Smart and adaptive interfaces for INCLUSIVE work environment

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Deliverable 1.1 – Summary of all the requirements of the project

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Executive Summary

This deliverable provides a complete analysis of the industrial use cases considered in the INCLUSIVE project. In particular, three industrial use cases are presented, that are representative of a wide variety of relevant industrial situations in Europe.

Referring to specific representative scenarios, we describe the technological solutions currently adopted for the interaction with the operators, and we highlight the main issues and difficulties related to such systems.

From the analysis of the use cases, we derive then the main user needs, related to adaptive HMI systems for automatic machines and robotic cells, in particular referring to specific target groups of operators, namely elderly, disabled and inexperienced.

System requirements are then derived, that abstract the user needs, and define what issues the INCLUSIVE system will tackle.
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1 Introduction

The objective of the INCLUSIVE project is to develop a smart interaction system that adapts the information load of the human-machine interface (HMI) and the automation capability of the machine to the physical, sensorial and cognitive capabilities of workers.

Three main pillars constitute the INCLUSIVE system:

1. Human capabilities measurement (Measure): the INCLUSIVE system will measure the human capability of understanding the logical organization of information and the cognitive burden she/he can sustain (automatic human profiling). The system will also identify the actual skill level of the user, analyzing on-line how she/he operates in the common working processes.
2. Adaptation of interfaces to human capabilities (Adapt): the INCLUSIVE system will adapt the organization of the information (e.g. the complexity of the information presented), the means of interaction (e.g. textual information, only graphics, speech, etc.), and the automation task (normal operation, adaptation to new processes, predictive maintenance, etc.) that are accessible by the user depending on her/his measured capabilities.
3. Teaching and training for unskilled users (Teach): the INCLUSIVE system will be able to teach the correct way to interact with the machine to the unskilled users. Depending on the skill level of the user and the operation performed by the machine, the interface will train the user by using a step by step procedure, also supported by simulation on a virtual environment.

The INCLUSIVE project aims at providing technological solutions for compensating workers’ limitations (e.g. due to age or inexperience), while taking full advantage of their knowledge. Three main groups of operators are considered: elderly, disabled, and inexperienced operators.

In this deliverable, we derive the requirements that the INCLUSIVE system will have to fulfill. These requirements are defined based on the analysis of real industrial use cases. In particular, we consider three different examples that are representative of a wide area of interest for industry in Europe:

1. Machines for small companies, possibly run by elderly owners (Use case 1, woodworking machine produced by SCM)
2. Automation solutions made by a European company in developing countries (Use case 2, robotic cell for industrial process integrated by GIZELIS and deployed in SILVERLINE)
3. Industrial plants made by a big company (Use case 3, labeling machine provided by KHS)

This deliverable contains a detailed description of each use case, with explicit reference to the state of the art solutions in terms of HMI. The main issues related to current solutions are highlighted, referring explicitly to representative target scenarios. Target users for each use case are also defined.

From the analysis of the use cases, a set of user needs is defined. Specifically, user needs describe what issues and difficulties the industrial partners highlight with the currently available technological solutions.

User needs are then abstracted, to define the system requirements, which describe what problems will be solved by the INCLUSIVE project.

Subsequently, starting from the requirements described in this deliverable, the specification (at system level, and at module level) will be derived, and collected in Deliverable D1.3. Specifications will describe how the INCLUSIVE project will solve those problems.

This process is summarized in Figure 1.
This deliverable is organized as follows. In Section 2 we first present a unified view of the industrial use cases considered in the INCLUSIVE project and then address each use case in details, discussing the main critical issues related to human-machine interaction. In Section 3 the user needs are derived, which result in the system requirements presented in Section 4. Further, in Section 5 we discuss how the Inclusive pillars, namely measure, adapt and teach, are meant to address the system requirements. Section 6 presents a unified analysis of the target users involved in the three use cases. Finally, Section 7 reports some concluding remarks.
2 Industrial context

Modern automatic machines and robotic cells in production plants are becoming more and more complex because of higher demands for fast production rate with high quality. Over these basic functions, today’s factories need to allow for higher levels of product customization and variable requirements. To this end, advanced functions are implemented, such as fault diagnosis and fast recovery, fine-tuning of process parameters to optimize environmental resources, fast reconfiguration of the machine and robot parameters to adapt to production change, etc. Despite high levels of automation of machines and robots, humans remain central to manufacturing operations, since they take charge of control and supervision of manufacturing activities. Human operators interact with machines and robots by means of user interfaces that are the modern cockpit of any production plant. For example, they set up machine production parameters, identify and solve faults, coordinate machine and robot re-configuration to enable adaptation to product changes. These activities are all performed by means of computerized HMI that are inevitably becoming more and more complex, as new functions are implemented by the production system. In this new scenario, human operators experience many difficulties to interact efficiently with the machine; this is particularly true for middle age workers who feel uncomfortable in the interaction with a complex computerized system, even if they have a great experience about the underlying manufacturing process. On the other hand, complex HMIs linked to complex machine and robot functions create a barrier to young inexperienced or disabled people for an effective management of the production lines. Therefore, such an increasing gap between machine complexity and user capabilities calls for smart and innovative human-centered automation approaches that lead to the determination of adequate levels of automation for optimal flexibility, agility and competitiveness of highly customized production. Novel automation systems should embed HMIs that accommodate to the workers’ skills and flexibility needs, by compensating their limitations (e.g. due to age or inexperience) and by taking full advantage of their experience. The INCLUSIVE project tackles this goal and aims at developing a methodology for the design of adaptive human-centered HMIs for industrial machines and robots.

The design of the INCLUSIVE system will be based on the analysis of typical HMI systems, commonly utilized in the European industries. Therefore, we will analyze three different industrial use cases, that are representative of a wide variety of relevant industrial situations in Europe:

1. Machines for small companies, often run by elderly owners (Use case 1, woodworking machine produced by SCM)
2. Automation solutions made by a European company in developing countries (Use case 2, robotic cell for panel bending integrated by GIZELOIS and deployed in SILVERLINE)
3. Industrial plants made by a big company (Use case 3, labeling machine provided by KHS)

The use cases will be analyzed in details in this section. For each use case:

1. we describe in details the system, and some representative working scenarios, referring explicitly to the interaction between the operators and the machine;
2. we then highlight the main issues related to the current HMI technologies;
3. we define what is expected to be achieved with the INCLUSIVE project;
4. we also highlight the target users that are considered in each use case.

