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REMODEL - Robotic tEchnologies

for the Manipulation of cOmplex

DeformablE Linear objects

Deliverable 2.4 – Risk assessments, safety requirements and measures

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1 Executive Summary

The Factory of the Future will witness the increase of high-level robotic manipulation skills applied in human-intensive labor manufacturing processes. Automotive and aerospace industries arise many complex assembly tasks involving cable and wire manipulation, tasks characterized by large deformability and unpredictable configurations. REMODEL's objective is to develop hardware and software tools, as well as innovative methodologies, to enable the manipulation of complex deformable objects in industrial production lines.

Under the deliverable D2.4 "Risk assessments, safety requirements and measures" that was submitted at the end of M9 of the project, the scenarios of the four use cases of REMODEL were analyzed in order to evaluate their potential risks and define the safety measures. The information compiled in this document will be the basis for the work of task T2.5 "Safety implementation, testing and evaluation".

2 Introduction

This document summarizes all activities carried out under task T2.4 "Risk assessments, safety requirements and measures" of WP2. In particular, the document analyses the risks of the proposed scenarios, as well as the safety measures to mitigate them. This analysis will include all the use cases of REMODEL project:

- Switchgear cabling use case – IEMA: This use case will deal with the cabling of a switchgear at IEMA factory. The scenario will be based on a dual-arm platform composed by two UR5 collaborative robots, which will be enhanced with an innovative user interface to support human operators.
- Wiring harness manufacturing use case – ELIMCO & ELVEZ: This second use case will investigate the wiring harness manufacturing at both ELIMCO and ELVEZ factories, who specialize in the aerospace sector and automotive sector, respectively.
    - The cable harness assembly for the ELIMCO use case entails a dual arm robot and human operators working side by side in a collaborative environment, combining operator actions with the dual arm robot in order to bring flexibility to the manufacturing process.
    - The wire harness assembly for the ELVEZ use case implemented in TAU for the early TRLs, will be performed using a dual arm industrial robot (the only non-collaborative implementation), and would be requiring special conditions and considerations for assessing safety requirements.
- Wiring harness assembly use case – VW: In this use case the robotic platform will be exploited to accelerate branches arrangement and the cockpit testing at VW training facility. This use case will evaluate the use of different robotic platforms as well as their placement in the continuous assembly line.
- Hose manipulation use case – ENKI: The fourth use case tackles the hose inspection process at ENKI. A single manipulator will be the basis of the scenario, which will put attention to safety requirements and features of the production line of ENKI.

Based on these four use cases and the designed preliminary setups, an initial risk analysis is included in the document as outcome of the work carried out in task T2.4. The risk analysis is focused on the next items:

- Robot operation, including teaching, maintenance or installation;
- Access of personnel to the robotic cell;
- Hazards associated to the specific robot applications;
- Misuse of the robot;
- Unexpected behaviours created by errors or deviations.

Besides, safety measures are proposed for the found risks in order to eliminate or adequately reduce them. These safety measures will reduce even by design, control or substitution, the risks identified during the installation and standard operation of the robotic systems. Next section provides information about the scope of a risk analysis as well as the risk rating.

2.1 Risk analysis scope and rating

A risk analysis comprises the assessment of what might cause harm to people and decide the actions to prevent that harm. After this initial risk identification, it is necessary to score and prioritise them, putting in place appropriate and sensible control measures. The risk analysis should cover all people who might be affected and consider all significant risks in mounting and operation situations. Once the analysis is performed and the appropriate control actions have been decided, only low-level risks will remain.

The risk analysis carried out in task T2.4 is covering the installation and operation of the PROTOTYPES in the RELEVANT ENVIRONMENTS of the use cases (TRL 4 to TRL 6). This document shall be supported and extended by any subcontractor safety documentation and client safety documentation for hazards arising on customer's plant from sources other than the PROTOTYPE.

Table 1 summarizes the risk rating of the assessment. The rating determines the risk level based on the likelihood of an event occurring and the severity of the injuries that may cause this event. The likelihood ranges from *most unlikely* to *most likely* while the severity vary between *slight* to *major injuries*.

Risk Assessment		Severity of Injuries			
		Slight (1) (Injuries that could be treated by the local First Aider form the First Aid Box)	**Minor (2)** (Injuries that may require more expert treatment, administered at a sick bay or out-patients)	**Serious (3)** (Chronic conditions or injuries involving urgent hospital treatment)	**Major (4)** (Injuries involving manor trauma or death)
Likelihood of Injuries	**Most Unlikely (1)** Probability close to zero	Low (1)	Low (2)	Medium-Low (3)	Medium-Low (4)
	Unlikely (2) (Injuries possible)	Low (2)	Medium-Low (4)	Medium-High (6)	Medium-High (8)
	Likely (3) (Injuries highly possible)	Medium-Low (3)	Medium-High (6)	Medium-High (9)	High (12)
	Most likely (4) (Injuries probable)	Medium-Low (4)	Medium-High (8)	High (12)	High (16)

Table 1 - Risk rating

Based on the rating obtained by each identified risk, actions might be required to reduce their level and maintain the risks at minimum. Table 2 contains the information to determine the action type for each risk rating.

Risk Rating	**Risk**	**Action Required**
1 - 2	Minimal	Controls Adequate
3 - 4	Low	Review controls, take actions as necessary
6 – 8	Medium	Action to be taken to reduce risk
9 - 16	High	Urgent action required. Consider halting activities / processes

Table 2 - Actions for the size of Risk Rating

Based on these premises, the risk analysis will include the possible hazards, person's likely to be affected, existing control measures and the actions that will be taken to mitigate these risks. This information will summarize the possible risks of all the scenarios, highlighting the most critical issues and the safety measures needed to mitigate them.

The rest of the document will include the risk analysis of the four use cases of REMODEL project. As many of the risks are common to all use cases, an initial section will include all these general risks. Additionally, the specific risks of each use case will be included in its own section, sections that will also incorporate a brief description of the setup to highlight their special features and characteristics.

3 General REMODEL risk analysis and safety measures

This section summarizes the common risks of all use cases of REMODEL project. Due to the similarities of the four scenarios, which in some cases even use the same robot and gripper type and perform similar operations, it has been decided to comprise them in this initial section and avoid duplicities. This general REMODEL setup, shared among various use cases, includes the next elements and features:

- Robotic system composed by two manipulators/arms;
- Use of electrical grippers enhanced with tactile sensors;
- Collaborative robots although equipped with standard non-collaborative grippers;
- Pneumatics included in the robotic cell;
- Use of additional devices as cameras or screwdrivers attached to the robot.

