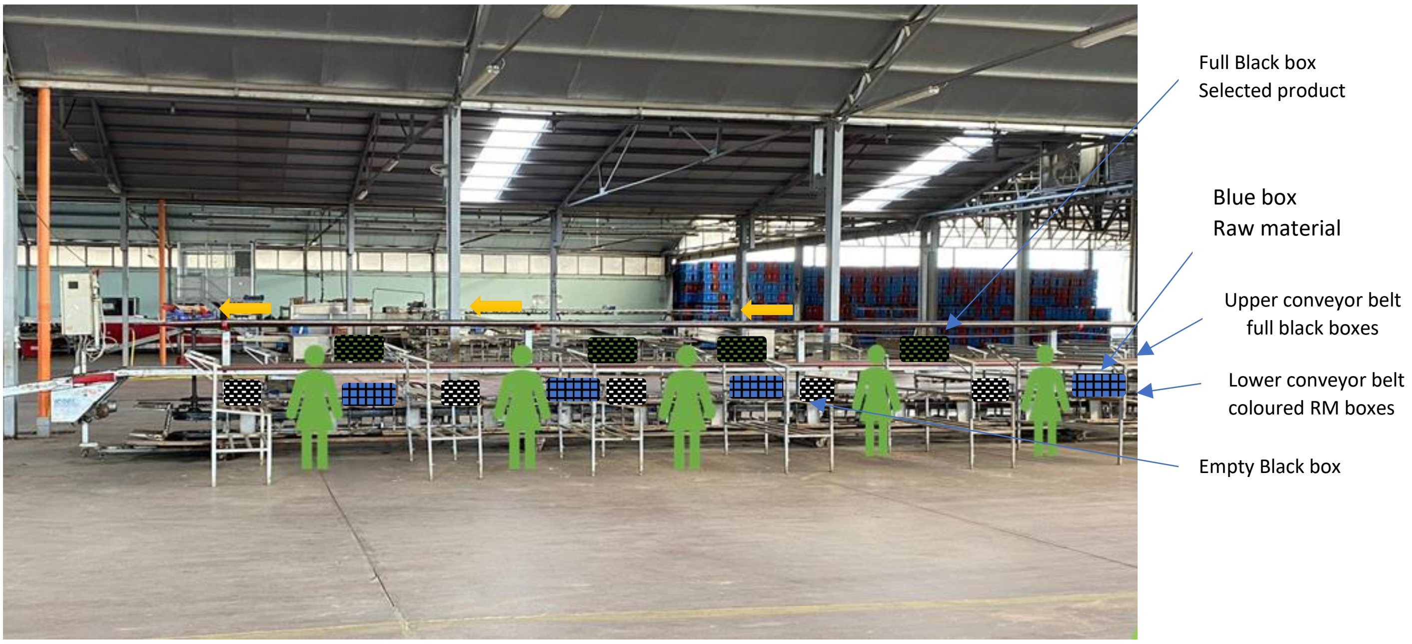


Figure 51. Line 1 in Centro Lazio for zucchinis and some type of tomatoes.

Line 1 is used for zucchini and some kinds of tomatoes, and is composed of two layers:

- the lower conveyor belt carries colored boxes with raw products from the field, moving in a continuous circular direction.
- the upper conveyor belt transports black boxes with selected products.

The products are loaded in coloured boxes onto the line with different size and quality, without a previous washing phase. At the head of the line, coloured boxes are loaded and start moving until an operator picks them up from the line and places them near the workstation.

Funded by
the European Union

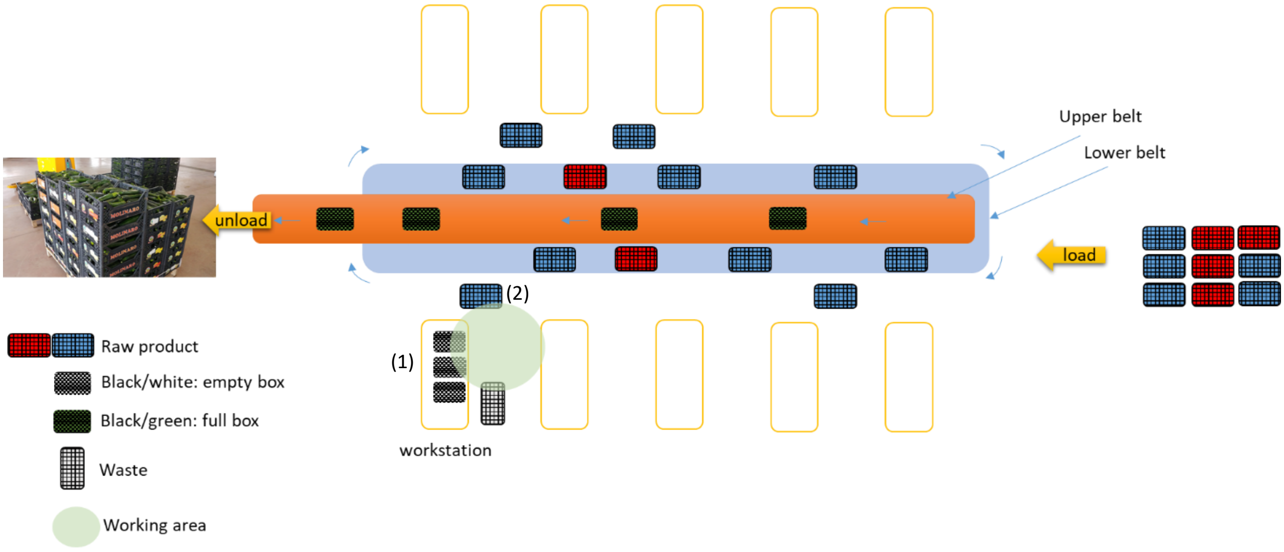


Figure 52. Setup of Line 1 of Centro Lazio

The workflow is as follows:

1. the operator loads 3 or 4 empty boxes on the workbench (black boxes (1) in Figure 52) to be filled with selected products;
2. takes a coloured box of unsorted zucchinis from the rotating loading belt and places it next to the workbench (box (2) in Figure 52);
3. picks a zucchini from the input box;
4. checks that the zucchini has the right size and shape;
5. checks for defects on the zucchini;
6. places the zucchini in the corresponding black box according to quality and size (1° class, 2° class, 3 class, waste);
7. in case of serious defects, the operator places the zucchini in the waste bin on the left;
8. puts the full black box on the upper conveyor belt for unloading.

Figure 53. Line 1 workbench. On the left the blue box with unsorted products. The black boxes are for the sorted product

Funded by the European Union

Line 2 (Eggplant)

Line 2 is used for eggplant and is characterized by a different working method, including a washing phase at the beginning of the line. The main difference is that the product runs on the belt in bulk, rather than in boxes. The operator at the workstation picks the products from the belt and places them in the box according to their quality and size.

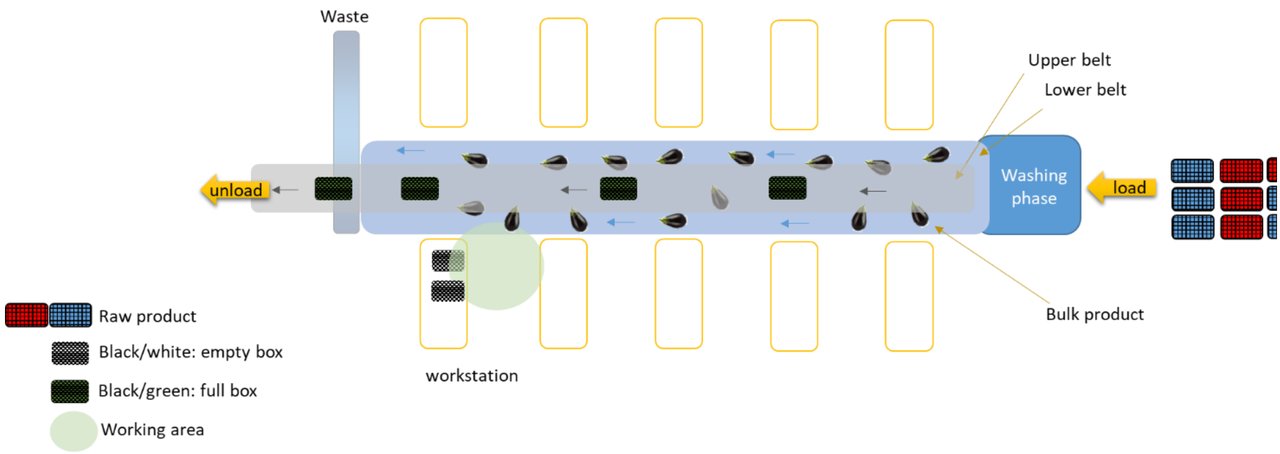


Figure 54. Setup of Line 2 of Centro Lazio

The workflow is as follows:

1. The operator places the empty boxes on the workbench;
2. takes the item from the conveyor belt. (blue belt in Figure 55);
3. checks the product for defects;
4. places the product without defects in the box;
5. if the product has defects, the operator places it in the waste bin;
6. when the box is full, the operator places it on the output line (upper grey belt in Figure 55)

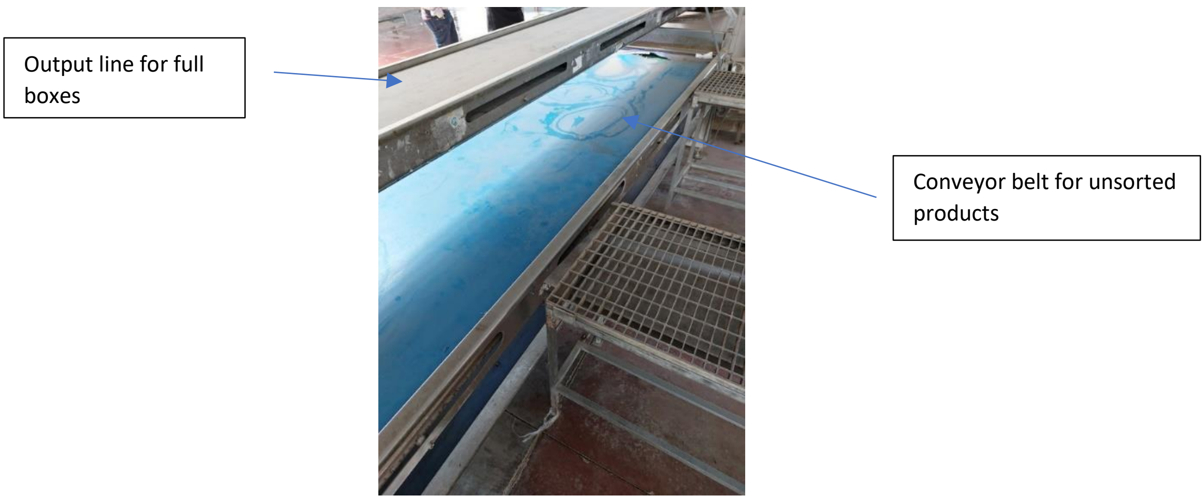


Figure 55. Conveyor belt and workbench of Line 2 in Centro Lazio

Funded by the European Union

Categorization of boxes used in the use case

Type	Material / Dimensions (W x L x H) cm	Used for
	Plastic box: 30 x 50 x 27	**Input** box from the field used to load the production line. Used for **tomatoes** and **zucchinis**
	Plastic bin: 34.5 x 52 x 30	**Input** box from the field used to load the production line. Used for **eggplants. They will not be considered in the use case**
	Plastic box: 30 x 40 x 15	**Output** box for sorted products. Usually, black colored Used for **zucchinis** and **eggplants**
	Plastic CPR box: 40 x 60 x 10	**Output** box for sorted products with collapsible sides. Used for **zucchinis** and **eggplants**
	Cardboard box: different sizes 40 x 60 x 12-14 30 x 40 x 12-14 30 x 50x 12-14	**Output** box for sorted products. Used for **tomatoes**
	Wooden box: different sizes 40 x 60 x 12-14 30 x 40 x 12-14 30 x 50 x 12-14	**Output** box for sorted products. Used for **tomatoes**

Funded by
the European Union

5.2.1.2 Inputs

The working environment is **an agricultural shed**. The shed is an open space, with no physical separation between areas. There are several lines for different food products. There is not any air conditioning control system, therefore, the temperature and humidity of the working environment depends on the outside temperature and humidity in a range that usually varies between 6°C and 30°C, and up to 90% humidity. Processing does not require a clean room.