The following table summarizes the working scenarios addressed by INCLUSIVE, that will be detailed in the following sections.

<table>
<thead>
<tr>
<th>Use case</th>
<th>Main partner(s)</th>
<th>Working scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use case 1</td>
<td>SCM</td>
<td>Tuning of the machine, to make it ready for woodworking (tuning of the tools warehouse, tuning of the worktable area components) and routine maintenance procedures (ordinary maintenance)</td>
</tr>
</tbody>
</table>
### Use case 1: woodworking machine by SCM

SCM group produces machine centers for the production of windows, doors, stairs, solid wood parts and for all those processes that require heavy duty machining, while maintaining high standards in terms of precision and finishing quality. Figure 2 shows a machine center produced by SCM. Further information about it can be retrieved in the attached video (see Annex 1).

![Figure 2: Machine center by SCM](image)

#### 2.1.1 State of the art

One of the standard machines developed by SCM is represented by the 4 axes CNC machining center.

The 4 axes CNC machining center is able to move on the surface of the workpiece, with a fixed work table, and moving the motorized heads along the three interpolating axes X-Y-Z.

The main advantage of this kind of machine is in the wide range of shapes that can be achieved, in plane working. Moreover, this machine is able to perform, with a single work program, several complex operations including nesting, boring, routing, cutting, rounding.

The 4 axes working center is indicated for high precision machining, since it requires a small number of workpiece settings, compared to conventional 3 axes routing cutters. In fact, each change of workpiece position produces an inevitable loss of precision of the relative positioning between different processes.
The working center, with its 4 simultaneously controlled axes, is able to complete the required operations for 3 or more panel faces at the same time.

The machining center is developed as a modular system: each module provides a different functionality, and these functionalities are combined to obtain the aforementioned results. In the following, the characteristics of the main modules are described.

### 2.1.1.1 Mechanical structure

The structure consists of a monolithic steel base, strongly ribbed and particularly rigid; the structure, characterized by a very wide base, is designed to ensure stability to the machine and precision over time, in any working condition. The base is a broad and solid element for the moving portal, able to offer a balanced support to the work unit; it is designed to ensure stability and reliability even in the most severe stress conditions, thus achieving superior performance in quality and precision. The mobile portal is made from a solid block, which is connected to the base, and slides on prismatic guides with high quality recirculating balls. Operating groups are installed on the mobile portal: they move along the Y and Z directions on prismatic guides with recirculating ball bearings.

![Figure 3: The portal mobile structure](image)

The fast and precise positioning of the mobile portal (X axis) and of the operating units (Y axis) is made with rack and pinion with tilted teeth; large section recirculating ball screws ensure the precise positioning of the operator group along the axis Z.

The perfect mechanical dynamics and the highest positioning accuracy are guaranteed by digital drives with brushless motors and high-quality static inverters, dimensioned to achieve high movement speed with the highest quality results and finishing. The base and the portal are the main elements of the machine that guide the development of the whole system.

A powered conveyor belt is located in the lower part of the base. Its purpose is to convey wooden chips and residual wood from nesting outside of the machine. The triangular crushproof base makes it easier, for the scraps, to fall on the conveyor belt, leaving the machine clean.
2.1.1.2 Worktable

The smart worktable is made of 6 to 12 bars of extruded aluminum, positioned normal to the main axis of the machine (X axis); bars are able to slide along the X axis on cylindrical guides integrated with the base. The bars, that can accommodate suction cups or clamps, slide on dovetail guides, formed directly on the bar. Each bar is equipped with 3 (or, optionally, 4) suction cups connected with a pneumatic system, that have the function of assuring a rigid and reliable locking of the wood panel during operations.

The motorization of each bar along the X axis is independent; in the same way, each suction cup is able to move along the Y axis in and automatic and independent mode. The simultaneous movement of bars and suction cups allows the worktable set up in a few seconds.

2.1.1.3 Operating groups

The machining center is equipped with the following main operating groups, that are positioned on the mobile portal, and that are able to move along the Y and Z axes in order to approach the piece to work on the table:

1. The spindle head (Figure 6 - Nr.1).
2. The boring head (Figure 6 - Nr.2).
Figure 6 represents the relative position of the working units compared to the mobile portal position. The spindle head and the boring head are assembled on the same “Y Car”, able to move along Y axis thanks to a transmission system with rack and pinion. Each head also has an independent movement along the Z axis, thanks to a transmission system with screw and nut.

2.1.1.4 The tools warehouse

The working center unit is equipped with a tools warehouse, composed of a mechanical support mounted directly on the mobile portal, able to contain from 6 to 48 tools.

The whole device is able to ensure absolute accuracy and reliability during the tool change; it also allows the automatic replacement of tools in masked time while the machine is working or during other "empty" movements on the 3 axes.
2.1.1.5 **HMI device**

The **Panel mac** and the **Tec pad unit** are the HMI devices used by the operator to interact with the machine center. The HMI has been conceived in order to simplify all kind of interactions between the machine and the operator as much as possible.

Below are the main features of Panel mac:
- Manually handling of the machine and the equipment for panels loading / unloading;
- Execution of individual programs (PGMX) and of lists of programs (MIX);
- Production and alarms reporting;
- Machine state monitoring (diagnostics);
- Tools warehouse management;
- Interrupted program recovery.
The Tec Pad unit is a wireless handheld terminal that, providing the freedom of movement and eliminating extension cord hazards, is able to ensure the highest safety and assurance in machine controlling.

The Tec Pad unit is a small, light and comfortable remote system controller 5” TFT LCD colour touch display, which, appositely configured and connected to the machine control logic, guarantees machine control and configuration and the implementation of safety related functions.

The Tec Pad is equipped with two over-ride potentiometers that can be used for different purposes: for instance, setting the spindle speed or the machine movement speed along a certain axis.

It is equipped with a powerful processor, that runs Windows CE and a Java application, which manages all system settings and control, which are sent to the machine control logic through a RS-422 serial communication channel.

Figure 9 illustrates the basic functioning scheme, highlighting the main interactions between the device and the most important machine circuits.

In particular, the Tec pad allows the operator to:

- select the axis to move;
- select the moving direction;
- start and stop a working process;
- change potentiometers values.