The risks are grouped based on their type, separating the risks related to the installation from the operational ones for an easier interpretation of the tables. Specifically, the next table illustrates the different risk types and the use cases where they are applicable:

	UC1	UC2.1	UC2.2	UC3	UC4
Installation and dismounting	X	X	X	X	X
Calibration	X	X	X		X
Teaching		X	X	X	
Regular operation	X	X	X	X	X
Maintenance	X	X	X	X	X

Table 3 - Risks applicable to each use case

The rest of the section provides further information about the risks associated to each phase.

3.1 Risk analysis

This first table includes the different risks detected for the **installation and dismounting phase**, besides the actions taken to mitigate them.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
End-effector fall during mounting/dismounting on robot	People mounting/dismounting the end-effector on the robot	Safety Shoes. End-effector weight limited to 5 kg.	2 x 1 = 2 Low	During normal change, the end-effector is placed on a tool storage place. During maintenance or malfunction, two operators perform the activities: one operating the tools and other holding the gripper.	1x1=1 Low

Cables (Trip hazard, also potential electrical hazard if damaged/cut)	People working in the robotic cell	All tools to be PAT tested in accordance	3 x 3 = 9 Medium-High	Ensure all cables routed and use of trunking.	3 x 2 = 6 Medium High
Air supply restoration: risk of hand/finger entrapment in end-effectors and additional pneumatic devices	People working in the robotic cell during installation tasks	Air supply to end-effectors and additional devices must be off during maintenance tasks inside the cell	2 x 2 = 4 Medium-Low	Safety connections to PLC and air supply valves are included.	1 x 2 = 2 Low
Air supply restoration: risk of injuries due to loose air pipe connections	People working in the robotic cell during installation tasks	Nobody should be inside the cell during air supply restoration	2 x 2 = 4 Medium-Low	Inform operators that air supply should never be restored while somebody is inside the cell.	1 x 2 = 2 Low

Table 4 - Risks during installation and dismounting of the robot

Next table summarizes the risks related with the **calibration** phase, where different elements such as tools, grippers and vision systems are calibrated and referenced.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collisions with the environment due to misuse of calibration devices	Operator and programmer	Emergency button in calibration area.	3 x 3 = 9 Medium-High	Additional operator/programmer in the initial calibration phase to manage the emergency button. Only trained personnel can perform calibration. Reduce maximum robot speed during calibration. Use vison-based calibration to avoid collisions.	2 x 2 = 4 Medium-Low
Entrapment of hand/fingers with gripper, tools or robot components during calibration	Operator and programmer	Protective gloves.	2 x 2 = 4 Medium-Low	Only trained personnel can perform calibration. The user must press two buttons in robot panel to ensure that hands are out of reach of the robots.	1 x 2 = 2 Low

				Reduce maximum robot speed during calibration.	

Table 5 - Risks during calibration

This table includes the different risks detected for the **teaching phase** which also includes the *teaching-by-demonstrator*, besides the actions taken to mitigate them.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Robot operator using the teach pendant near the robot can be harmed by it	Operators and programmers	Operator pulsing the dead-man button in the teach pendant.	2 x 2 = 4 Medium-Low	Ensure a trained professional manipulates the robot. Not allow more people in the robotic cell.	1 x 2 = 2 Low
Robot operator using gravity compensation mode for teaching-by-demonstration can be harmed by the robot	Operators and programmers	Emergency button in the workbenh.	2 x 3 = 6 Medium-High	Ensure a trained professional manipulates the robot. Not allow more people in the robot cell. Limit the workspace of the robot.	2 x 2 = 2 Medium-Low

Table 6 - Risks during teaching

This table includes the different risks during the **operation phase** where robots perform their tasks and execute the programs.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Human is harmed by the robot	Person visiting the installation	Close the cell, even during operations where the robot is not moving.	3 x 4 = 12 High	The system must be connected to the cell safety system. No one is allowed inside the cell except the trained operator when the robot is operative.	2 x 4 = 8 Medium-High

Human is harmed by the robot	Operator	Close the cell, even during operations where the robot is not moving. Formation of operators in safety procedures.	2 x 4 = 8 Medium-High	The system must be connected to the cell safety system. Safety procedure to enter the cell when robot is operative.	1 x 4 = 4 Medium-Low
Part falls during picking operations by robot – not related with fail in the grippers/air	Persons around robot workspace	Safety Shoes. Parts weight limited to 5kg.	2 x 1 = 2 Low	Risk is acceptable.	2 x 1 = 2 Low

Table 7 - Risks during operation

This final table includes the risks of the **maintenance** phase:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collisions while cleaning the cell	Maintenance personnel	Protective gloves and safety shoes. System in Stop state	1 x 3 = 3 Medium-Low	Only trained personnel allowed in maintenance tasks. Emergency stop pushed.	1 x 2 = 1 Low
Collisions while debugging programs	Programmer/ Maintenance	Protective gloves and safety shoes.	3 x 3 = 9 Medium-High	Only trained personnel allowed. Reduced speed for debuging. Safety space between robots and operators/programmers marked in the cell.	2 x 2 = 4 Medium-Low

Table 8 - Risks during maintenance

4 UC1 – Switchgear wiring

This section includes the risk analysis for the switchgear wiring use case. As a general safety approach, the robot will be isolated from human operators by protective devices (such as protective fences and a laser scanner) since no direct human-robot collaboration is required. Moreover, the teaching phase will be significantly reduced by the exploitation of product CAD data coming from WP3 and the perception systems developed in WP4.

4.1 Scenario and setup description

This use case is based on the needs of IEMA for the manufacturing of switchgears, and in particular to perform the wiring operation. For more information about the use case definition, check deliverable D2.1 "Application requirements".

This subsection contains two main blocks. Initially a brief summary of the cell design is presented in order to have general view of the elements of the setup. Next, the core of the risk analysis of this scenario is presented, dividing the risk analysis in the different phases of the work.