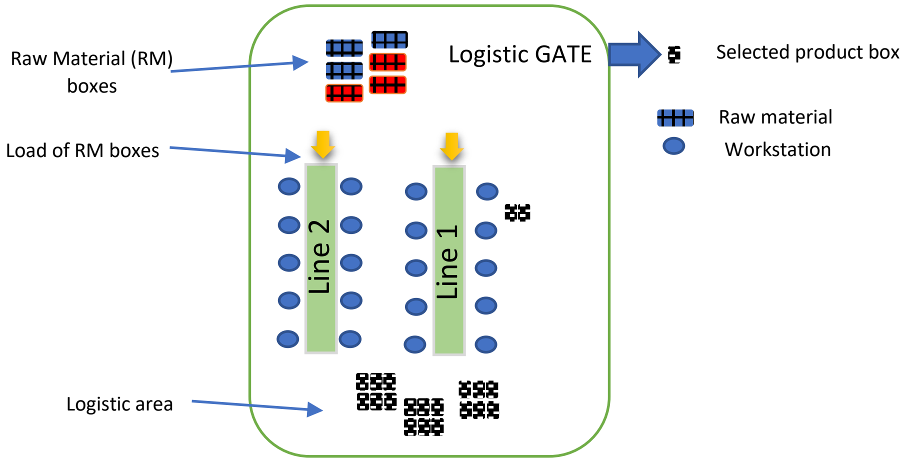


Figure 56. Overview of the processing area

The activity of selecting and boxing the product is performed by one person per working station, but a line can have several people working at the same time on different stations (see Figure 51). The operator works close to the line where the raw product is distributed (in coloured boxes or in bulk). The operator picks up a box from the line and places it in a buffer area (the conveyor belt brings the boxes in a circular ring) or picks up the bulk product. The operator must be able to handle the product carefully and quickly with both hands, visually detect any defects on the product, sort and place the product in the correct box in an oriented way until this output box is completely full. Another operator collects the filled boxes and builds the pallet, that is finally weighed and labelled.

No specific skills are required, other than the ability to sort the product, for which they rely on training and experience.

5.2.1.3 Outputs

The output of the process is **a box filled with products**. The products are homogeneous and meet the selection criteria. In some cases (For example zucchinis and eggplants), the products are arranged in the box in an oriented way (Figure 57).

Funded by
the European Union

Figure 57.Output of processing lines: boxes with products of similar quality/size

Products must not overflow from the box.

5.2.2 Product specifications

Regarding the food user case, 3 relevant products have been identified:

- Zucchinis;
- Eggplants;
- Tomatoes.

5.2.2.1 Zucchini

The zucchini is a long, cylindrical vegetable, slightly smaller at the stem end, usually dark green in colour. The flesh is a pale greenish-white and has a delicate, almost sweet flavour. The zucchinis fruit grows quickly and is harvested within 2 to 7 days of flowering.

Zucchinis must be sorted by category and size according to COMMISSION REGULATION (EC) No 1757/2003 of 3 October 2003:

Figure 58. Zucchinis

Class Extra - the zucchinis in this category must be of superior quality. They must present the characteristics of the variety and/or commercial type. They must be:

- well developed,
- well formed,
- provided with a peduncle, cut cleanly and not more than 3 cm in length.

They must be defect-free. Only very slight superficial defects provided these do not affect the general appearance of the product and its essential characteristics are admissible.

Class I - the zucchinis in this class must be of good quality. They must be characteristic of the variety and/or commercial type. The following slight defects, however, may be allowed provided these do not affect the general appearance and quality of the product:

Funded by the European Union

- slight shape defects. Zucchinis may be curved, with a curvature of no more than 10° from vertical. Spearhead shape is not allowed.
- slight colour defects: small areas with a lighter or darker colour than the rest of the product.
- very slight skin defects: small, barely visible scratches.
- very slight defects due to diseases provided they are not progressive and do not affect the flesh (presence of small black dots or areas where the has small white spots).

The zucchinis must have a stalk not exceeding 3 cm in length.

Class II - includes zucchinis which do not qualify for inclusion in the higher classes. They may show the following defects, provided these do not affect the essential characteristics as regards the quality, keeping quality and presentation:

- slight shape defects The zucchini may be curved, with a curvature of no more than 20° from vertical. spearhead shape is not allowed)
- slight colour defects, (Small areas with a lighter or darker colour than the rest of the product)
- very slight skin defects, (small visible scratches)
- slight sunburn (small with or yellow stain less than 1 cm in diameter),
- very slight defects due to diseases provided they are not progressive and do not affect the flesh. (presence of small black dots or areas where the has small white spots)

Size category

The size of the zucchinis is determined by both length and weight.

Length in cm: between the junction with the stalk and the tip:

Categories for the demonstrator:

- Cat.1: 7 cm ≤ d ≤ 14 cm
- Cat.2: 14 cm < d ≤ 21 cm
- Cat.3: 21 cm < d

We can assume a measuring tolerance of ±1 cm.

Weight in g.: the minimum weight is 50 g. and the maximum weight is 450 g.

- from 50 g. to 100 g.,
- 100 g. to 225 g,
- 225 g. to 450 g.

5.2.2.2 Eggplant

Fruits are round or elongated in shape, very smooth, with shiny black or very dark purple skin and bright green petiole. Fruit texture and hardness are very high.

Funded by
the European Union

Eggplants must be:

- whole; fresh-looking; firm; clean (free of visible foreign matter); with the calyx and stalk attached;
- healthy (products affected by rot or showing changes that make them unsuitable for consumption are excluded);
- with bright black epicarp, without reddish tinge, abrasions or other alterations; firm fruit
- with non-fibrous or woody flesh and underdeveloped seeds; free of abnormal external moisture; free of strange smell and/or taste.

Figure 59. Eggplant

Eggplant Quality Category

Class I (good quality) with typical characteristics of the variety, free from sunburn. Slight defect in shape, slight discoloration of the base, slight damages not exceeding 3 cm² of the surface.

Class II (with minimum quality characteristics) must exhibit the essential characteristics of quality and presentation. There may be present defects in shape, discoloration, slight sunburn and healed skin defects not exceeding 4 cm² of the surface area.

Eggplant Size Category

Calibration is determined by diameter (in mm), or weight (in g), and is mandatory for Class I.

Classification by diameter

- minimum allowed 70 mm.
- the difference, in the same box, between the smallest and the largest must not exceed **25 mm.**

In addition, for long ones, the minimum length of the stalk is 80 mm.

For the eggplants used in the demonstrator we will consider these categories:

- Cat.1: 70 mm ≤ d < 95 mm
- Cat.2: 95 mm ≤ d < 120 mm
- Cat.3: 120 mm ≤ d < 145 mm
- Cat.4: 145 mm ≤ d

Classification by weight

- minimum weight 100 gr.
- 100 to 300 g with a maximum difference of 75 g between the smallest and largest eggplant within the same box;

Funded by the European Union

- 300 to 500 g with a maximum difference of 100 g between the smallest and the largest eggplant within the same box;
- greater than 500 g with a maximum difference of 250 g between the smallest eggplant and the largest eggplant within the same box.

5.2.2.3 Tomato

Characterized by a large fruit, the tomato is consumed when it turns from a deep green to a red coloration.

Tomatoes Quality Category

- Extra (higher quality): very slight surface defects of the epidermis are allowed. Greenback is not allowed.
- Class I (good quality): they must not show cracks or green back. Slight defects in shape, development and coloration, epidermis defects and bruising allowed.
- Class II (with minimum quality characteristics): tomatoes must have no unhealed cracks. Allowed slight defects related to shape, development and coloration, epidermis defects or bruises, provided they do not seriously damage the fruit, healed cracks up to 3 cm in length.

Figure 60. Tomatoes

Tomatoes Size Category

The size is determined by the maximum diameter of the section normal to the axis of the fruit.

- 30 mm ≤ d < 35 mm
- 35 mm ≤ d < 40 mm
- 40 mm ≤ d <47 mm
- 47 mm ≤ d < 57 mm
- 57 mm ≤ d < 67 mm
- 67 mm ≤ d < 82 mm
- 82 mm ≤ d < 102 mm
- 102 mm ≤ d

The difference in diameter between tomatoes in the same box is limited to:

- 10 mm, if the diameter of the smallest fruit is < 50 mm;
- 15 mm, if the diameter of the smallest fruit is ≥ 50 mm < 70 mm;
- 20 mm, if the diameter of the smallest fruit is ≥ 70 mm < 100 mm;
- no threshold difference is set for tomatoes with a diameter of 100 mm or more.

Funded by
the European Union

For the tomatoes used in the demonstrator we will consider three different categories, such us:

- Cat.1: 30 mm ≤ d < 35 mm
- Cat.2: 35 mm ≤ d < 40 mm
- Cat.3: 40 mm ≤ d < 47 mm

It is accepted that 10% of the products are outside the category dimension.

5.2.3 Key figures

Product	Cycle time	Tolerances
Zucchini	**2-3 minutes** to complete a box of zucchinis (approximately 6-7 kg)	**Zucchini Size tolerance** • The difference in size between the fruits in the same box for all categories is 10% in +/- in number or weight. **Zucchini quality tolerance:** • Class Extra: up to a maximum 5% by number or weight of products not conforming to the characteristics of the class. • Class I: up to a maximum of 10% by number or weight of product not conforming to the characteristics of the class. • Class II: up to a maximum of 10% in number or weight of product not meeting the characteristics of the class, However, non-standard fruits must be suitable for consumption.
Eggplants	1 box of finished product of eggplant processing time **3 minutes**. Box weights 10 kg	**Eggplant size tolerance** • Class I, +/- 10% by number or weight of the indicated size. • Class II, +/- 10% by number or weight of the minimum size. • Tolerated product below the minimums: 5 mm and 90 g. **Eggplant quality tolerance** • Class I: up to a maximum of 10% by number or weight of product not meeting the characteristics of the category. • Class II: up to a maximum of 10% by number or weight of product not meeting the characteristics of the category.
Tomatoes	1 box of finished product of tomato: processing time **5 minutes**. Box weights 12.5 kg	**Tomatoes size tolerance** The difference in diameter between the fruits in the same box for all categories is 10 % in +/- in number or weight. **Tomato quality tolerance** • Class Extra: up to a maximum of 5% by number or weight of product not meeting the characteristics of the category. • Class I: up to a maximum of 10% by number or weight of product not meeting the characteristics of the category. • Class II: up to a maximum of 10% by number or weight of product not meeting the characteristics of the category.