Thanks to the display, it is also possible to:

- view log messages;
- change current language;
- change device backlight;
- view wireless diagnostics.

The application provides also the following functionalities:

- visualization of the selected axis and current axes values (for each axis, the system also shows the distance to go);
- visualization of the potentiometers;
- current function mode change (jog, reference, MDI);
• status information (start/hold, alarm, casing, stops, vacuum pump, ...);
• manual tool changing handling (lock/unlock tool, casing up/down, stops up/down, rotate store, vacuum pump on/off);
• visualization of the suction cups and bars graphic and tabular.

2.1.2 Working scenario addressed by INCLUSIVE

Within the framework of the INCLUSIVE project, we will focus on the following operational modes:

1. Tuning of the machine, to make it ready for woodworking. In particular:
   a. tuning of the tools warehouse
   b. tuning of the worktable area components
2. Routine maintenance procedures to extend the components lifetime. In particular:
   a. ordinary maintenance procedures for the machine
   b. ordinary maintenance procedure for the drilling unit.

These operational modes are implemented by specific machine modules, which occur on different machines. Hence, the user-machine interaction required to accomplish the above mentioned tasks follows the same procedures on different SCM machines, essentially differing for the commercial name or for other modules not addressed by this project. Thus, from the point of view of the INCLUSIVE project, we are not constrained to consider a specific machine model, provided that we stick with machines implementing the procedures considered in the INCLUSIVE project.

2.1.2.1 Current implementation

Without loss of generality, in the following we will describe in detail the procedure related to the tuning of the tools warehouse. Additional details can be found in [1]. For the other operational modes, details can be found in [2], [3], and [4]. Moreover, the tuning procedures and the ordinary maintenance procedure for the drilling unit are shown in a real setting in the attached video (Annex 1), which was recorded during a visit to the SCM showroom.

The tools warehouse set up operations are defined as follows.

First of all, the tools being used must be defined, by stating the dimensions requested and by giving them a progressive number (E..). From the Panel mac interface, the user has to click on "open file" and select "file type" (*.tlg).

It is important that the file for every tool is compiled.
The user has then to select the MDI mode (F6) from the Panel mac interface. Subsequently, she/he has to enable the machine graphics with SHIFT+F11.

The selector A is then used to connect the previously configured tools to a specific position in the warehouse. If the machine includes additional storage slots, the keys B and C are used to display them.
The tools arranged in the deposits must perfectly correspond to the numbers displayed on the screen that appears when the menu in Figure 12 is activated. The manufacturer suggests that, in order to prevent errors, an identification tag must be placed on all tools showing reference “A”.

The table represents, in a circular manner, the fields relative to the warehouse locations on the machine.

Deleting tools:

In order to delete tools, the user has to select the function key then (to confirm) to delete all tools in both warehouses.

In order to load tools, the user has to select the corresponding fields, and then use the “arrow” keys on the keyboard to view the tools present among the loaded equipment, and confirm the selection pressing key .

The lower left hand corner (Ref. F) displays the electrospindle enabled and the tool, if loaded.

To prepare the store, the user has to complete the following operations

- Activate warehouse selection with key F4;
- Select the warehouse with the “S04” switch in Figure 13;
- Go inside the perimeter guards with the mobile push-button;
- Warehouse activation is only possible when the door is open;
- Keep the "P07" button pressed (the "P07" button, shown in Figure 13, has a dual position: it has to be pressed in the intermediate position, since fully pressed button (anti-panic function) has the same effect as if it were released);
- Using buttons " + / - " rotate the warehouse (+ = clockwise rotation; - = anti-clockwise rotation);
- Load the tool in the correct location;
- After loading all the tools, move away from the protective devices and restart the machine.
The following sequence of operations represents the typical interaction of the user with the machine, in setting a specific tool:

1. The operator defines tool characteristics of tool E45  
   a. Information is saved in the database
2. The operator selects the MDI mode  
   a. The status of the machine is changed to CN
3. The operator presses SHIFT+F11  
   a. The screen for the configuration of the tools change is shown
4. The operator sets the tool E45 in position 1 of the tools change 2
5. The operator presses the confirm button  
   a. The configuration is saved  
   b. The machine records tool E45 on the tools change 2 in position 1
6. The operator presses F4 on the Tec pad  
   a. The list of the tools change is shown
7. The operator selects the tools change with the S04 switch
8. The operator goes inside the perimeter guards with the Tec pad near the tools change
9. The operator presses P07 in the intermediate position
10. The operator uses buttons “+/-” to rotate the tools change  
    a. The tools change rotates
11. The operator loads tool E45 in the correct position
12. The operator goes outside the perimeter guards

2.1.2.2 Main issues

In the current situation, there is a clear lack of guided procedures assisting the user. In fact, as described before, the user is currently barely supported by the interface, which only gives the following guidelines:

1. In case of ordinary maintenance, alarms are displayed on the HMI. The alarm typically describes the maintenance to be done. An example is shown in Figure 14.
2. For the setup of the tools change, it is very important to equip the physical store in the same way of the virtual store made through the HMI. Currently, the operator must pay attention to avoid mistakes that could jeopardize the operation of the machine.

3. For the setup of the working area, the interface supports the operator by displaying the positioning values of the components. The operator manually moves the various components in the correct position.

4. Often the manual is not used by the operators, because it is considered unnecessary and inconvenient.

5. Given the lack of guidance, often errors of inexperienced operators severely compromise the operation of the machine.

### 2.1.2.3 Target users

To assess the quality of the results achieved in INCLUSIVE, the developed system will be evaluated on the target users summarized in the table below.

<table>
<thead>
<tr>
<th>Elderly</th>
<th>Disabled</th>
<th>Inexperienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system will be evaluated with users with different age (18 - 70 years)</td>
<td>The system will be evaluated with physically impaired users, specifically considering users with missing fingers</td>
<td>The system will be evaluated with users with different level of work experience on the technology (low - high)</td>
</tr>
</tbody>
</table>
2.2  Use case 2: robotic cell of GIzELIS applied to SILVERLINE process

The GIzELIS company objective is to provide “automation system solutions”, such as robotic cells, for a variety of industrial applications, such as welding, handling, palletizing, packaging, assembling, cutting, bending, etc. In particular, bending is a particular process in which an operator places a sheet pallet to be rolled at a specific point (feeding area) inside the system.