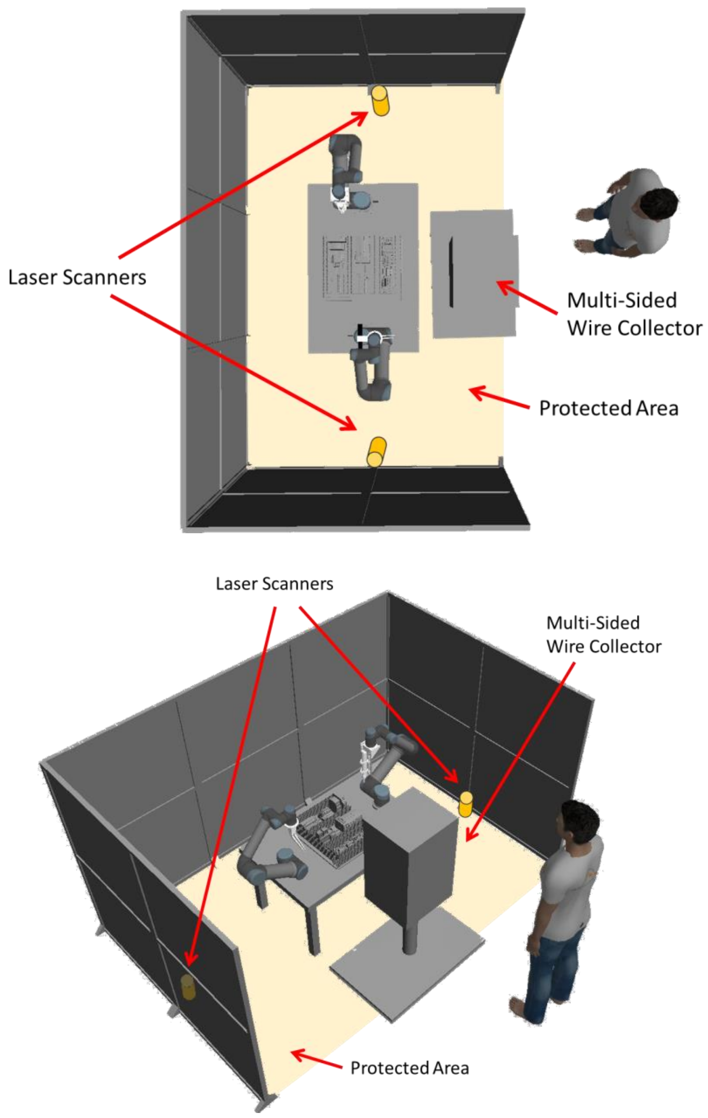

Figure 1 - Setup of IEMA's use case

The main elements of the setup are listed below:

- Two collaborative robots UR5 from Universal Robots;
- Properly designed tools for the execution of the wiring tasks;
- The table for switchgear fixing and cable allocation;
- A multi-sided wire collector to allows the robot to work while the user replace the cable on the opposite side of the collector;
- A couple of laser scanners to monitor the robot area.

Regarding the regular operation of the cell, next lines provide the main information:

- Operators, programmers and general personnel will not enter the cell during the robot operations;
- Access is possibile only from the front part of the workbench and it will be protected by a couple of laser scanners measuring the distance from the cell and slowing down the robot if somebody is close to the cell or completely stopping the robots if people are too close;
- The back and lateral parts of the cell are closed by protective fences, they should only be accessed for installation and maintenance purposes;
- The cell materials loading and unloading will be performed with the robots stopped;
- The use of laser scanner safety devices is proposed, in addition to safety signalling and procedures, to implement the safety policies.

Next section describes the risk analysis of IEMA's use case, which extends the general risk analysis presented in section 3.

4.2 Risk analysis

This initial table includes the risks related with the **installation of the robotic cell** for IEMA use case.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collisions with gripper and tool in power supply restoration or during the robot testing	Personnel assembling the cell	Protective gloves and safety shoes	2 x 2 = 4 Medium-Low	Add safety glasses to operators. Operators leave the surroundings of the robot during power supply restoration or robot testing	1 x 2 = 2 Low

Table 9 - UC1: Risks during installation.

The risks associated to the **operation phase** are listed below:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Person enters in the cell during operation	Operator	Protective gloves and safety shoes. Emergency stop in workbench. Laser scanner to measure people distance	2 x 4 = 8 Medium-High	Safety devices detecting persons entering the cell and stopping the manipulator. Signs and safety procedure around the cell. Only trained personnel allowed to enter during operation.	1 x 4 = 4 Medium-Low

Table 10 - UC1: Risks during operation.

Finally this table includes the risks in regular **maintenance**:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collisions with gripper and tool in power supply restoration or during the robot testing	Programmer/ Maintenance	Protective gloves and safety shoes	2 x 2 = 4 Medium-Low	Add safety glasses to operators. Operators leave the surroundings of the robot during power supply restoration.	1 x 2 = 2 Low

Table 11 - UC1: Risks during maintenance.

5 UC2 – Wiring harnesses manufacturing

This section includes the risk analysis of the wire harness manufacturing use case. As this use case includes two different scenarios based on different robotic platforms and setups, the section is divided in two parts in order to tackle the specific safety needs of both scenarios.

5.1 Wiring harnesses manufacturing for aerospace industry

This first use case is based on the needs of Elimco company for the manufacturing of wire harnesses. Elimco produces wire harnesses for aeronautic sector, mainly aircrafts and helicopters. For more information about the use case definition, check deliverable D2.1 “Application requirements”.

This subsection contains two main blocks. Initially a brief summary of the cell design is presented in order to have general view of the elements of the setup. Next, the core of the risk analysis of this scenario is presented, dividing the risk analysis in the different phases of the work.

5.1.1 Scenario and setup description

As stated previously, Elimco produces wire harnesses for aeronautic sector, aircrafts and helicopters, with wire harnesses with sizes ranging from 1m to long references with more than 10m. Due to the wide variety of sizes, the robotic cell designed in task T6.1 is focused on references of sizes between 1m and 3m. Additionally, one of the main features of the cell is the reconfigurability, as the workbench is designed to be used for the manufacturing of different references with minor modifications on it.

Next figure shows the setup for Elimco’s use case:

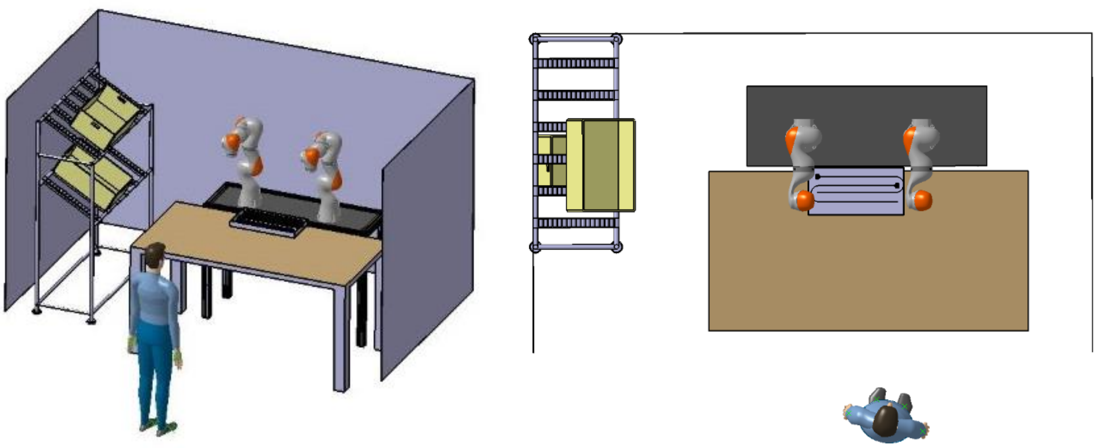

Figure 2 - Setup of ELIMCO’s use case

The main elements of the setup are listed below:

- Two Kuka LBR iiwa robots, with capabilities to measure and control force thanks to the torque sensors placed on each joint;
- Two Schunk WSG 50 electrical grippers, coupled to Schunk tool exchangers to allow a fast tool change;
- A front workbench used to assemble the wire harnesses;

- The cell includes also pneumatic devices, as the electrovalves used to manage the Schunk tool exchanger for example.

Regarding the regular operation of the cell, next lines provide the main information:

- Operators, programmers and general personnel will only enter cell from the front part of the workbench;
- The back part of the cell should only be accessed for installation and maintenance purposes;
- Due to the collaborative nature of the application, the installation of physical fences all around is discarded. The use of laser-based safety devices is proposed, in addition to safety signalling and procedures, to implement the safety policies.

Next section describes the risk analysis of Elimco's use case, which extends the general risk analysis presented in section 3.

5.1.2 Risk analysis

This initial table includes the risks related with the **installation of the robotic cell** for Elimco use case.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Gripper fall during placement/removal using the Schunk tool exchanger	Personnel assembling the cell	Protective gloves and safety shoes	3 x 2 = 6 Medium-High	An additional operator to support the tool exchange operation. Procedure with one operator holding gripper and additional operator activating electro-valves.	1 x 2 = 2 Low
Collisions with gripper's fingers in power supply restoration due to the automatic homing process of Schunk WSG 50 grippers.	Personnel assembling the cell	Protective gloves and safety shoes	2 x 2 = 4 Medium-Low	Add safety glasses to operators. Operators leave the surroundings of the robot during power supply restoration.	1 x 2 = 2 Low

Table 12 - UC2.1: Risks during installation

Next table summarizes the risks related with the **teaching** phase.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collisions with the environment due to misuse of teleoperation devices.	Operator and pogrammer	Emergency button in teaching area.	3 x 3 = 9 Medium-High	Additional operator/programmer in the initial training phase to manage the emergency button. Only trained personnel can perform teaching.	2 x 2 = 4 Medium-Low
Entrapment of hand/fingers with gripper in teaching using direct interaction through gravity compensation.	Operator and pogrammer	Protective gloves.	3 x 2 = 6 Medium-High	Only trained personnel can perform teaching. Add handle in gripper to ensure that hands are out of reach of the fingers.	1 x 2 = 2 Low

Table 13 - UC2.1: Risks during teaching

The risks associated to the **regular operation** are listed below:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collision while operator provides raw materials required for assembly	Operator	Protective gloves and safety shoes . System status is Paused.	2 x 3 = 6 Medium-High	Emergency stop in workbench. Only trained personnel can enter the cell. Add signals with safety procedures.	1 x 3 = 3 Medium-Low
Collision between operator and robot during the manual assembly of the wire harness.	Operator	Protective gloves and safety shoes . System status is stoped.	2 x 3 = 6 Medium-High	Emergency button pushed during the manual assembly process. Only trained personnel can enter the cell. Add signals with safety procedures.	1 x 3 = 3 Medium-Low

Person enters in the cell during operation	Operator	Protective gloves and safety shoes. Emergency stop in workbench.	2 x 4 = 8 Medium-High	Safety devices detecting persons entering the cell and stopping the manipulator. Signs and safety procedure around the cell. Only trained personnel allowed to enter during operation.	1 x 4 = 4 Medium-Low

Table 14 - UC2.1: Risks during operation

Finally this table includes the risks in regular **maintenance**:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Gripper fall during placement/removal using the Schunk tool exchanger	Personnel assembling the cell	Protective gloves and safety shoes	3 x 2 = 6 Medium-High	An additional operator to support the tool exchange operation. Procedure with one operator holding gripper and additional operator activating electro-valves.	1 x 2 = 2 Low
Collisions with gripper's fingers in power supply restoration due to the automatic homing process of Schunk WSG 50 grippers.	Personnel assembling the cell	Protective gloves and safety shoes	2 x 2 = 4 Medium-Low	Add safety glasses to operators. Operators leave the surroundings of the robot during power supply restoration.	1 x 2 = 2 Low

Table 15 - UC2.1: Risks during maintenance

5.2 Wiring harnesses manufacturing for automotive industry

The implementation of a robot-based system is estimated by ELVEZ to reduce the cycle time for producing an individual assembly by 4 seconds. The time study of the current manual production process has set the average estimate to be 44s. The initially proposed robot-based system designed and implemented in FAST will be a dual arm industrial robot where the operation would be orchestrated by a ROS based planner which determines the specific task to be performed while being actively aware of changes taking place in and around the production cell. The information input to the planner are CAD data of the system and the DLOs, the real time information from safety devices, vision system, tactile sensing system and the devices for teaching by demonstration. The standards which determine the system safety would be different for the implementation of the ELVEZ use case in TAU, as it is the only partner working with an industrial robot.

5.2.1 Scenario and setup description

The physical setup is initially developed to be non-colloborative (the role of the operator is to manage production and to keep the raw materials stocked) and this involves special safety guidelines. The cell structure is fenced, and it visibly and intelligently prohibits unauthorized humans from entering it (visual signs, raising alarms and suspending production process). The implementaition of the ELVEZ use case in TAU will be merged with an existing intelligent production cell, therefore requiring special modifications to be made to existing cell design to accommodate the ELVEZ layout for ease of use.

The dual arm industrial robot used is the Yaskawa SDA10F which has a 10kg payload for each arm. The entrances to the cell will be protected and monitored along with the insides of the cell. The devices used for safety will be connected to a high priority safety PLC and provisions can be made for redundancy to predict the occurance of an accident or alarm.