It is noteworthy the trend to reduce the defects rate to below 1%.

Funded by the European Union

5.2.4 Target state

Nowadays, picking, sorting and placing activities are carried out by hand by the workers. This is a repetitive work where the products are handled and transferred piece by piece along the line or into the boxes for delivery. This is costly and can lead to unhealthy working conditions and, above all, possible hygienic problems. Also, some products require major attention for not damaging them during this phase, compromising its quality and shelf life. A robot (a cobot or an industrial robot with the corresponding safety measures) that can handle vegetables of different sizes, shapes, weights and softness, even when they are randomly distributed is a wish. The system must be fast and safe for the products and working alongside humans.

Because of line process (boxes running on conveyor belt), a human handling the boxes is required for moving unsorted box out of the line (close to the robot) and manage full boxes.
Using the HARTU solution a few number of persons will be necessary for coordinating and synchronizing the activity of the system.
In line with the objectives of the HARTU project, a simplified user case will be developed to demonstrate the effectiveness of the grasping technology. This use case will use the shape and dimension classification criteria (no defect inspection or weight).

5.3 Demonstrator design

5.3.1 System description

The demonstrator will be based on the packaging of zucchinis, eggplants, and tomatoes. It basically consists of a robot picking products from the input box, classifying them according to size and shape and placing them in the corresponding output box.

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 inbox. The most suitable product to be picked is identified using the grasping point identification component (TEK)
- 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.
    1. If it is detected that the box is full, a warning is sent to the line operator.

Funded by
the European Union

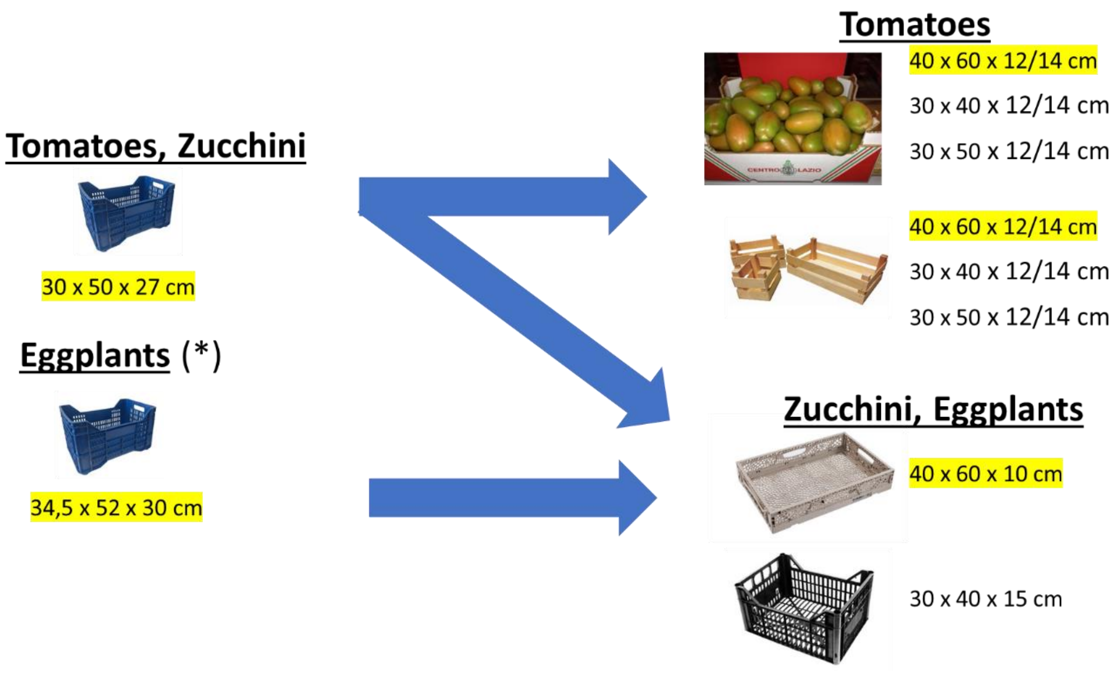


Figure 61. TCA demonstrator overview

The largest boxes in each category are marked in yellow in the previous scheme.

The categories for each type of vegetable are:

Categories by Size

	ZUCCHINI	TOMATO	EGGPLANT
Category	Length	Diameter	Diameter
1	7-14	30-34	70-95
2	14-21	35-39	95-120
3	>21	40-46	120-145
4		>46	>145

Where:

- The length of the zucchinis is measured from the extreme to the beginning of the stalk.
- The diameter of the tomatoes and the eggplants is the maximum diameter of the section normal to the axis of the vegetable.

5.3.2 Components of the system

The setting for the demonstrator consists of the following elements (see picture)

Funded by the European Union

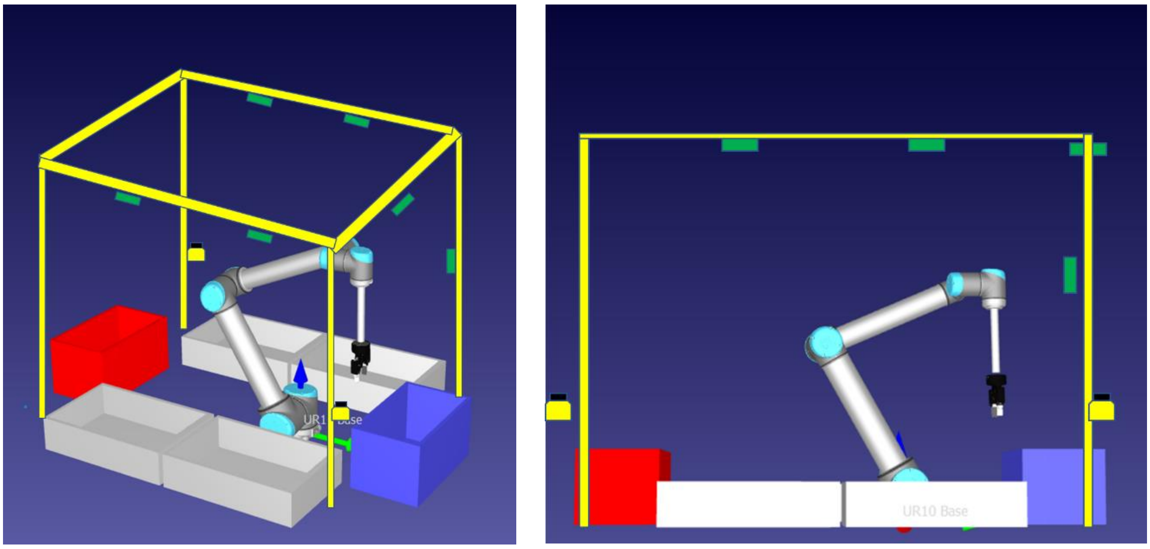


Figure 62. Initial design of the TCA demonstrator

The approximate dimensions of the settings are:

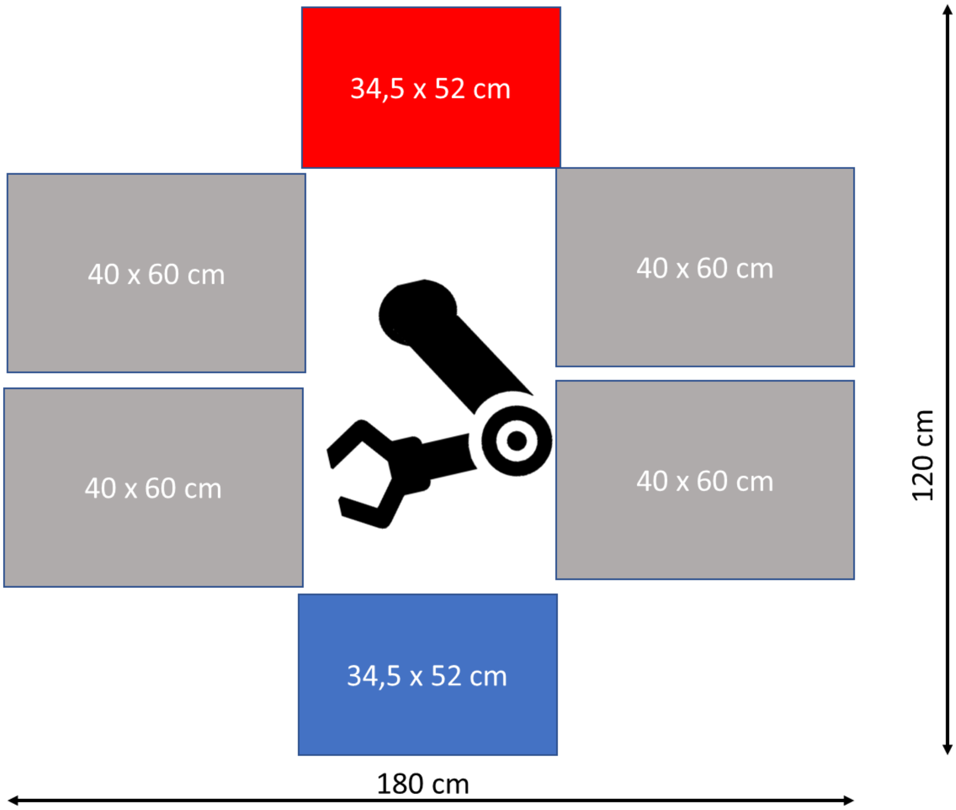


Figure 63. Footprint of the TCA demonstrator

Even if a cobot is initially considered for this demonstrator, the safety strategy will include the use of two safety lasers placed, each of them covering 270º as shown in the picture below:

Funded by the European Union

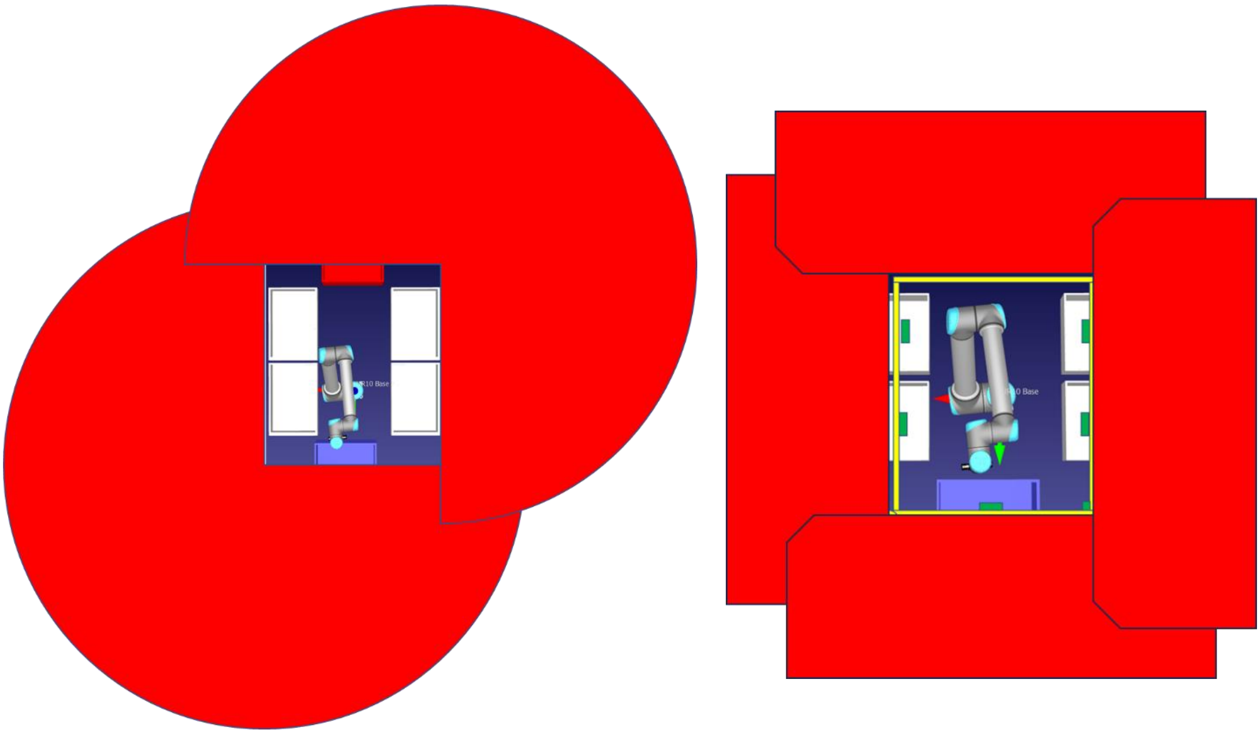


Figure 64. Safety monitoring areas covered by the two lasers (left) or four radars (right)

Alternatively, one safety radar in each side can be used.

In summary, the components in the scenario are:

- A robot. It could be a cobot, such as UR 10
- An input box and 4 output boxes
  - The possibility of picking eggplants directly from a conveyor belt (as humans currently do) will be studied in the TEK laboratory demonstration.
- The electro-adhesion gripper developed by OMNIGRASP and POLIBA
  - For the lab version of the demonstrators, a standard suction gripper will be used. Such as
    - https://www.piab.com/suction-cups-and-soft-grippers/round-suction-cups/multibellows-suction-cups/fcx/#features
    - https://millibar.com/product/mg-40x100/
- 6 RGB-D Zed-I cameras (or similar), https://www.stereolabs.com/zed-2i/
  - One above each box
  - One additional one to measure the size and shape of the product, once it has been picked.
- A control PC
- 2 safety lasers (each covering 270º) or 4 Safety lasers (one at each side of the workstation)
- 3 small form factor PCs (Jetson Orin) for image acquisition, each one will manage two cameras.
  - It will be tested if the control PC is able to control the 6 cameras. In such a case, these 3 PCs will not be needed.

Funded by the European Union

- A led base lighting system to guarantee a controlled lighting.
- Aluminium frame to fix the cameras and the lighting system.

5.3.3 System deployment

There will be 3 lab setups for this scenario:

- One at TEKNIKER
- One at AIMEN
- One at POLIBA/OMNIGRASP, with a simplified version, consisting in one input box and one output box.

Once the system has been validated in the lab, it must be validated at Centro Lazio (the company that collaborates with TCA to setup this scenario). Two alternatives are foreseen:

- TCA purchases the aluminium frame, and the rest of the system components are transported from TEK/AIMEN to Italy.
- TCA purchases the aluminium frame and rents a robot (or borrows one from a local robot dealer), the rest of the system components are transported from TEK/AIMEN to Italy.

In both cases, the robot may also be provided by OMNIGRASP (to be decided).

5.4 Technical risks

The following risks have been identified in the development of the system:

CODE	Description	Probability	Impact
R.1	The system is not safe for operators in the vicinity	Low (2)	Very High (5)
R.2	System not ready at the right time of the year for the products.	Medium (3)	High (4)
R.3	Risk of damaging the vegetable due to the robotized grasping and placing.	Low (2)	Very High (5)
R.4	Variation in appearance (colour, size, dimension etc)	Medium (3)	Medium (3)

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Funded by
the European Union

6 INFAR: Fixtureless assembly in hand tool manufacturing sector

6.1 Introduction

INFAR, a hand tool manufacturer located in Taiwan, produces almost 25M wrenches, ratchet handles, and various types of accessories per year. During manufacturing process, the most critical procedure is part assembly to complete a hand tool, be it a wrench or a ratchet handle.

Automation is a challenge as it requires specific fixtures for each hand tool, dexterity and accurate motion planning.

6.2 Use case description

This scenario corresponds to the assembly of hand tools by INFAR. Currently, this process is done entirely manually and one of the main challenges is the small size of the parts that have to be manipulated. HARTU proposes a multi-robotic assembly system to meet the needs of the use case.

HARTU has selected the ratchet wrench assembly as representative of this type of application. The main components to be assembled to create the final product are shown in Figure 65

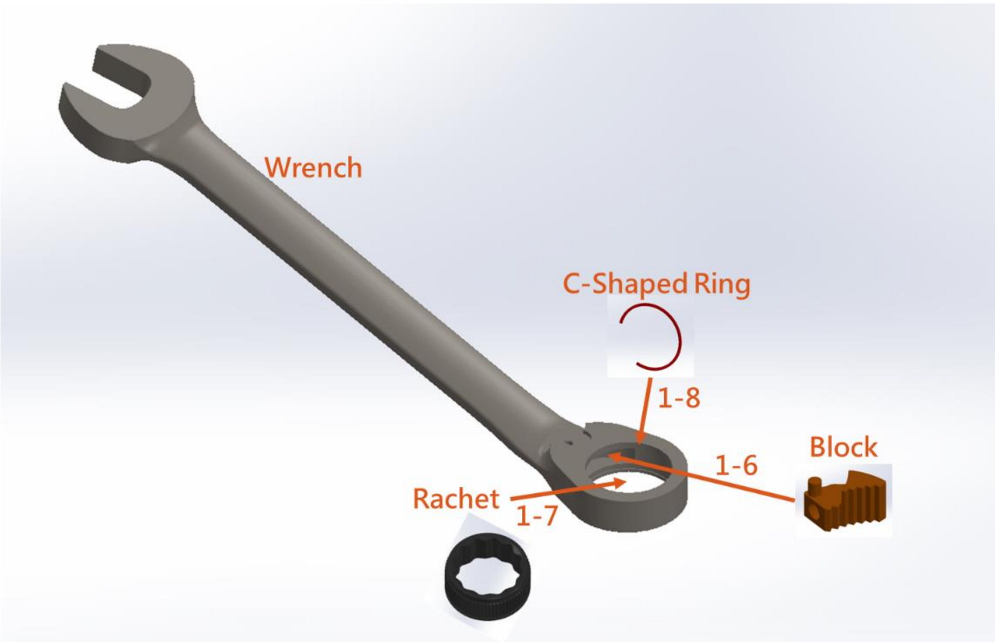


Figure 65. Main components of the wrench

6.2.1 Initial state

Currently, the operator takes the different components placed randomly at the working table and follows the defined procedure to assemble the components, as described in next subsection.

Funded by the European Union

Figure 66. Assembly workshoop overview

Figure 67. Operators at the assembly tables

6.2.1.1 Assembly process

Table 1: INFAR Scenario: current process

	Step 1: Assembly, of two springs in wrench. One spring is for "fix-pin", the other spring is for "a tiny steel ball". Place the wrench on the desktop. Place fix-pin spring in the upper hole and the steel ball spring in the lower hole.
	Step 2: Assembly of fix-pin and steel ball Place the wrench on the desktop. Place the fix-pin on the spring in the upper hole. Place the steel ball on the spring in the lower hole.
	Step 3: Assembly, toggle placement Hold the toggle with one hand, place the toggle slot and test whether it falls out.

Funded by
the European Union

	Step 4: Oiling Hold the toggle with one hand an oil inside the ratchet hole with a brush.
	Step 5: Assembly, block assembly Place the two small blocks and a spring with oil into one block.
	Step 6: Assembly, block insertion Press the block (the component that does or does not allow movement of the ratchet) inside the big hole of the wrench.
	Step 7: Assembly, ratchet insertion Place the ratchet in the big hole of the wrench.
	Step 8: Assembly, C-shaped ring insertion Place the C-Shaped ring around the ratchet.

Funded by the European Union

	Step 9: Assembly, C-Shaped ring sealing Seal the C-Shaped ring using pliers in the right hand and a peg in the left hand
	Step 10: Testing Test the direction of rotation with the Texting fixture.
	Step 11: Polishing Polish the wrench.
	Step 12: Package Arrange the wrenches in an orderly fashion.

The process can be seen in these videos:

- HARTU-INFAR-place_block_ratchet.mp4
- HARTU-INFAR-push-ratchet_place_C-Ring.mp4

6.2.1.2 Inputs

Environmental conditions:

- Room temperature around 5 to 40ºC

Personnel:

- One assembly operator
- One day training for a new operator

Components used:

Funded by the European Union

- Wrench
- C-shaped ring
- Block
- Ratchet

Tools used:

- Clamp
- Brush
- Pliers
- Peg
- Testing fixture
- Polishing cloth

Information available:

- CAD data for components available

6.2.1.3 Outputs

Process output

Materials out:

- Assembled ratchet wrench

6.2.2 Product specifications

HARTU will focus on 3 different assembly tasks:

- Step 6 (1-6)
- Step 7 (1-7)
- Step 8 (1-8)

The corresponding parts and tasks are shown in Figure 68.