SILVERLINE production process uses several kinds of very simple machines for bending metal parts and components, which are currently manually fed mainly because of the variability of the process itself and the lack of skilled personnel, in the production line, able to manage automatic machines or robots. In fact, despite SILVERLINE being a large company that exports in the entire world, it is operating in a central region of Turkey, where population still has, in average, a low level of education.

We will then hereafter consider a Robot Bender Solution, to be applied by GIzELIS to a representative SILVERLINE production case. An example of robot bender can be found at this link: https://www.youtube.com/watch?v=p9t0qJnRdfY.

2.2.1  State of the art

Figure 15 depicts a representative part from the SILVERLINE production. The sheet metal is large and then, it requires a manual bender with a pressbrake. In fact, standard panel benders are not capable of handling this kind of parts, since their dimensions are too large.

![Figure 15 Representative part from the SILVERLINE production](image)

Generally speaking, the bending process is very important in the sheet metal industry. Many products around the world are constructed using bending technology. Nowadays, the factories are changing, increasingly introducing automation, as well as the possibility of reconfiguring programs for lower part production, reducing, in this way, material stock.

Robots are very helpful when factory automation is needed. They can be programmed to continuously repeat movements and tasks, and are thus a very useful solution for reducing the total cost of a product. However, although they are very helpful, they require to be programmed using specific (and, often, difficult) languages and procedures, thus they are not easily reconfigurable in new tasks.
Panel benders are machines that are used to bend parts from sheet metal with small thickness and, although great evolution has been made in the last years concerning programming, they are divided in 2 categories:

1. Semi-automatic machines: they perform the bending sequence but they need operator(s) to load and unload parts from them.
2. Fully-automatic systems: they perform all the sequence with very small assistance from operators, but they consume very large footprint of the factory as their automation system is very big. Moreover, their cost is extremely high, making this solution viable only for big companies.

Within the INCLUSIVE project, we will build a system with a combination of a robot and a panel bender, as shown in Figure 18. In this way, the system will be easily reconfigurable and programmable, the footprint of the system will be very small (as the robot can perform also picking, palletizing and handling operation) and the total cost will be significantly reduced (with respect to current fully automatic solutions), making it affordable by smaller companies.
2.2.1.1 Panel bender principle

The panel benders work in a different way than traditional pressbrakes. The sheet metal is inserted into the holding beam, which grips the part securely. Then, a moving beam is used for making the bend in the excessive material. The universal tool system enables greater bending precision than conventional bending machines. Bending is performed in both directions, positive and negative, which translates into a great reduction in part cycle time and less operator intervention.

2.2.1.2 HMI

The HMI plays a very important role in the design of an effective robot bender solution. While HMI systems have not been developed yet for robot bending solutions, general purpose robotic systems HMIs are
available. In the following subsections, the main features of standard robotic systems HMI s are summarized.

2.2.1.2.1 Manual programming of simple parts
Usually, profiles can be used in a large variety of factories that construct, e.g., doors, construction elements, hydraulic connections, etc. The operator easily imports dimensions, up or down angle, create the part through a table with values. The HMI can be used to manually draw the shape that needs to be created.

![Figure 20 Manual programming of simple parts](image1)

2.2.1.2.2 DXF import
With this option, the operator can import a dxf file with the bending lines (or a 3D part) directly from the design department. The system can then recognize it, and perform bending automatically. This is an easy and fast way to start production, as well as to visualize, in advance, the expected result.

![Figure 21 DXF or 3D part import](image2)

2.2.1.2.3 Adjusting the parameters
In some cases, it is necessary to make small correction to the automated procedures, for instance to change angles, change material/thickness, change bending distances, change tools, etc. The HMI easily enables such changes.
2.2.1.2.4 Tools selection
The operator can select the tools that are mounted on the system. This can be used for collision checking or, if the robot is equipped with an automatic tool changer, to change the tools.

![Figure 22 Tools selection](image)

2.2.1.2.5 Simulation
The simulation provides large benefit for the operator, as she/he can visualize the result of the complete process before performing it. She/he can see the bends of the parts, the movements of the robot, thus solving unpredictable problems. However, simulation requires a significant effort, to model the complex kinematic of the system.

![Figure 23 Simulation of part bending](image)

2.2.1.2.6 Collisions checking
For the correct operation of the machine, the operator must make sure that collisions among parts are avoided. The HMI generates alarms for possible collisions, thus preventing any damage.

2.2.1.2.7 Palletizing Patterns
The robot can not only bend the parts that are requested, but also palletize them for easy transport. For this reason, the HMI provides some predefined patterns of palletization: the operator needs only to specify the numbers of layers, lines and rows.

2.2.1.2.8 Barcode scanner
With a barcode the operator can read the batch and the system is automatically reconfigured according to the program that exists in its memory. This reduces significantly set up times.
2.2.1.2.9  Alarm generation
An alarm database, with possible recovery scenarios including photos, videos of solution procedures, electrical and pneumatic drawings related to specific problems, is very important since it guides, in an easy way, unskilled personnel. This significantly reduces the downtime of the machine.

2.2.2  Working scenario addressed by INCLUSIVE
We will consider the standard activities performed by a user for bending a part, and replacing malfunctioning tools.

2.2.2.1  Current implementation
We will hereafter describe the situation that could be achieved installing currently available robotic system and HMIs on a bending machine.

The operator gets the new part to be made. Based on the HMI capabilities, she/he can program the system by numeric input according to the dimensions or with the use of a 3D import of the part where she/he can visualize the bending. After the input, the system simulates the path and reports for any problem (collision, wrong angle, etc.) where the operator can reenter some data. After successful finishing, she/he can start the operation.