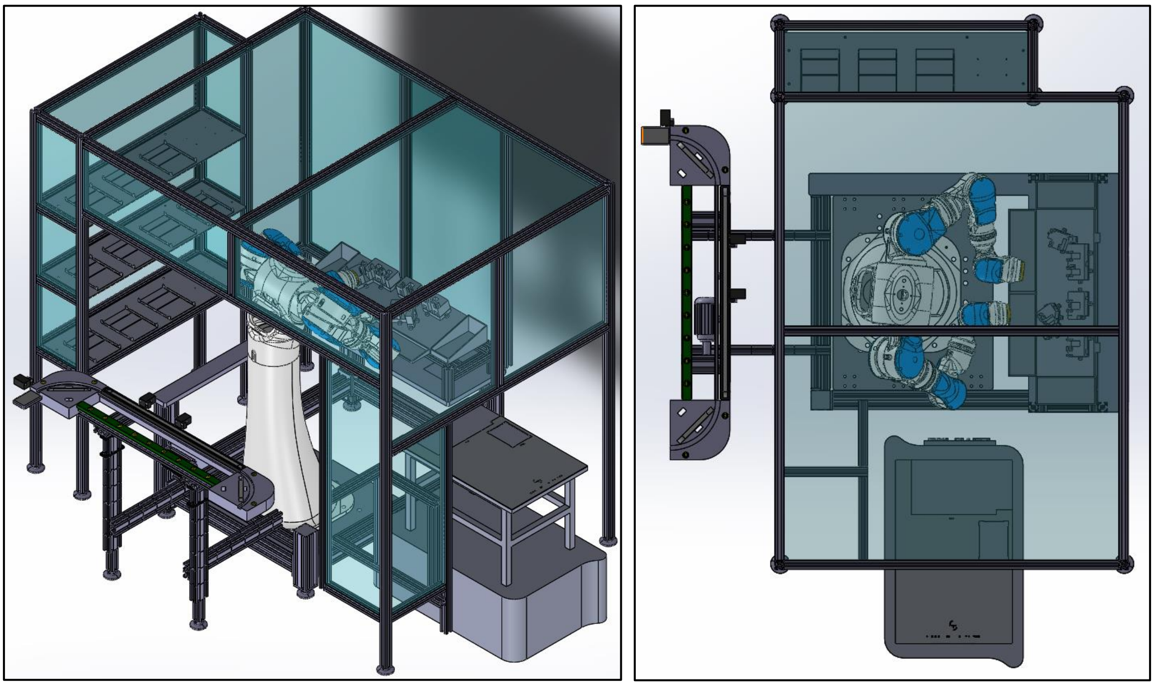

Figure 3 - Setup of ELVEZ use case

5.2.2 Risk analysis

This first table includes the different risks detected for the **installation and dismounting phase**, besides the actions taken to mitigate them.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Injury during modular profile assembly	Personnel Assembling the cell	Protective gloves and safety shoes	2 x 2 = 4	An additional personnel to help hold profiles in position while they are being fastened together.	2 x 1 = 2

				Overhead cranes can be used to hold the heavier beams in place with helmets.	
Manipulator falling during shifting	Personnel moving the elements	Protective gloves and safety shoes	2 x 3 = 6	Using authorized personnel to operate crane and check license. Wear helmets. Check quality of the harness tape	1 x 3 = 3
Moving heavy objects with an overhead crane	Personnel moving the elements	Protective gloves and safety shoes	2 x 3 = 6	Using authorized personnel to operate crane and check license. Wear helmets. Check quality of the harness tape	1 x 3 = 3
Exposed Robot cell	Visitors and occupants of the lab	-	3 x 3 = 9	Include warning signs and safety barriers.	1 x 3 = 3

Table 16 - UC2.2: Risks during installation and dismounting

This table includes the different risks detected for the **teaching phase** which also includes the *teaching-by-demonstrator*, besides the actions taken to mitigate them.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
System safety compromised during teaching and comissioning phase.	Programmer/ Engineer	Insulation gloves and safety shoes.	2 x 3 = 6	Protective helmet. Safety manuals and simple instructions relating to safety.	2 x 2 = 4
Maintenance (Calibrate safety gun, vision system, tactile sensor, etc.)	Programmer/ Engineer	Insulation gloves and safety shoes.	2 x 3 = 6	Protective helmet. Seminars/ Meetings to update and remind operators of safety techniques and guidelines	1 x 2 = 2

Testing safety devices	Programmer/ Engineer	Insulation gloves and safety shoes.	3 x 2 = 6	Protective helmet. Seminars/ Meetings to update and remind operators of safety techniques and guidelines	1 x 2 = 2

Table 17 - UC2.2: Risks during teaching

This table includes the different risks during the **operation phase** where robots perform their tasks and execute the programs.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Replacing raw materials required for assembly	Operator	Protective gloves and safety shoes. System status is Paused.	3 x 1 = 3	Emergency stop inside the cell. Ensure redundancy with the safety devices. Wear protective helmet	2 x 1 = 2
Person enters in the cell during operation	Operator	Protective gloves and safety shoes.	2 x 4 = 8	Having devices detecting person entering and stopping the manipulator. Install a door connected to system safety. Wear protective helmet.	2 x 1 = 2
Person enters in the cell thourgh the MiR door	Anyone with lab access	-	1 x 4 = 4	Install a Light screen for MiR. Warning signs around the cell. Wear protective helmet	1 x 2 = 2
Robot arms collide with elements of the cell	Operator/ bystander	Protective gloves and safety shoes.	1 x 3 = 3	Fortify the physical structure.	1 x 1 = 1
Person in the cell while operation starts	Operator	Protective gloves and safety shoes.	3 x 4 = 12	Global vision system monitors system occupants before operation starts.	1 x 3 = 3

				Physical Start button is installed outside the cell along with start from UI. Emergency stop installed inside the cell.	

Table 18 - UC2.2: Risks during operation

This table includes the different risks during the **maintenance phase** where the robot system activities are suspended for the human to enter the cell and perform maintenance of equipment

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Replacing raw materials required for assembly	Maintenance/ operator	Protective gloves and safety shoes.	3 x 1 = 3	Emergency stop inside the cell. Ensure redundancy with the safety devices. Wear protective helmet	2 x 1 = 2
Testing system safety	Programmer/ Maintenance	Insulation gloves and safety shoes.	2 x 3 = 6	Protective helmet. Seminars/ Meetings to update and remind operators of safety techniques and guidelines	1 x 2 = 2
Changing the end effectors (fingers, etc)	Maintenance/ Operator	Insulation gloves and safety shoes.	2 x 1 = 2	During normal change, the end-effector is placed on a tool storage place. During maintenance or malfunction, two operators perform the activities: one operating the tools and other holding the gripper.	1 x 1 =1

Removing faulty taping by the gun	Operator/ Maintenance	Insulation gloves and safety shoes.	2 x 4 = 8	Having devices detecting person entering and stopping the manipulator. Install a door connected to system safety. Wear protective helmet.	2 x 1 = 2
Debugging physical Alarms generated	Programmer/ Maintenance	Insulation gloves and safety shoes.	3 x 3 = 9	Protective helmet. Seminars/ Meetings to update and remind operators of safety techniques and best practises guidelines. Emergency stop inside the cell. Restricting access to specialised personnel.	1 x 2 = 2

Table 19 - UC2.2: Risks during maintenance

6 UC3 – Wiring harnesses assembly

This section includes the risk analysis of the wiring harness assembly use case. This use case includes a scenario based on robotic platforms and setups concerning to the TRL4 phase, so it tests the station in laboratory conditions.