Funded by the European Union

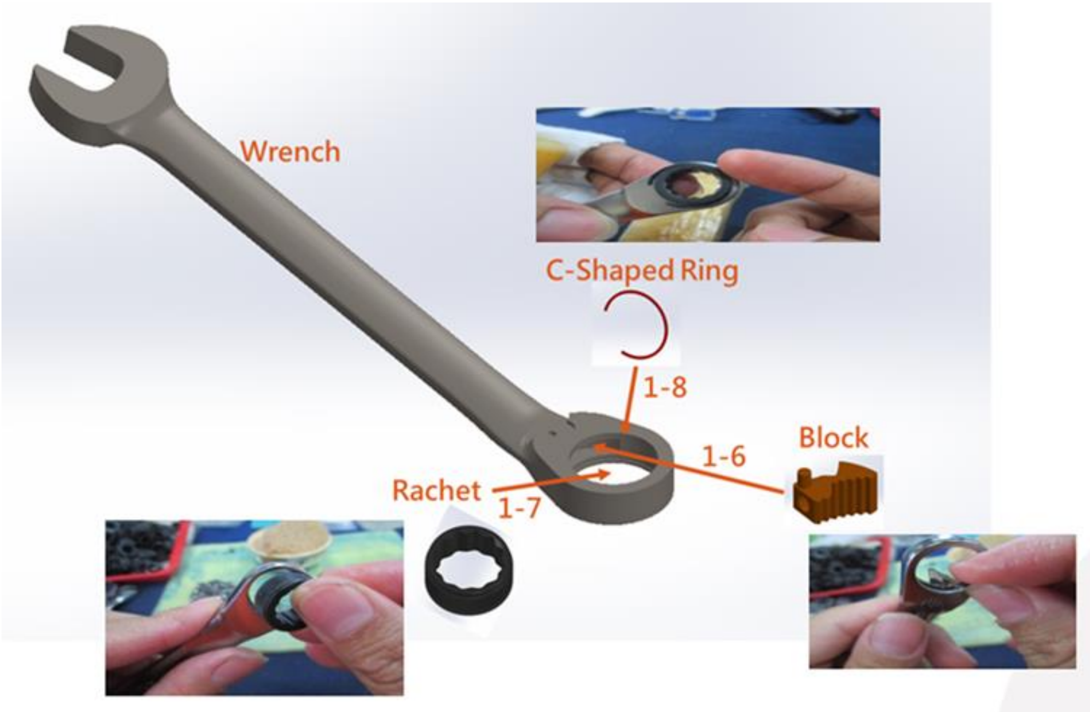


Figure 68. INFAR: Selected operations

Figure 69. Parts involved in the INFAR use case

Funded by the European Union

Family name 工件名稱	Industrial Scenario	Morphology 樣子	Material 材質	Colour 顏色	Brighness 光澤	Weight 重量	Dimensions of the container parallelepiped (mm) 尺寸 x*y*z
ratchet wrench (棘輪板手本體)	INFAR	Parallelepiped	Ferromagnetic	Any	Shiny	100g-500g	320X50X30
C-Shaped Ring (C形環，C扣)	INFAR	Toroid	Ferromagnetic	Any	Shiny	<100g	40X40X1
A component for allowing moving in one direction (擋塊)	INFAR	Irregular	Ferromagnetic	Any	Shiny	<100g	3X3X5
Ratchet (棘輪)	INFAR	Toroid	Ferromagnetic	Any	Shiny	<100g	10X10X10
A component for fixing (固定片)	INFAR	Irregular	Ferromagnetic	Any	Shiny	<100g	12X12X2

The average cycle time for these three operations is less than 30 seconds.

6.2.3 Key figures

- Cycle time for the operations: 30 sec.
- Number of produced parts / years: 25M

6.2.4 Target state

According to some market studies (Figure 70), the hand tool market is growing at a CAGR of 4.2%.

To meet the increasing demand for orders, many operators are required to perform the assembly of ratchet wrenches in a dangerous (heavy part manipulation, plating process involving chemicals) and noisy working environment. This causes a labor shortage problem. In addition, the dual digital and green transformation is a critical issue for conventional manufacturing industries like INFAR.

HARTU technology and system implementation, can help addressing both labor shortage and dual digital and green transformation. Via AI-enabled multi-robotic assembly system developed in HARTU, some operators may be freed from hand tool assembly tasks and can carry out higher-value tasks.

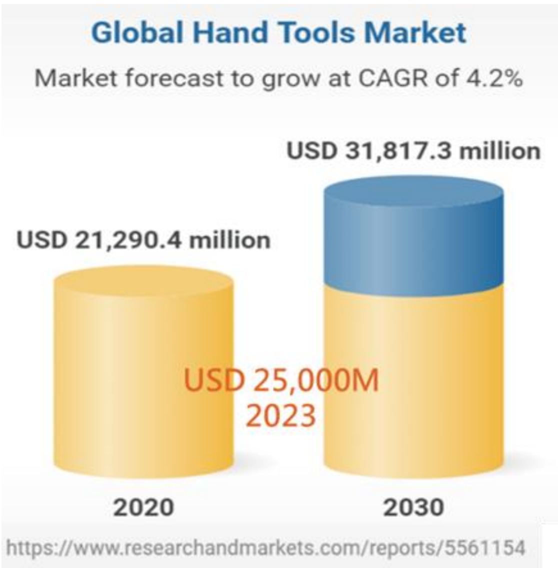


Figure 70. Hand tools market

Moreover, by adopting robotic automation manufacturing, Carbon emission can be indirectly reduced since automation can improve the efficiency of energy use.

6.3 Demonstrator design

6.3.1 System description

- Two robots equipped with specific designed gripper and workpiece loading/unloading mechanism, will automatically assemble a ratchet wrench as shown in the following figure.
- A robot cell controller will be included to coordinate the movements of these two robots to complete the assembly task as shown in the following figure where Assembly Planning is mapped with Control Target, Assembly Movement is mapped with two robot commands A

Funded by the European Union

& B assigned by the Robot Cell Controller, and there could be some interactions between robots A & B. The Robot Cell Controller can implement the concept illustrated within the purpose dashed block.

➢

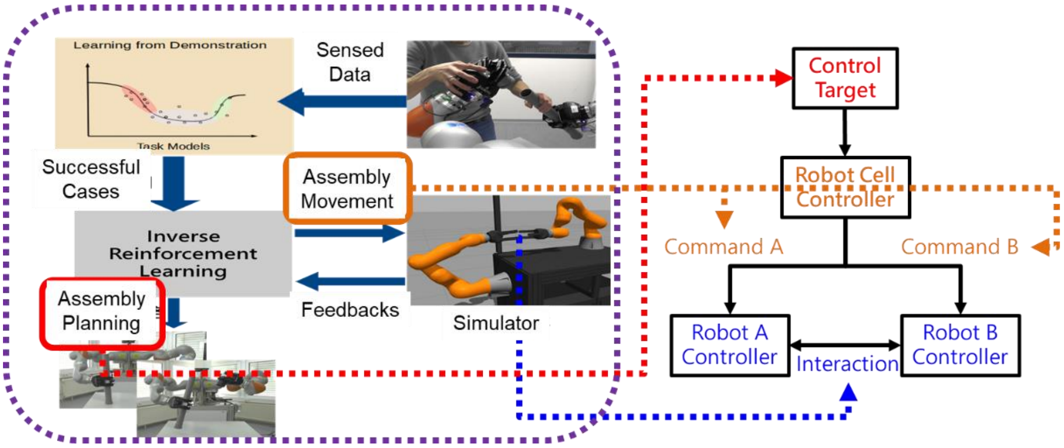


Figure 71. Proposed The Robot Cell Controller for multi-robotic assembly

Figure 72. From the exploded-view drawing to assembly completeness via robotic assembly process

6.3.2 Components of the system

- Two robots
- Specific designed gripper for grasping the ratchet and the wrench.
- Robot Cell Controller
- 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.
- 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.

Funded by
the European Union

6.3.3 System deployment

The system described above will be first implemented at ITRI located in Hsinchu for further experiments and functionality verification. And the system will be shipped to INFAR located in Changhua (two-hour driving distance from Hsinchu).

The core of this system including the robot cell controller, workpiece loading/unloading mechanism, and the software modules for perception functionalities could be delivered to other HARTU Partners for further system testing and development purposes.

6.4 Technical risks

CODE	Description	Probability	Impact
R.1	The tiny size of workpieces could be the major risk for robot grasping and then assembly.	High (4)	High (4). Without correct workpiece grasping, the following assembly could not be completed.

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Funded by the European Union

7 ULMA-1: Order preparation: pallet to pallet

7.1 Introduction

In logistics, there are different types of order preparation needs 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 for bulky products, packed in carboards, large cans and sacks.
  - Small size products arrive in boxes, orderly or randomly distributed.
- Output
  - Products are stacked on pallets, either single or multi-reference.
  - 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.

7.2 Use case description

For the sake of clarity, this use case will be described in reference to the needs of the company BESA S.A., one of ULMA's customer. In this paint manufacturing company, ULMA has implemented a logistic solution in which products are automatically stacked on pallets at the end of the production line, transported in autonomous AGVs to the warehouse, stored on shelves using an automatic stacker crane and, when required, transported with the Sorting Transfer Vehicles and conveying system to the preparation area, where human operators prepare the orders.

7.2.1 Initial state

7.2.1.1 Process

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 73.

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

- The incoming pallets are always monoreference 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 also 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).

Funded by
the European Union

- In some few occasions, the incoming pallet transports a box with products inside, which have to 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 73. Real example of output pallet at BESA

A video of the current process is available here: [BESA-Example: Pallet to pallet]

In the following pictures it is shown the operators manipulating products manually (Figure 74) or with the support of material manipulators (Figure 75).

Figure 74. Operator manually placing a box on the pallet

Figure 75.Operator placing a can on the pallet with the help of a material handling crane

The overall workflow is depicted in the next picture:

Funded by the European Union

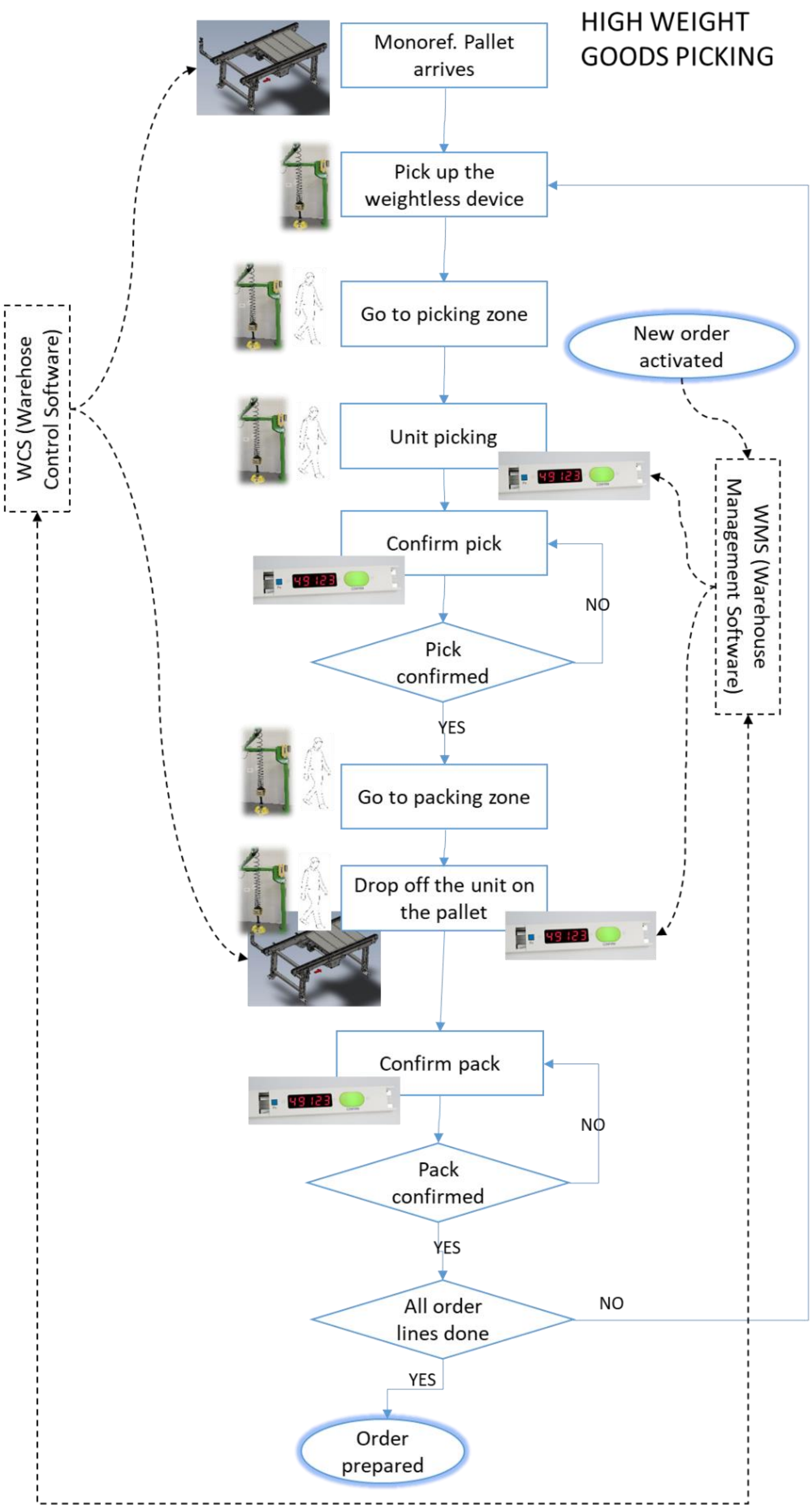


Figure 76. Pallet to pallet order preparation workflow

7.2.1.2 Inputs

- Input pallet with the products to be picked.

Funded by the European Union

- Empty output pallet to create the order.
- Number of items to be picked from the incoming pallet, shown in the pick-to-light system and also available in the GUI in the preparation area control desk.
- One material handling crane to support the operators picking the heaviest items. The working principle of the crane is vacuum.
- Personnel
    - The number of persons required to carry out the process depends on Customer requirements. In the case of BESA there are two workers per shift.
    - No special skills are requested.

7.2.1.3 Outputs

- Incoming pallets that have to return to the warehouse.
- Output pallet with the prepared order
- Confirmation of each picking operation through the pick-to-light system

7.2.2 Product specifications

- Carboard boxes of different dimensions. Maximum weight is 25 kg.
- Metallic cans weighting up to 30 kg
- In some few cases, plastic bottles that are transported in plastic boxes.
- In other similar scenarios to this at BESA, we can consider also:
    - Bottle packs up to 15 kg
    - Sacks (rice, flour, sugar, etc.) up to 20kg

Figure 77. Examples of products manipulated in a pallet to pallet scenario

7.2.3 Key figures

- Cycle time: 400 cycles/h
- Error rate (number of items incorrect): less than 1/ 1000 picking

7.2.4 Target state

A robot is able to handle the number of items requested by the WMS from the pallet in the picking station and place them in the position defined by the WMS on the output pallet, monitoring the stability of the input and final pallets. The WMS can provide basic information about the products on the pallet, in particular their dimensions and weight.

Funded by
the European Union

7.3 Demonstrator design

7.3.1 System description

In this scenario, products arrive at the preparation area mainly on pallets (Euro Pallet, EPAL, although sometimes they can be in the interior of boxes.

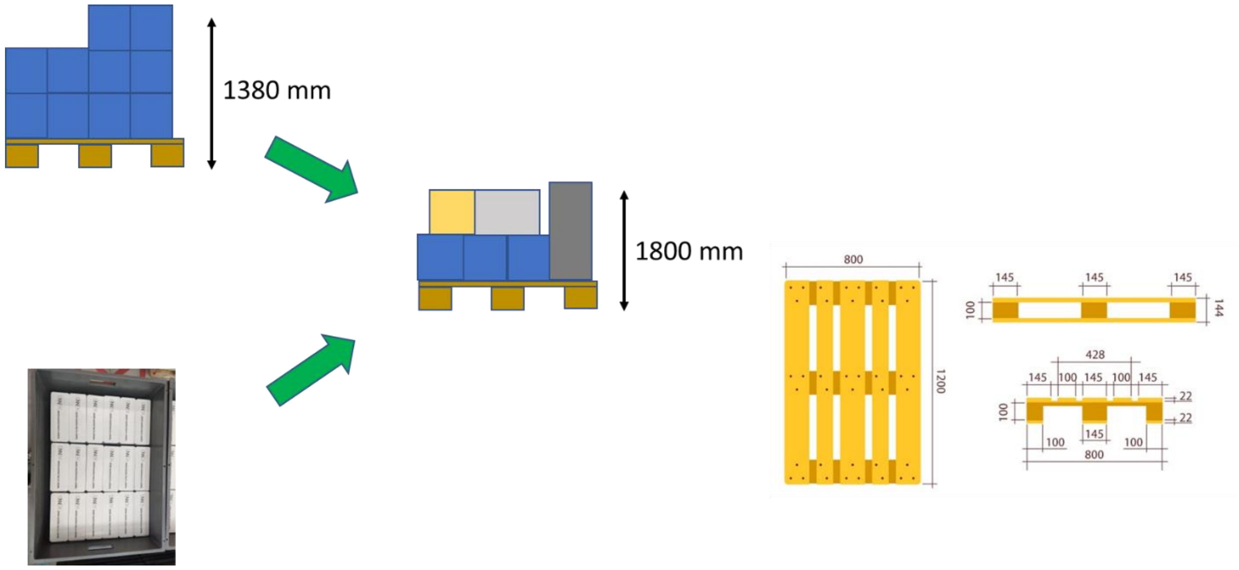


Figure 78. ULMA palletizing use case

The products considered in the demonstrator are: Carboard boxes, cans, sacks and film-packed product sets.

Figure 79. Product types in the ULMA palletizing scenario

The demonstrator will be setup at ULMA showroom, using some already available equipment. The foreseen process is as follows:

- A pallet arrives in the picking station.
    - The robot knows which is the product on the pallet (information provided by the WMS), including the dimensions of the product and its orientation on the input pallet.
- A point cloud of the pallet is acquired and the most suitable product to be picked is identified.

Funded by the European Union

- The robot calculates the trajectory and picks the product.
- The robot places in the target position (mosaic creation algorithm provided by ULMA)
- A point cloud of the output pallet is acquired to monitor its status
    - Stability measuring
    - Free volume calculation

7.3.2 Components of the system

The demonstrator will simulate a real setup, integrating the following components:

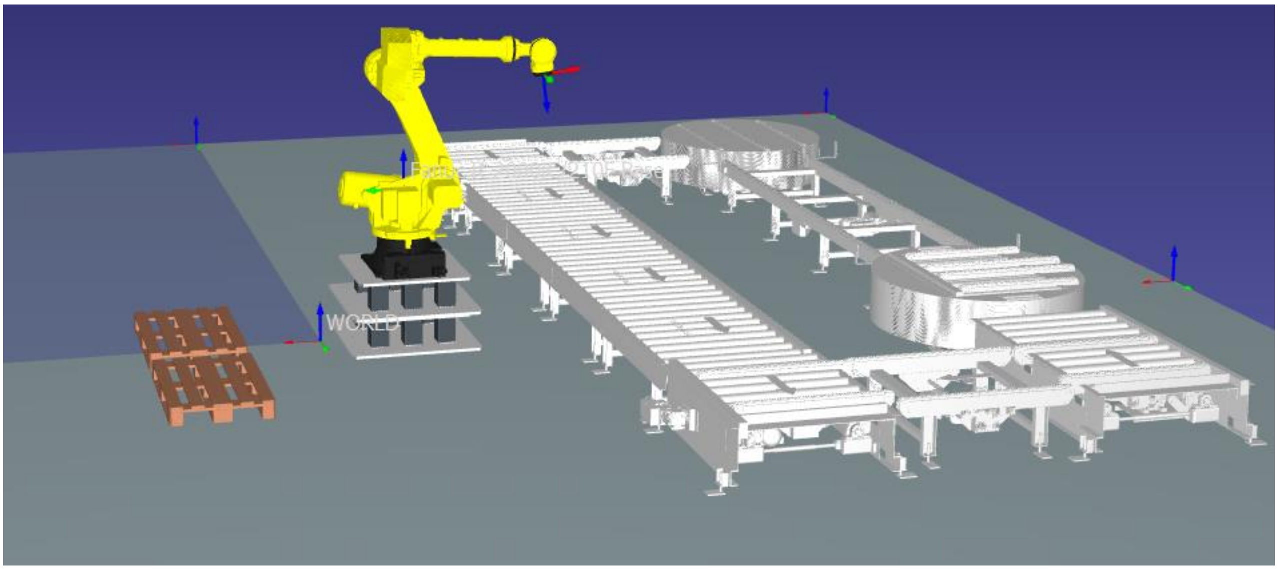


Figure 80. ULMA Palletizing station design

- Conveyor system to transport the input pallets
    - It is a rolling conveyor system, including two rotating stations. The system is controlled by the MFC (Material Flow Control or Warehouse Control System).
    - The output pallet is placed by the operator using a forklift in the working area of the robot. In an industrial setting, it could include a film-packaging system and also a elevation mechanism.
- Robot FANUC R-2000Ic/210F
    - According to the simulation done, it has to be mounted on a 86 cm high pedestal.
- Grippers:

  Due to the heavy weight of some products, surface irregularities and different product sizes, different grippers will be needed. To enable automation, a tool changing station may be required.

Funded by
the European Union

The grippers will use suction to allow handling the products from the top and create compact pallet mosaics (the use of finger grippers would mean that there would be a gap between products).

The two grippers initially available are:

- JOULIN CG-VG 400x400-J-P20-3STx8
- JOULIN EGV2-VG-125x400-J-4P30-3STx1

Other industrial grippers will be analysed and integrated in case of need due to the dimensions of the products to be handled.

For automatic tool exchange, all tools are equipped with a RSP P1804, mechanical interface.

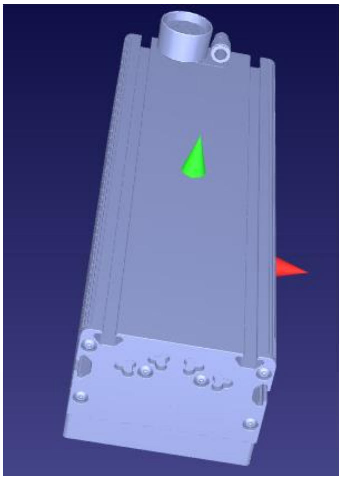


Figure 81. EGV2-VG-125x400-J-4P30-3STx1 available

- 2 Photoneo L cameras
  - One placed on top of the input pallet (or the input box) to monitor its status.
  - One placed on top of the output pallet to monitor its status, identifying free volume and control the stability of the pallet
- PC to run the control software.
- The WMS and MFC application to manage the movements of pallets on the conveyor and provide information about the products on the input pallet and the expected mosaic configuration of the output pallet.