The following sequence of operations represents the typical interaction of the user with the machine, for changing a malfunctioning spare part (e.g. a photo sensor):

1. The photo sensor is not working
   a. The alarm bell is on, and the red light is blinking
   b. A malfunction message is displayed
2. The operator presses the help button
   a. The alarm bell is off
   b. Instructions with photos and drawings are displayed, for instructing the operator on the repair procedure
3. The operator presses the request to enter
   a. The safety door is unlocked
   b. The corresponding “door unlocked” message is displayed
4. The operator opens the door
   a. The red light is on
   b. The “door open” message is displayed
5. The operator identifies the broken photo sensor
6. The operator collects the correct tool for removing the broken sensor, and removes the broken sensor
7. The operator collects the replacement, and places it in the correct position
8. The operator fixes the sensor with screws
   a. The sensor is correctly working
   b. Malfunctioning message disappears
9. The operator closes the door
10. The operator presses the lock button
    a. The safety door is locked
    b. The red light is off
    c. The “safety door secured” message is displayed
11. The machine is correctly working
    a. The orange light is on
2.2.2.2 Main issues

1. These machines can be used only by highly skilled personnel. In particular, background education in mechanical or electrical fields is necessary, since operators need both to program the system, and to be able to recover from problems that could arise during operations (e.g. photocell malfunction).
2. Main problems of breakdown: bad programming, wrong selection of tools, wrong thickness of material, low air pressure.

2.2.2.3 Target users

To assess the quality of the results achieved in INCLUSIVE, the developed system will be evaluated on the target users summarized in the table below.

<table>
<thead>
<tr>
<th>Elderly</th>
<th>Disabled</th>
<th>Inexperienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system will be evaluated with users with different age</td>
<td>The system will be evaluated with people with disabilities of the upper limbs, and with blind and deaf operators.</td>
<td>The system will be evaluated with operators with different education level, ranging from Level 1 to Level 5A according to the ISCED 1997 standard.</td>
</tr>
</tbody>
</table>
2.3 Use case 3: production line by KHS

KHS manufactures production lines including mainly packaging and filling machines. In particular, solutions are developed for filling PET or glass bottles, in CANs and KEGs with beverages, and for packaging the single container into cradles or wrapping with shrink foil or cartons. At the end of the line, the packages are deployed on pallets ready for warehousing. Different procedures of filling are available for a wide range of beverages (e.g. beer, wine, juices, etc.).

INCLUSIVE will focus on a representative machine, namely the Innoket Neo machine, which is a modern and modular labeling machine for bottles.

2.3.1 State of the art

Labeling machines are modular systems. In the following, we will provide the description of the main modules, that are common to several kinds of machines, such as cold-glue label and self-adhesive label.

![Figure 24 Innoket Neo design](image)

Figure 24 represents the layout of the Innoket Neo machine. In particular, the following elements are highlighted:

1. Container guide
2. Operator console
3. Front table
4. Labeling carousel
5. Centering hood

The Innoket Neo has a modular design and consists of a front table, the labeling carousel and the respective labeling stations. The container guides convey the containers to and from the labeler. The labeling carousel
conveys the clamped containers through the labeling mechanism. The labeling station applies the labels to the containers. Additional details can be found in [5].

The machine can work in three main operational modes:

1. Automatic mode
2. Semi-automatic mode
3. Jog Mode

Operational modes are described in details in Section 3.5.2 of [5].

The device depicted in Figure 25 is used to select the jog mode: in particular, the operator is requested to switch to Jog Mode (switch 2) and control the movement by pushing the button 1 (OK switch). The Jog mode is used for the operator to interrupt the automatic program processing, and to manually define the activities of the machine.

In particular, to interrupt the automatic program processing, the operator can either:

- select the jog mode or
- set the flowgate to the open position.

The machine can be operated at low speed using the OK switch and with the safety doors open in order to prepare for production, rectify faults or carry out setup work.

The **semi-automatic mode** can be activated as follows:

1. Switch off the Line control function
2. Set the flowgate to Automatic
When in semi-automatic operating mode, the machine is not integrated into the control concept of the entire line. The machine runs according to the accumulation switch activation status. The working speed is set manually at the operator console.

The **automatic mode** can be activated as follows:

1. Switch on the *Line control* function
2. Set the flowgate to *Automatic*

When in automatic operating mode, the machine is integrated into the control concept of the entire line. The working speed of the machine is regulated automatically.

### 2.3.2 Working scenario addressed by INCLUSIVE

Within the INCLUSIVE project, we will focus on the following operational modes:

1. Changeover of the format parts required by the individual containers, performed in jog mode.
2. Fault recovery procedure for neck ring misalignment

Since human-machine interaction is mainly needed in the jog mode, we will focus on this operational mode. In particular, we will consider the activity related to changeover of the format parts required by the individual containers.

#### 2.3.2.1 Current implementation

Changeover of the format part is typically performed at the system startup, that is:

- at the beginning of each working day,
- or when a completely different product (bottle or label) is produced in the line.

We will hereafter report the sequence of operation performed by an operator for the changeover of the format parts. Additional details can be found in Section 5.11 of [5].

1. Complete the current operation (let the machine run until it is empty)
2. The operator activates the jog mode
3. If necessary, the operator changes the centering rings
4. The operator ends the current program
5. The operator selects the “Changeover” program
6. The operator selects the “Height adjustment” function
7. The operator uses the “up” button to move the centering hood upward
8. The operator dismantles the contained guide parts and feed screw
9. The operator changes the label brush and the label applicator
10. The operator fits the new container guide parts and feed screw
11. The operator selects the new type in the display
12. From “Changeover”, the operator selects “Type selection”
13. In the “Type selection” screen, the operator selects the desired container type
14. The operator changes format parts
15. The operator selects the “Type data” screen
16. The operator defines the setting for the machine and for the labeling station
17. The operator uses the “down” button to move the centering hood to the appropriate height for the selected type
18. The operator deselects the “Height adjustment” function for the centering hood
19. The operator sets the position of the monitoring switch (accumulation switch, gap switch) and the label sensors on the labeling carousel in accordance with the bottle height
20. The operator quits the “Changeover” program
21. The operator selects the “Production” program
22. The operator pre-runs the machine in jog mode, until all the VarioDrive drive units have been initialized
23. The operator checks the work cycles, and corrects any error in the assembly of the format parts

During production, some faults may occur with the machine. A remarkable example is represented by the neck ring misalignment, needs multiple interactions between the user manual and the operator. Details are given in Figure 26.