6.1 Scenario and setup description

Wiring harness assembly (UC3) in car cockpits is a challenging manipulation activity completely executed by hand along the production chain. At the beginning of the VW cockpit assembly line, the wiring harness is contained in a box in an unknown configuration. A passive device is used to lift up the wiring harness to support its weight (up to 20kg). The wiring harness is then arranged by the worker on a metal plate which will be the base of all the components. The manipulation task associated to the wiring harness arrangement is particularly complex since up to 20 branches are present, and some of them must be passed through narrow holes into the metal plate, by grabbing and pulling them from the opposite side.

At the end of the of the cockpit assembly process, the cockpit electric functional test is performed by connecting suitable wiring harness branches to the connectors of the ECOS. Then, the test is performed automatically, and at the end of the process the ECOS connectors are unplugged. The plug and unplug task requires two hands since no support is available for both the ECOS and the cockpit-side connectors. After this station, the wiring harness branches for the connection of the cockpit to other car components are arranged into the transportation rack that allows to prepare the cockpit for the transportation to another plant where it will be assembled into the car body. In this task, the branches hanging from the cockpit at the end of the assembly line are collected into suitable containers, to avoid any damage during transportation or successive assembly phases.

The robotic setup for TRL4 consists of two Universal Robots UR3 arms equipped with Robot RG-2 grippers. The robotic cell is equipped with RGB-D cameras both in the robot wrists and the ones for monitoring the whole assembly process and detecting people coming close to the cell to predict their presence close to the robots and act accordingly. Additionally, the cell is equipped with certified safety sensors connected to safety lines in the robots‘ control unit. The current view of the robotic setup consisting of two robots, the pallet for holding the cockpit plate and the wiring harness to be mounted in the cockpit, is shown in Figures 4 and 5.

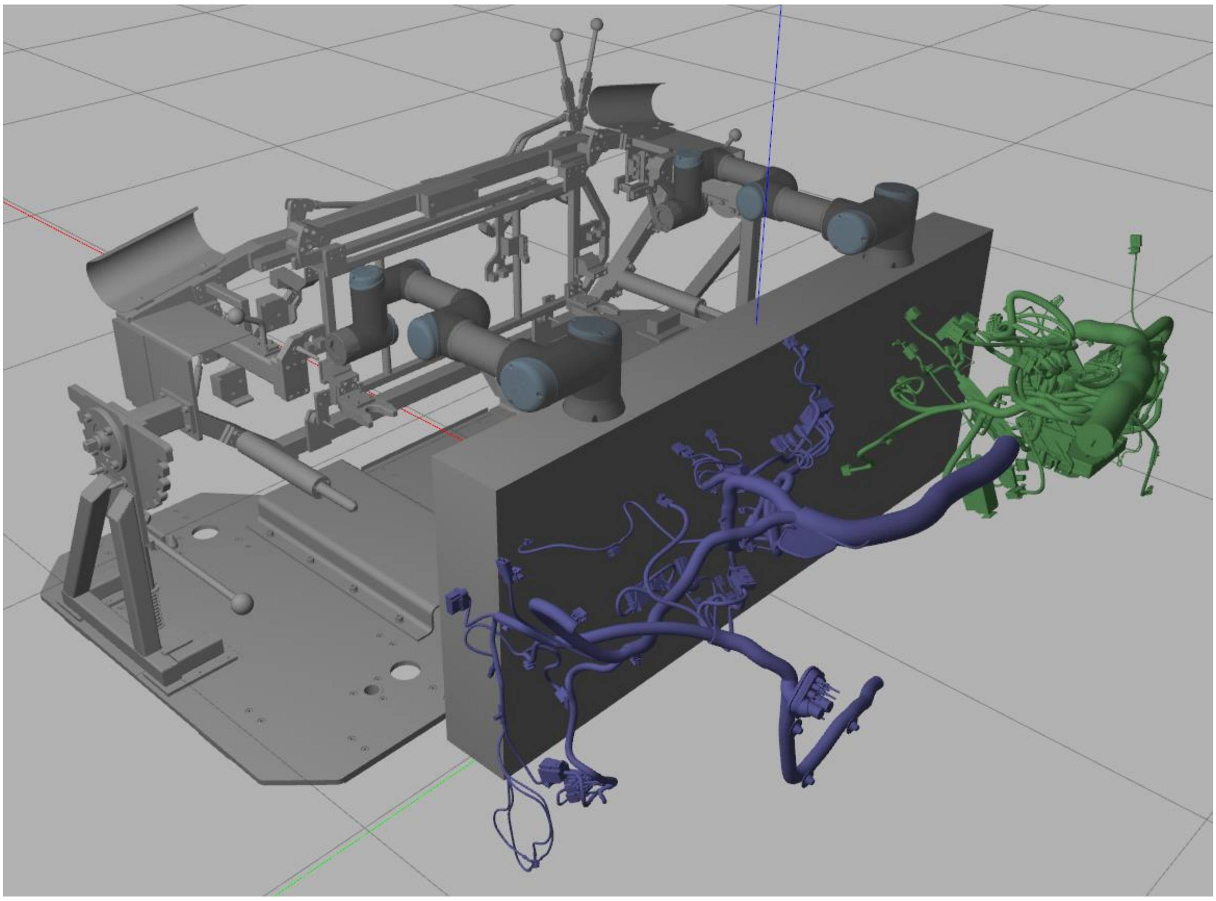

Figure 4 - Simulation setup of VW's use case

Figure 5 - Setup of VW's use case

6.2 Risk analysis

This initial table includes the risks related with the **installation of the robotic cell** for Volkswagen use case.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Pallet is falling on the ground	Person visiting the installation	Pallet attached to the line with single set of screws	2x 4 = 8 Medium -High1 x 3 = 3	The pallet must be safely attached to the production line using double mounting	1 x 4 = 4 Medium-Low
Pallet is falling on the ground	Operator	Pallet attached to the line with single set of screws	3x 4 = 12 High	The pallet must be safely attached to the production line using double mounting	1 x 4 = 4 Medium-Low
Cockpit plate can cut the fingers while performing assembly	Worker directly responsible for the assembly process	Safety gloves	3 x 3 = 9 Medium-high	Provide the robot with the force sensor in the wrist	3 x 1 = 3 Medium-Low