7.3.3 System deployment

The system will be developed and validated at ULMA facilities. ULMA will provide all the components and TEKNIKER will integrate them and the rest of results (in collaboration with other partners).

7.4 Technical risks

The following risks have been identified in the development of the system:

CODE	Description	Probability	Impact
R.1	The box or the can opens during the handling operation	Very Low (1)	Medium (3)

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Funded by
the European Union

8 ULMA-2: Order preparation: box to box

8.1 Introduction

As explained in section 7.1, in logistics, there are different types of order preparation needs depending on how the products arrive at the preparation area and how the orders are delivered.

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

8.2 Use case description

For the sake of clarity, this use case will be described in reference the needs of the company Abacus, one of ULMA's customers.

8.2.1 Initial state

8.2.1.1 Process

In the order preparation area operators pick units from the incoming boxes and place them inside the corresponding output box. The products are placed without stacking because these output boxes are transported to a workstation for packaging in the final envelope 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 (the size of the box limits this value), and the weight is below 8 kg.
- 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.

A video of the current process is available here ABACUS Example : box to box

The overall workflow is depicted in next picture:

Funded by
the European Union

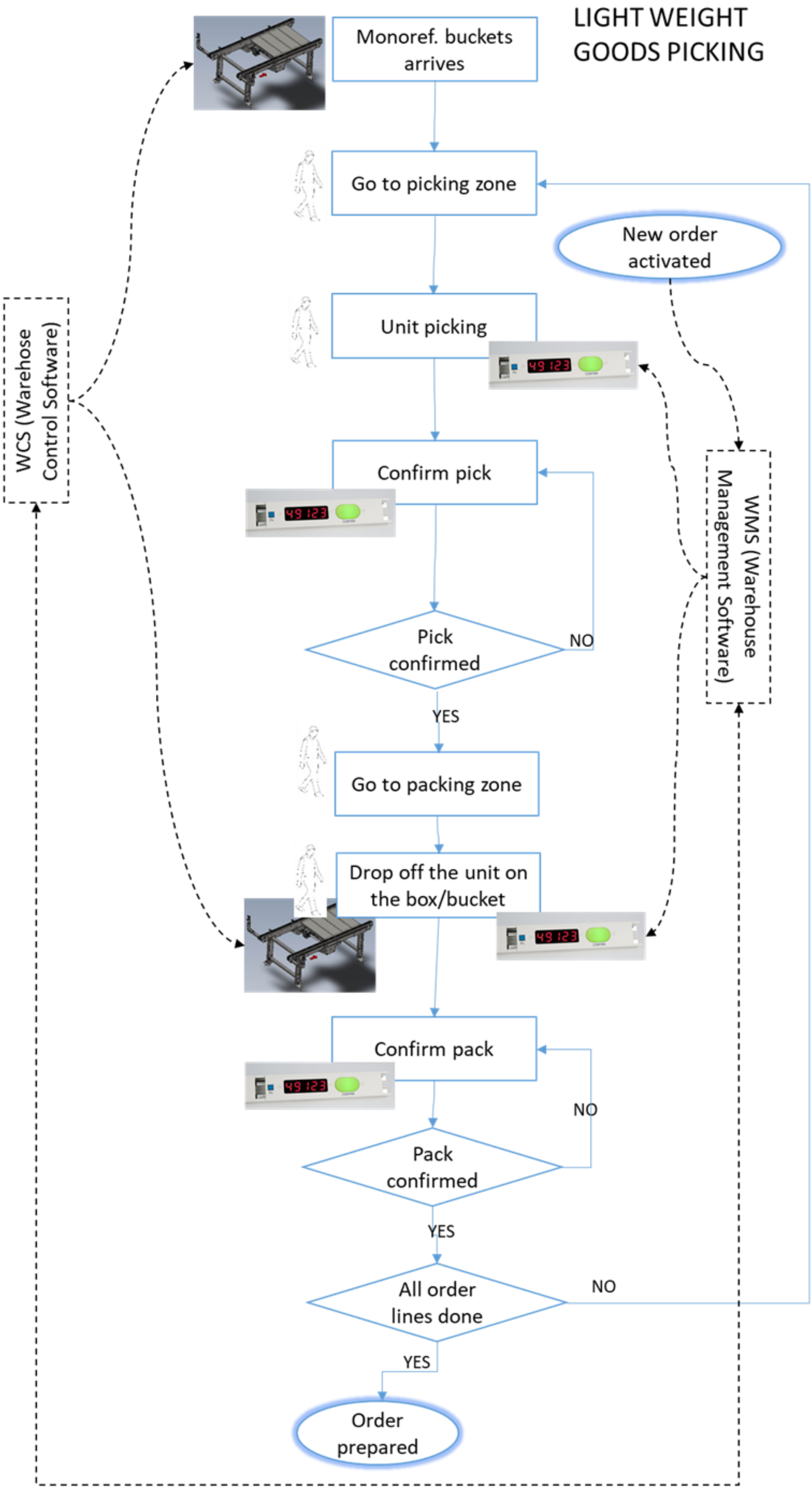


Figure 82. Box to box order preparation workflow

8.2.1.2 Inputs

Funded by the European Union

- Number of items to be picked from the incoming pallet, shown in the pick-to-light system
- Input box with the products to be picked.
- Empty output box to create the order.
- Environmental conditions

Category	Temp (ºC)	Humidity
Dry	4-40	<85%
Cool	1-5	<95%
Frozen	-25-1	<85%

8.2.1.3 Outputs

- Mono-reference incoming boxes
- Multi-reference output boxes
- Confirmation of each picking operation through the pick-to-light system

8.2.2 Product specifications

- Small boxes, pots, small cans, irregular shape products, blisters, etc.

Figure 83. Examples of products manipulated in a box to box scenario

8.2.3 Key figures

- Cycle time: from 250 to 1.000 cycles / hour, depending on the product
- Error rate (number of items picked or wrong reference):1 / 1.000 pickings

8.2.4 Target state

There are many reasons to try to automatize the order preparation operations:

- Workforce scarcity: companies are suffering the lack of workforce for this type of job
- In some sectors, e.g. pharmacy, companies don’t like human operators to handle products by hand, as they can be medicines with restricted access, products of reduced dimensions and with high economic value.
- Operators make mistakes:
    - grasping the wrong product
    - wrong number of items.
    - wrong destination box

Funded by
the European Union

The scenario envisaged for ULMA is a robotic system, which receives as input information about the product in the box, is able to pick the number of items requested by the WMS and deposits them in the corresponding output box. From an industrial point of view, it is important to achieve a performance as close as possible to that of humans.

8.3 Demonstrator design

8.3.1 System description

The objective of this demonstrator is to validate the grasping strategies. The system will be the alternative to current pick-to-light used in logistic centers for manual processes.

Products arrive at the picking area inside standard plastic boxes (600 x 400 x 320 mm), that sometimes have internal dividers to create 2 or 4 sub-boxes (see Figure 85). Inside the boxes (or the sub-boxes) only one type of reference is possible. The robot has to pick the products from these boxes (sub-boxes) and deposit them in the output boxes.

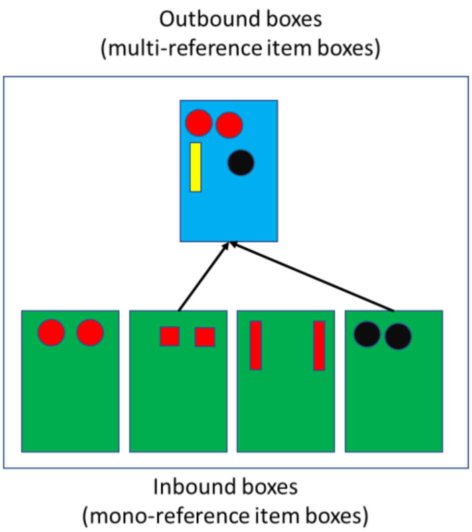


Figure 84. Flow of products in the scenario: from monoreference to multirefences boxes

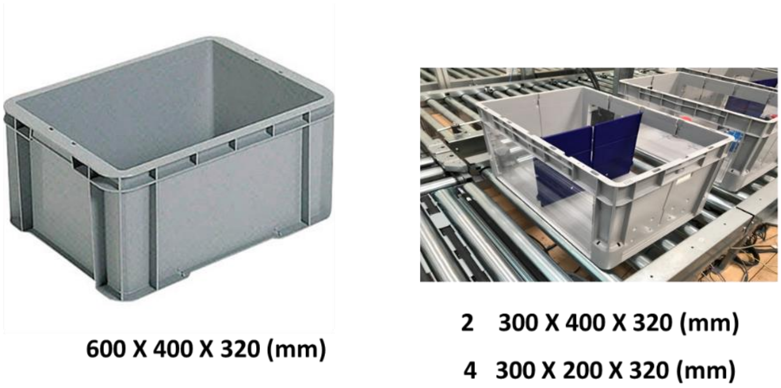


Figure 85. Standard box (left) and one with one divider to create two sub-boxes

8.3.2 Components of the system

To simulate a realistic system we will adapt an already existing robotic cell available at TEK, that allows creating a multi-station setting.

Industrial system	HARTU demonstrator
Input boxes arrive automatically to the picking station. Once products are picked the box is automatically sent to the warehouse.	We will have up to 7 input boxes each of them with a monoreference product. We will have one output box