<table>
<thead>
<tr>
<th>Description of fault</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
</table>
| Neck ring misalignment | Label output is misaligned. A gripper finger is not holding the label securely. Fault occurs regularly. | Set the output point on the station differential gear. Check gripper fingers:  
- Simultaneous gripping?  
- Gap width 0.3 mm?  
- Gripper bar vertical?  
For regularly occurring faults:  
- Determine assignment to individual gripper fingers using the markings and by counting backwards. |
| Pressure and position of the blow air ring set incorrectly on the gripper cylinder: label is blown away from the target position. Does not occur regularly. | Check the blow air ring:  
- Does the blow air move the label?  
- Pressure 3–4 bar?  
- Deviation from target form? |
| Brush-on applicator: brush missing or not positioned correctly. The majority of the neck rings are affected. | Check the brush-on applicator:  
- Are all brushes fitted?  
- Is the brush-on position correct? |

Figure 26 Neck ring misalignment

2.3.2.2 Main issues

1. Operators need a specific training phase, before being able to interact with the machine.
2. In particular, during the first uses, operators perceive the interaction with the system as uncomfortable.
3. Operators feel afraid of damaging the system, the machine or the product, especially if a KHS-trainer or a supervisor is close by. Although these people are trying to help or prevent disasters, the employee is stressed by this situation even more.
4. Unexperienced operators need the manual to check for every possible fault cause and how to correct them.
5. Often operations are not correctly performed according to the manual.
6. Often the wrong operational mode is selected, e.g. “semiautomatic” or “off” instead of “jog mode”.
7. These problems occur with many operators, especially with those new to KHS machinery or low educated people.

2.3.2.3 Target users

To assess the quality of the results achieved in INCLUSIVE, the developed system will be evaluated on the target users summarized in the table below.

<table>
<thead>
<tr>
<th>Elderly</th>
<th>Disabled</th>
<th>Inexperienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system will be evaluated with users with different age</td>
<td>The system will be evaluated with users with different level of work experience and, if available, with customer-personnel with different level of experience on current technology and HMIs from KHS</td>
<td></td>
</tr>
</tbody>
</table>
3 User needs

For each use case, in this section we describe the corresponding user needs. In particular, starting from the analysis of the use cases, user needs are derived as a description of what issues and difficulties the industrial partners highlight with the currently available technological solutions.

3.1 Use case 1: woodworking machine by SCM

<table>
<thead>
<tr>
<th>#</th>
<th>User need</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The system should provide guided procedures for ordinary maintenance</td>
<td>Currently, the operator is barely supported by the interface. Only simple alarms are displayed, that describe what is the current problem, but not the procedure to solve it.</td>
</tr>
<tr>
<td>1.2</td>
<td>The virtual tool store should correctly represent the physical tool store</td>
<td>Currently, the virtual tool store represented in the HMI does not always correctly represent the deployment of the tools in the physical tool store. As a consequence, the operator must pay attention to avoid mistakes that could jeopardize the operation of the machine. This activity is time-consuming and prone to errors.</td>
</tr>
<tr>
<td>1.3</td>
<td>The system should guide the operator in the setup of the working area</td>
<td>Currently, the interface supports the operator only by displaying, in a picture, the positioning values of the components. The operator manually moves the various components in the correct position.</td>
</tr>
<tr>
<td>1.4</td>
<td>Studying the manual should not be necessary</td>
<td>Often the manual is not used by the operators, because considered unnecessary and inconvenient. However, due to the lack of guided assistance and the poor user-friendly interface, often the users have to stop normal operations to check the manual or directly contact the assistance service to solve routine issues. In some other cases, they end up to perform some tasks following some unofficial shortcuts rather than the official procedures recommended in the manual.</td>
</tr>
<tr>
<td>1.5</td>
<td>The system should be effectively usable by inexperienced operators</td>
<td>Errors of inexperienced operators often severely compromise the operation of the machine. The presence of an easily accessible guidance could be a substantial advantage.</td>
</tr>
<tr>
<td>1.6</td>
<td>Procedures should adapt to the operator’s skills</td>
<td>It is important to guarantee that adaptive guided procedures are able to self-adapt to the user profile (i.e. sufficiently clear for unskilled operators; not too long-winded for the skilled operators).</td>
</tr>
<tr>
<td>1.7</td>
<td>Portable interfaces should be available, to guide the operators in the working area</td>
<td>The system must support the operator, guiding him/her during the operation to be performed. A possible solution is represented by augmented reality techniques, utilizing wearable devices (e.g. smart glasses, such as Hololens), or tablets, to show the operator the information currently written in the manual.</td>
</tr>
<tr>
<td>1.8</td>
<td>The system should be usable by operators with different age</td>
<td>18 - 70 years</td>
</tr>
<tr>
<td>1.9</td>
<td>The system should be usable by operators with different level of work experience</td>
<td>Both for first-time users and for expert operators.</td>
</tr>
</tbody>
</table>
1.10 The system should be usable by operators with physical impairments
   In particular, missing fingers is a typical situation for woodworking operators

1.11 The execution time should be improved
   With respect to the current system

1.12 The number of errors should be reduced
   With respect to the current system

### 3.2 Use case 2: robotic cell of GIZELIS applied to SILVERLINE process

<table>
<thead>
<tr>
<th>#</th>
<th>User need</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>The system should be usable by low educated operators</td>
<td>Currently, these machines can be used only by highly educated personnel. In particular, background education in the mechanical field, electrical field and computer science is necessary, since operator need both to program the system, and to be able to recover from problems that could arise during operations (e.g. photocell malfunction)</td>
</tr>
<tr>
<td>2.2</td>
<td>Programming by code writing should not be necessary</td>
<td>Currently, operators need to have significant coding skills. Often bad programming is a source of issues.</td>
</tr>
<tr>
<td>2.3</td>
<td>Choice of the wrong tools should be prevented</td>
<td>Often the unskilled operators chose the wrong tool to perform the bending operations</td>
</tr>
<tr>
<td>2.4</td>
<td>Choice of the wrong material thickness should be prevented</td>
<td>Often the unskilled operators chose the wrong material thickness, and bending is then not possible</td>
</tr>
<tr>
<td>2.5</td>
<td>The correct value of the air pressure should be automatically selected</td>
<td>Often unskilled operators chose wrong settings in the definition of the air pressure, that thus leads to incorrect bending operations</td>
</tr>
<tr>
<td>2.6</td>
<td>The system should be usable for physically impaired people</td>
<td>Current HMIs are based on touch screens and standard computers, and they cannot be effectively utilized by people with disabilities of the upper limbs, or by deaf people. An example of solution could be represented by voice recognition/synthesis</td>
</tr>
<tr>
<td>2.7</td>
<td>Problem solving should be possible also for unskilled operators</td>
<td>Currently, no guided procedure is available, besides the manual. Hence, only operators with a long experience are able to solve problems. An example of solution could be to exploit augmented reality for providing a step-by-step guided procedure</td>
</tr>
<tr>
<td>2.8</td>
<td>The system should guide the operator according to common practice solutions</td>
<td>Several choices need to be made for setting up the system (e.g. the correct angle to be used for bending a certain part). Typically, commonly adopted solutions exist, that are however only known by expert operators. A teaching module could be implemented, to suggest unskilled operators common practice solutions</td>
</tr>
<tr>
<td>2.9</td>
<td>The system should suggest the operator what parameters need to be changed, based on the desired result</td>
<td>Currently, the operator needs to decide what parameters need to be changed, and then see what the result will be. This operation is mainly based on the operator’s experience. A solution for unskilled operators could be to provide suggestions on what parameters need to be changed, knowing how they influence the achieved result</td>
</tr>
</tbody>
</table>
3.3 Use case 3: production line by KHS