Table 20 - UC3: Risks during installation

Next table summarizes the risks related with the **teaching** phase.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Pallet is falling on the ground	Operator / Other visiting persons	Pallet attached to the line with single set of screws	3x 4 = 12 High	The pallet must be safely attached to the production line using double mounting	1 x 4 = 4 Medium-Low
Robot is hitting a person	Person who is not directly involved in the assembly tasks logistics, parts supply.	Markings on the floor indicating the workspace	2 x 3 = 6 Medium-high	Provide the safety zone, people are not beneath the robot while moving the wiring harness	1 x 3 =3 Medium-Low
Robot is hitting a person	Worker directly responsible for the assembly process	Markings on the floor indicating the workspace	3 x 3 = 9 Medium-high	Provide the safety zone, people are not beneath the robot while moving the wiring harness	1 x 3 = 3 Medium-Low
Slipping on a wiring harness lying on the floor	Assembly worker or logistics person	Safety shoes with high friction	3 x 3 = 9 Medium-high	Camera for global scene tracking and indicating hazardous objects	1 x 3 =3 Medium-Low

Stumble over a wiring harness lying on the floor	Assembly worker or logistics person	Safety shoes with high friction	3 x 3 =9 Medium-high	Camera for global scene tracking and indicating hazardous objects	1 x 3 = 3 Medium-Low
Risk of hand beeing trapped (teaching phase)	Robot programmer	Safety gloves	3 x 3 =9 Medium-high	Provide the robot with the force sensor ath the wrist	3 x 1 = 3 Medium-Low
Unforseen movement of the robots	Robot Programmer	Robot safety buttons	4 x 3 = 12 High	Single safety button for whole station	1 x 3 = 3 Medium-Low

Table 21 - UC3: Risks during teaching

The risks associated to the **regular operation** are listed below:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Wiring harness falls during picking operations by robot – not related with fail in the air	Persons around robot workspace	Safety Shoes. Parts weight limited to 20kg.	3 x 2 = 6 Medium-high	Provide the safety zone , people are not beneath the robot while moving the wiring harness	2x2=4 Medium-Low
Robot is hitting a person	Person who is not directly involved in the assembly tasks logistics, parts supply.	Markings on the floor indicating the workspace	2 x 3 = 6 Medium-high	Provide the safety zone , people are not beneath the robot while moving the wiring harness	1 x 3 =3 Medium-Low
Robot is hitting a person	Worker directly responsible for the assembly process	Markings on the floor indicating the workspace	3 x 3 = 9 Medium-high	Provide the safety zone , people are not beneath the robot while moving the wiring harness	1 x 3 = 3 Medium-Low
Slipping on a wiring harness lying on the floor	Assembly worker or logistics person	Safety shoes with high friction	3 x 3 = 9 Medium-high	Camera for global scene tracking and indicating hazardous objects	1 x 3 =3 Medium-Low
Stumble over a wiring harness lying on the floor	Assembly worker or logistics person	Safety shoes with high friction	3 x 3 =9 Medium-high	Camera for global scene tracking and indicating hazardous objects	1 x 3 = 3 Medium-Low

When the robot is performing an action, the wiring harness hits the arm	Robot programmer	Safety clothes	3 x 2 = 6 Medium-high	Camera for global scene tracking and indicating hazardous objects	1 x 2 = 2 Low
When the robot is performing an action, the wiring harness hits the head	Robot programmer	Safety helmet	3 x 4 = 12 High	Camera for global scene tracking and indicating hazardous objects	1 x 4 = 4 Medium-Low
Loss of pressure while robot is performing the action – pneumatic gripper	Assembly worker	Gripper opens	3 x 3 = 9 Medium-high	Safety power supply to recover from situation	1 x 3 = 3 Medium-Low
Loss of power supply when the robot is performing the action – electric gripper	Assembly worker	Gripper blocks	3 x 3 = 9 Medium-high	Safety power supply to recover from situation	1 x 3 = 3 Medium-Low
Unforseen movement of the robots	Assembly worker	Robot safety buttons	2 x 3 =6 Medium-high	Single safety button for whole station	1 x 3 = 3 Medium-Low
Unforseen movement of the robots	Robot Programmer	Robot safety buttons	4 x 3 = 12 High	Single safety button for whole station	1 x 3 = 3 Medium-Low

Table 22 - UC3: Risks during regular operation

Finally this table includes the risks in **maintenance during operation**:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Loss of pressure while robot is performing the action – pneumatic gripper	Assembly worker	Gripper opens	3 x 3 = 9 Medium-high	Safety power supply to recover from situation	1 x 3 = 3 Medium-Low
Loss of power supply when the robot is performing the action – electric gripper	Assembly worker	Gripper blocks	3 x 3 = 9 Medium-high	Safety power supply to recover from situation	1 x 3 = 3 Medium-Low
Unforseen movement of the robots	Assembly worker	Robot safety buttons	2 x 3 =6 Medium-high	Single safety button for whole station	1 x 3 = 3 Medium-Low
Unforseen movement of the robots	Robot Programmer	Robot safety buttons	4 x 3 = 12 High	Single safety button for whole station	1 x 3 = 3 Medium-Low

Table 23 - UC3: Risks during maintenance

7 UC4 – Hose manipulation

This section includes the risk analysis for the hose manipulation use case. As a general safety approach, the robot will be isolated form human operators by protective devices (such as protective fences, tables isolating the robot workspace or light barriers) since no direct human-robot collaboration is required.

7.1 Scenario and setup description

This use case is based on the needs of ENKI for the quality checks of extruded hoses. For more information about the use case definition, check deliverable D2.1 "Application requirements".

This subsection contains two main blocks. Initially a brief summary of the cell design is presented in order to have general view of the elements of the setup. Next, the core of the risk analysis of this scenario is presented, dividing the risk analysis in the different phases of the work.