Funded by the European Union

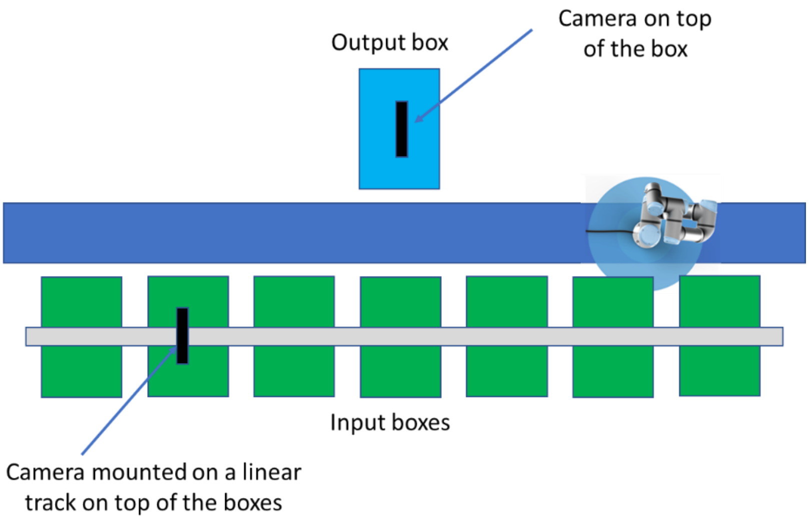


Figure 86.Laboratory system layout for order picking in boxes

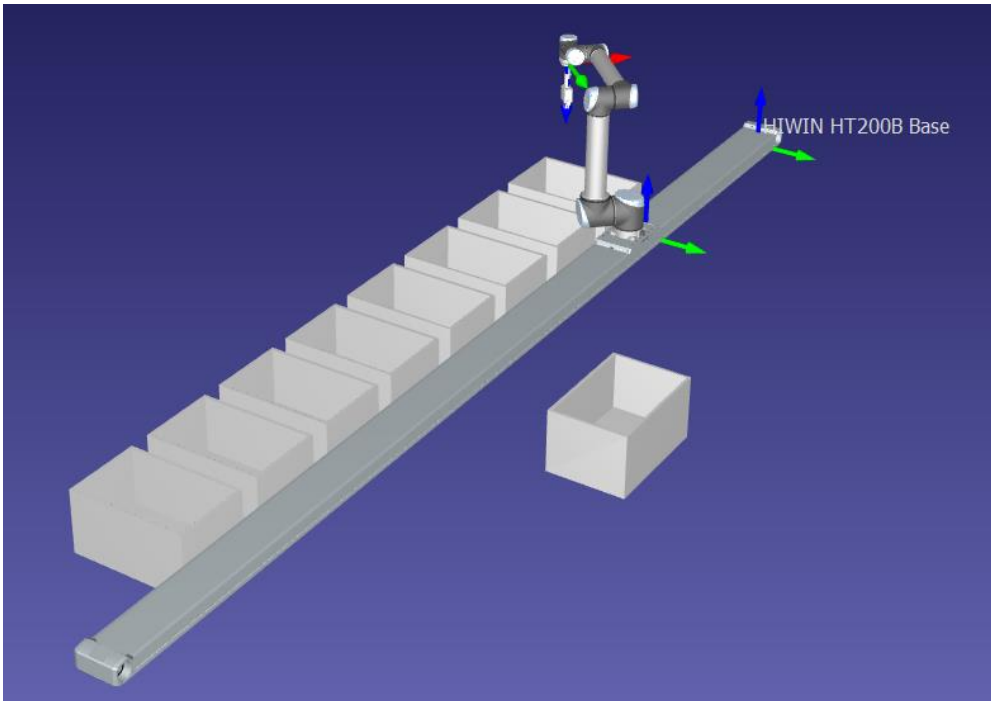


Figure 87. ULMA box-to-box scenario simulation

The components in the demonstrator are as follows:

- UR 10 mounted on 4m linear axis. Alternatively, the robot can be fixed in one position and the boxes can arrive at the picking station via a conveyor belt.
- 2 Finger or suction gripper.
    - Consider a tool exchanging station or a dual gripper, such as [OnRobot Dual Quick Changer - Unchained Robotics]

Funded by
the European Union

Figure 88. Too exchanger components for two tools

Figure 89. Dual tool

- Up to 7 input box stations (monoreference).
- 1 output box station (multireference).
- Photoneo L on top of the output box (box status monitoring).
    - Alternatively, an RGB-D camera on top of the station.
- Photoneo L mounted on a linear track above the input box stations.
    - Alternatively, an RGB-D camera on top of each box.

8.3.3 System deployment

The system will be developed and validated in TEKNIKER's facilities.

TEKNIKER will provide all the physical components and integrate them, and the rest of software components developed in HARTU (in collaboration with other partners).

8.4 Technical risks

The following risks have been identified in the development of the system:

CODE	Description	Probability	Impact
R.1	Performance far from that of humans, due to human dexterity and the use of two hands	High (4)	Medium (3)
R.2	Unpredictable product types used in e-commerce.	Very High (5)	High (4)

Very Low=1; Low =2; Medium = 3; High=4; Very High=5

Funded by
the European Union

9 Requirements

For requirement targets to be assessed by several tests, the number of tests shall be the statistically relevant number of tests. This value shall be decided on a case-by-case basis.

The validation methods is sometimes self-evident, and in other cases will be decided prior to experimentation, taking into account the effectiveness of the procedure and possible external constraints.

9.1 User requirements

USER REQUIREMENTS			
Ref.	UC	Description / target	Dem. (Y/N)
UR-01	ALL	Human operators should work safely in collaboration/presence with robots. **Target**: Y	Y
UR-02	ALL	An operator shall be able to start and stop the system. **Target**: Y	Y
UR-03	ALL	A skilled operator should be able to configure a new part handling. **Target**: Y	Y
UR-04	ALL	An operator should be able to change over the system from one part to another. **Target**: Y	Y
UR-05	ALL	The users need flexible lines, allowing the use of different box sizes, products and sorting criteria. **Target**: Y	Y
UR-06	ALL	The operator needs to be informed when the system completes its tasks (e.g., input box empty or output box full) so as to intervene promptly in the line. **Target**: Y	Y
UR-07	TCA	End user may need to move the sorting system to different places in the plant. **Target**: Y	N
UR-08	ALL	The operator needs to interact with a user-friendly GUI in order to control the system easily. **Target**: Y	Y

The list of user requirements is a preliminary list that will be further expanded in D1.2.

9.2 Functional requirements

FUNCTIONAL REQUIREMENTS			
Ref.	UC	Description / target	Dem. (Y/N)

Funded by the European Union

FR-01	TOFAS-1	The robot handles spare parts packaged in carboard boxes. Human operators the rest. **<u>Target</u>**: Y	Y
FR-02	TOFAS-1	The robot verifies the reference and number of products manipulated (using the same barcode reading procedure). **<u>Target</u>**: Y	Y
FR-03	TOFAS-1	The robot places the objects inside the outbound boxes. **<u>Target</u>**: Y	Y
FR-04	TOFAS-1	Both types of output boxes have to be considered: the standard grey big box and carboard smaller boxes. **<u>Target</u>**: Y	Y
FR-05	TOFAS-2	Cobot can insert the components. **<u>Target</u>**:	Y
FR-06	TOFAS-2	Cobot can screw the bolts. **<u>Target</u>**:	Y
FR-07	PCL	The system should be able to recognize the parts to be handled . **<u>Target</u>**: > 95% recognition rate	Y
FR-08	PCL	The system should be able to plan and execute a grasping action. **<u>Target</u>**: > 95% grasp success	Y
FR-09	PCL	The system should be able to identify empty jig positions. **<u>Target</u>**: > 95% recognition rate	Y
FR-10	PCL	The system should be able to plan and execute a fixturing action. **<u>Target</u>**: > 95% fixturing success	Y
FR-11	PCL	The system should be able to plan and execute the opposite removing action. **<u>Target</u>**: > 95% removing success	Y
FR-12	PCL	The system should be able to pick up and place parts from and onto trays. **<u>Target</u>**: Y	Y
FR-13	TCA	Detect the size and shape of the product. **<u>Target</u>**: Y	**Y**
FR-14	TCA	Pick products from a box (e.g., zucchini). **<u>Target</u>**: Y	**Y**
FR-15	TCA	Maximum number of layers of product in a box. **<u>Target</u>**: <4	Y
FR-16	TCA	Pick product from a conveyor belt (eggplants and tomatoes). **<u>Target</u>**: Y	**N**
FR-17	TCA	Recognize product defects. **<u>Target</u>**: Y	**Y**
FR-18	TCA	Place the item neatly in the output box. **<u>Target</u>**: Y	**Y**
FR-19	TCA	Do not damage the product during handling operations. **<u>Target</u>**: Y	**Y**
FR-20	INFAR	The system shall visually identify the components ready for assembly.	Y

Funded by
the European Union

		Target: > 90% recognition	
FR-21	INFAR	The system shall grasp the identified components. **Target**: > 95% success	Y
FR-22	INFAR	The system shall perform assembly task based on the specified assembly procedures. **Target**: Y	Y

9.3 Non functional requirements

NON-FUNCTIONAL REQUIREMENTS			
Ref.	UC	Description / target	Dem. (Y/N)
NR-01	TOFAS-1	Cycle time of the process **Target**: <60 seconds	Y
NR-02	TOFAS-1	Collision Detection Rate **Target:** 100%	Y
NR-03	TOFAS-1	Successful picking rate **Target:** (>95%	Y
NR-04	TOFAS-1	Successful part identification rate. **Target**: >95%	Y
NR-05	TOFAS-2	Up time specification. **Target**: OEE of 95%	Y
NR-06	TOFAS-2	Cycle time **Target**: 15 minutes for 10 box kitting preparation	Y
NR-07	TOFAS-2	Cycle time **Target**: 90 sec for the assembly operation	Y
NR-08	PCL	Cycle time **Target**: <10 seconds per part.	Y
NR-09	PCL	Reconfiguration **Target**: < 15 minutes	Y
NR-10	PCL	System footprint **Target**: 1 x 1 m	Y
NR-11	TCA	Material compliance with CE Regulation n. 1935/2004 **Target**: Y	N
NR-12	TCA	Material must be resistant to common washing with water spray from any direction (IP64) **Target**: Y	N
NR-13	TCA	Cycle time **Target**: < 3 minutes to complete a box of zucchinis	Y
NR-14	TCA	Cycle time **Target**: < 3 minutes to complete a box of eggplants	Y
NR-15	TCA	Cycle time **Target**: < 5 minutes to complete a box of tomatoes	Y
NR-16	TCA	Picking error rate **Target**: < 1% (1 failed item out of 100 picked)	Y

Funded by the European Union

NR-17	TCA	Compliance with Global G.A.P. Certification **Target**: Y	N
NR-18	TCA	Classification error **Target**: according to the tolerances	Y
NR-19	INFAR	Correct assembly on the ratchet wrench passing the testing criteria. **Target**: Y	Y
NR-20	INFAR	Cycle time **Target**: < 1 minute for the three selected steps of the ratchet wrench assembly	Y
NR-21	ULMA-1	Stability of output pallets: **Target**: Detect misalignments	Y
NR-22	ULMA-1	Product weight **Target**: < 30kg	Y
NR-23	ULMA-1	Stability of output pallet **Target**: Y	Y
NR-24	ULMA-1	Type of products. **Target**: boxes, paint cans, packed bottles	Y
NR-25	ULMA-1	Cycle time. Although it depends on the product and the final composition of the target pallet, we can consider, as an average: **Target**: 9 seconds / item	Y
NR-26	ULMA-1 ULMA-2	Robot shall be able to detect picking and/or placing errors. **Target**: Y	Y
NR-27	ULMA-2	Product weight **Target**: < 5 kg	Y
NR-28	ULMA-2	Error in picking operations **Target**: Detect any error	Y
NR-29	ULMA-2	Cycle time. It depends very much on the product, its arrangement in the box and the gripping mechanism used. For the best case, we can consider: **Target**: 4 seconds	Y
NR-30	ULMA-2	Products are place in the destination box randomly but checking that they don’t suffer any damage during dropping. **Target**: Y	Y

Funded by the European Union

10 Preliminary Risk assessment

A Preliminary risk assessment has been done based on the analysis of the use cases for an early detection of possible risks. 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	Maintenance, service, Manual	Sharp parts	Cutting	After maintenance the robot can be in undefined position	1	2	2	1	5	2: Middle (improvement necessary)

Funded by the European Union

		undefined positon										
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)
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		All	Moving part approaches	Getting stuck, being hit		1	1	1	1	1	

Funded by the European Union

		(automated) supply of new box		static part		In demonstrator manual replacement of boxes						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.

Funded by
the European Union