<table>
<thead>
<tr>
<th>#</th>
<th>User need</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Specific prior training should not be necessary</td>
<td>Currently, operators often need a specific training phase, before being able to interact with the machine</td>
</tr>
<tr>
<td>3.2</td>
<td>The system should be comfortable for all the users</td>
<td>In particular, during the first uses, operators perceive the interaction with the system as not comfortable</td>
</tr>
<tr>
<td>3.3</td>
<td>Operators should feel confident when using the system</td>
<td>Operators feel afraid of damaging the system, the machine or the product</td>
</tr>
<tr>
<td>3.4</td>
<td>The presence of supervisors should be avoided</td>
<td>First-time users are typically assisted by KHS trainers, or by a supervisor, that stands close by. Although these people are trying to help or prevent disasters, the employee is stressed by this situation even more</td>
</tr>
<tr>
<td>3.5</td>
<td>Operations should be performed in the correct sequence, according to the manual</td>
<td>Often wrong operations are performed, or operations are not correctly performed according to the manual</td>
</tr>
<tr>
<td>3.6</td>
<td>The correct operational mode should be selected</td>
<td>Often the wrong operational mode is selected, e.g. “semiautomatic” or “off” instead of “jog mode”</td>
</tr>
<tr>
<td>3.7</td>
<td>The system should be usable by inexpert operators, or with a low education level</td>
<td>All these issues appear, in particular, for operators that are new to KHS machinery or for low educated people</td>
</tr>
<tr>
<td>3.8</td>
<td>The stress level during the use of the system should be low</td>
<td>Operator often feel stressed, because they do not receive any feedback or acknowledgement, to help them to understand if they are performing well</td>
</tr>
<tr>
<td>3.9</td>
<td>Hands-free interaction should be possible</td>
<td>To enable the operators to interact with the machine when wearing gloves or protection equipment, or while not working in proximity of the HMI. For instance, speech recognition/synthesis</td>
</tr>
</tbody>
</table>
4 System requirements

Based on the description of the use cases and of the identified user issues, the following system requirements are derived, that describe what the INCLUSIVE system will achieve.

[R1] The interface adapts to the level of skills of the operator
[R2] The system can be used by low educated operators
[R3] The system can be used by physically and cognitively impaired operators
[R4] The system can be used by people with low computer skills
[R5] The system enforces the correct procedures
[R6] The operator feels satisfied from the interaction experience
[R7] Interaction with the system generates a low level of stress for the operators

In the following tables, the system requirements are put in relationship to the identified user needs.
4.1 Use case 1: woodworking machine by SCM

<table>
<thead>
<tr>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>R6</th>
<th>R7</th>
</tr>
</thead>
<tbody>
<tr>
<td>The interface adapts to the level of skills of the operator</td>
<td>The system can be used by low-educated operators</td>
<td>The system can be used by physically and cognitively impaired operators</td>
<td>The system can be used by people with low computer skills</td>
<td>The system enforces the correct procedures</td>
<td>The operator feels satisfied from the interaction experience</td>
<td>Interaction with the system generates a low level of stress for the operators</td>
</tr>
</tbody>
</table>

| USE CASE 1 | 1.1 | The system should provide guided procedures for ordinary maintenance | X | X | X | X |
| 1.2 | The virtual tool store should correctly represent the physical tool store |  |  |  | X | X |
| 1.3 | The system should guide the operator in the setup of the working area | X |  |  | X | X |
| 1.4 | Studying the manual should not be necessary | X | X | X | X | X |
| 1.5 | The system should be effectively usable by inexperienced operators | X |  |  | X | X |
| 1.6 | Procedures should adapt to the operator’s skills | X |  |  | X | X |
| 1.7 | Portable interfaces should be available, to guide the operators in the working area |  | X |  | X | X |
| 1.8 | The system should be usable by operators with different age | X |  |  |  |  |
| 1.9 | The system should be usable by operators with different level of work experience | X |  |  |  |  |
| 1.10 | The system should be usable by operators with physical impairments |  | X |  |  |  |
| 1.11 | The execution time should be improved |  |  |  | X | X |
| 1.12 | The number of errors should be reduced |  |  |  | X | X |
### 4.2 Use case 2: robotic cell of GIZELIS applied to SILVERLINE process

<table>
<thead>
<tr>
<th>Use Case 2</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>R6</th>
<th>R7</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 The system should be usable by low educated operators</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2 Programming by code writing should not be necessary</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3 Choice of the wrong tools should be prevented</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 Choice of the wrong material thickness should be prevented</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 The correct value of the air pressure should be automatically selected</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.6 The system should be usable for physically impaired people</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.7 Problem solving should be possible also for unskilled operators</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.8 The system should guide the operator according to common practice solutions</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9 The system should suggest the operator what parameters need to be changed, based on the desired result</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 4.3 Use case 3: production line by KHS

<table>
<thead>
<tr>
<th>Requirement (R)</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>R6</th>
<th>R7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific prior training should not be necessary</strong></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The system should be comfortable for all the users</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Operators should feel confident when using the system</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The presence of supervisors should be avoided</strong></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Operations should be performed in the correct sequence, according to the manual</strong></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The correct operational mode should be selected</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The system should be usable by inexpert operators, or with a low education level</strong></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The stress level during the use of the system should be low</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Hands-free interaction should be possible</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
5 How INCLUSIVE pillars address the system requirements

As detailed in the introduction, the INCLUSIVE system is made of three main pillars:

1. Human capabilities measurement (Measure): the INCLUSIVE system will measure the human capability of understanding the logical organization of information and the cognitive burden she/he can sustain (automatic human profiling). The system will also identify the actual skill level of the user, analyzing on-line how she/he operates in the common working processes.