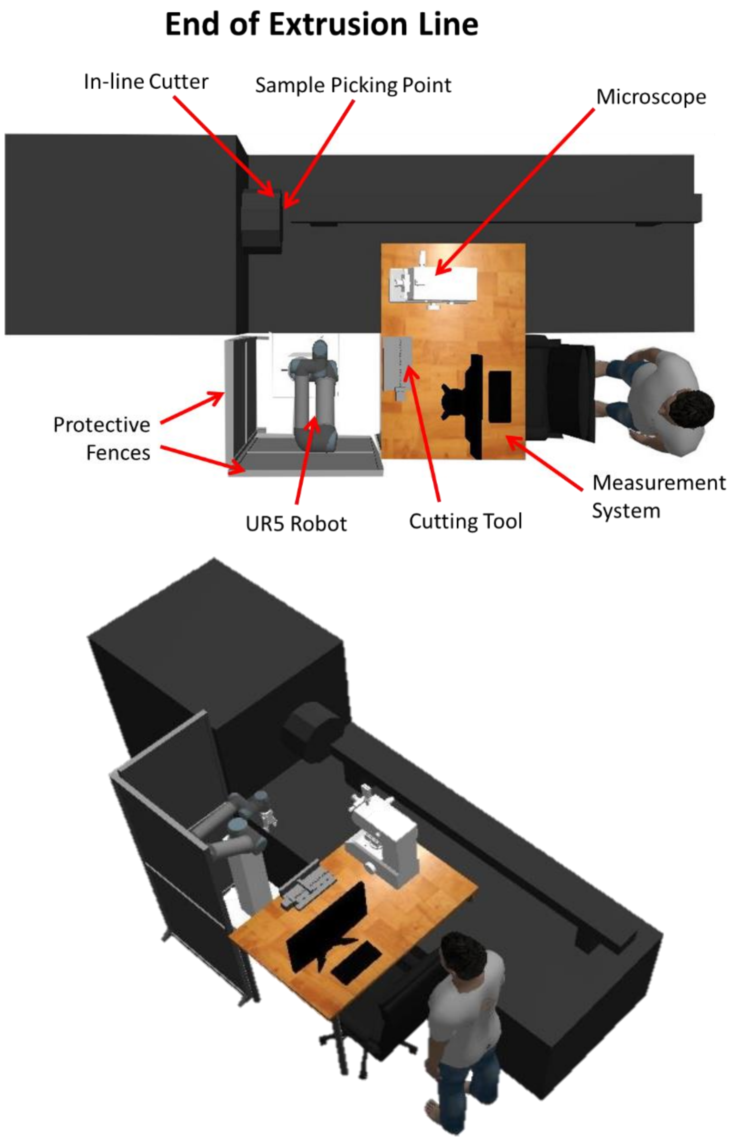

Figure 6 - Setup of ENKI use case

The main elements of the setup are listed below:

- One collaborative robots UR5 from Universal Robots;
- A collaborative electric gripper with designed fingers for the execution of the hose manipulation tasks;
- The table for hosting the cutting device and the microscope for visual inspection.

Regarding the regular operation of the cell, next lines provide the main information:

- Operators, programmers and general personnel will not enter the cell during the robot operations;
- Access is possibile only from the back part of the workbench and it will be protected by a door on the protective fence, a switch on the door will inform the safety system to stop the robot if the door is open;
- A table on one side of the workcell will isolate the user from the robot to avoid entering in the robot workscape;
- The back and lateral parts of the cell are closed by protective fences, they should only be accessed for installation and maintenance purposes.

Next section describes the risk analysis of ENKI's use case, which extends the general risk analysis presented in section 3.

7.2 Risk analysis

This initial table includes the risks related with the **installation of the robotic cell** for ENKI use case.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collisions with gripper and tool in power supply restoration or during the robot testing	Personnel assembling the cell	Protective gloves and safety shoes	2 x 2 = 4 Medium-Low	Add safety glasses to operators. Operators leave the surroundings of the robot during power supply restoration or robot testing	1 x 2 = 2 Low

Table 24 – UC4: Risks during installation.

Next table summarizes the risks related with the **teaching** phase.

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Collisions with the environment due to misuse of teaching devices.	Operator and programmer	Emergency button in teaching area.	3 x 3 = 9 Medium-High	Additional operator/programmer in the initial training phase to manage the emergency button.	2 x 2 = 4 Medium-Low

				Only trained personnel can perform teaching. Reduce maximum robot speed during teaching.	
Entrapment of hand/fingers with gripper, tools or robot components during teaching.	Operator and programmer	Protective gloves.	2 x 2 = 4 Medium-Low	Only trained personnel can perform teaching. The user must press two buttons in robot panel to ensure that hands are out of reach of the robots. Reduce maximum robot speed during teaching.	1 x 2 = 2 Low

Table 25 – UC4: Risks during calibration.

The risks associated to the **operation phase** are listed below:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Person enters in the cell during operation	Operator	Protective gloves and safety shoes. Emergency stop in workbench. Security switch on the workcell door.	2 x 4 = 8 Medium-High	Safety devices detecting persons entering the cell and stopping the manipulator. Signs and safety procedure around the cell. Only trained personnel allowed to enter during operation.	1 x 4 = 4 Medium-Low

Table 26 – UC4: Risks during operation.

Finally this table includes the risks in regular **maintenance**:

Hazard	Person's likely to be affected	Existing Control Measures	Risk rating (see Table 1)	Actions taken to mitigate risk	Residual risk rating
Cleaning the cell	Maintenance personnel	Protective gloves and safety shoes. System in Stop state	1 x 3 = 3 Medium-Low	Only trained personnel allowed in maintenance tasks. Emergency stop pushed. Workcell door opened.	1 x 2 = 1 Low

Collisions with gripper and tool in power supply restoration or during the robot testing	Programmer/ Maintenance	Protective gloves and safety shoes	2 x 2 = 4 Medium-Low	Add safety glasses to operators. Operators leave the surroundings of the robot during power supply restoration.	1 x 2 = 2 Low

Table 27 – UC4: Risks during maintenance.

8 Conclusions

This document summarizes the work carried out in task T2.4 “Risk assessment and safety requirements” of WP2. It includes the risk analysis of the four use cases tackled in REMODEL project, risk analysis that identifies the different sources of hazard of the proposed scenarios as well as the actions to mitigate them.

The risk analysis has been divided in different stages, starting from the installation of the robotic cell to the operation mode, including the teaching and maintenance phases. The study of all these stages for the four use cases has highlighted the diverse sources of hazard, paying special attention to the specific needs of each scenario.

The obtained results will be the basis of task T2.5 ”Safety implementation, testing and evaluation”, task devoted to the development of a safety controller suitable for the specific needs of REMODEL use cases.

As the design of some of the use cases is preliminary and can evolve along the project, this document should be considered a tentative risk analysis subject to changes and modifications. The updates of the risk analysis will be included in deliverable D2.6, which is planned by the final period of the project.