2. Adaptation of interfaces to human capabilities (Adapt): the INCLUSIVE system will adapt the organization of the information (e.g. the complexity of the information presented), the means of interaction (e.g. textual information, only graphics, speech, etc.), and the automation task (normal operation, adaptation to new processes, predictive maintenance, etc.) that are accessible by the user depending on her/his measured capabilities.

3. Teaching and training for unskilled users (Teach): the INCLUSIVE system will be able to teach the correct way to interact with the machine to the unskilled users. Depending on the skill level of the user and the operation performed by the machine, the interface will train the user by using a step by step procedure, also supported by simulation on a virtual environment.

In this section we explain how the three inclusive pillars will address the system requirements.

5.1 R1: The interface adapts to the level of skills of the operator

In this section we detail how the three pillars will address the requirement R1.

5.1.1 Measure

The INCLUSIVE system will measure the level of experience of the operators. These measurements will be performed online, while the operators utilize the system. By measuring, for instance, the frequency of errors, the speed of execution, or the kind of errors that are typically made, the system will be able to automatically profile the operators and asses their level of experience.

5.1.2 Adapt

Based on the assessed level of experience of the operator, the INCLUSIVE system will adapt the HMI. This adaptation will consist in changing the complexity of the information provided to the operators: specifically, the amount of information and the kind of data that are provided to the operators change, bases on their needs related to their experience. At the same time, the HMI will adapt the level of automation to the operators’ experience: specifically, advanced operation modes will be available only for more experienced operators, while inexperienced ones will be subject to additional constraints that will guide them.

5.1.3 Teach

The INCLUSIVE system will teach inexperienced operators how to interact with the machine in the correct manner. In particular, first-time users will be initially trained by means of step-by-step guided procedures, using simulations in virtual environments and, when possible, the real machines. An industrial social network app will also be developed, to put in contact operators with different levels of experience: the more experienced operators will have the possibility of assisting the less experienced ones.
### 5.1.4 R1 with respect to the use cases

<table>
<thead>
<tr>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use case 1</strong></td>
<td>The level of experience of the operators will be assessed, measuring their performance while executing tuning operations on the woodworking machines, and when executing routine maintenance operations.</td>
<td>Adaptive guided procedures will be implemented, making sure they are sufficiently clear for inexperienced operators and, at the same time, not excessively long-winded for operators with a sufficient level of experience.</td>
</tr>
<tr>
<td><strong>Use case 2</strong></td>
<td>The level of experience of the operators will be assessed, measuring their performance while controlling a robot to bend a standard metal part, and when replacing a malfunctioning tool.</td>
<td>Adaptive guided procedures will be implemented for parameter tuning. The kind of suggestions, and the possibility of changing parameters, will depend on the level of experience of the operators. For inexperienced operators, the HMI will highlight what values must be changed in order to achieved the desired effect, suggesting possible correct values.</td>
</tr>
</tbody>
</table>
5.2 R2: The system can be used by low educated operators

In this section we detail how the three pillars will address the requirement R2.

5.2.1 Measure

The INCLUSIVE system will have access to data related to the education level of the operators: in this manner, it will be possible to profile them, assessing a priori their level of education.

5.2.2 Adapt

Based on the assessed level of education of the operator, the INCLUSIVE system will adapt the HMI. This adaptation will consist in utilizing, for low educated operators, a sufficiently easy language (e.g. avoid technicalities or scientific jargon). Moreover, the HMI will utilize the native language of the operators.

Code writing will not be necessary for operators with a low education level.

5.2.3 Teach

The INCLUSIVE system will include a teaching module that will guide operators with low education level to perform those operations that require high level knowledge.

5.2.4 R2 with respect to the use cases

<table>
<thead>
<tr>
<th>Use case 1</th>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The level of education of the operators will be assessed based on prior information.</td>
<td>Based on the assessed education level of the operator, information will be provided from the HMI with a sufficiently simple language, utilizing the native language of the operator. In particular, error messages will be sufficiently clear and easy to understand, and will be accompanied by figures.</td>
<td>Guided procedures will be defined, to help operators with low education level to perform maintenance operations that require high level knowledge.</td>
</tr>
<tr>
<td>Use case 2</td>
<td>Use case 3</td>
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<tr>
<td>The level of education of the operators will be assessed based on prior information.</td>
<td>The level of education of the operators will be assessed based on prior information.</td>
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<tr>
<td>Based on the assessed education level of the operator, information will be provided from the HMI with a sufficiently simple language, utilizing the native language of the operator. In particular, the sequence of operations will be detailed in a sufficiently clear and easy to understand manner, possibly with the use of figures. Manual code writing will not be necessary, for low educated operators.</td>
<td>Based on the assessed education level of the operator, information will be provided from the HMI with a sufficiently simple language, utilizing the native language of the operator. In particular, procedures will be explained in a sufficiently clear and easy to understand manner, possibly accompanied by figures. Guided procedures will be defined that ensure the possibility, also for low educated operators, to perform common maintenance operations.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3 R3: The system can be used by physically and cognitively impaired operators

In this section we detail how the three pillars will address the requirement R3.

5.3.1 Measure

The INCLUSIVE system will assess the typology and level of physical and/or cognitive impairment of the operators based on a priori available medical certificates. When needed, those certificates will be complemented by off-line assessing tools, specifically designed based on the use case (e.g. level of visual impairment).

5.3.2 Adapt

Based on the assessed level of physical and/or cognitive impairment of the operator, the INCLUSIVE system will adapt the HMI. This adaptation will consist, for instance, in adapting fonts, colors, and size of words and buttons, as well as on the use of a possibly simplified language. The HMI will also be available on alternative interaction means, such as voice recognition and synthesis.

5.3.3 Teach

The INCLUSIVE system will include a teaching module that will include guided procedures that, possibly using differentiated interaction means (e.g. touch screen vs. speech recognition), will help physically and/or cognitively impaired operators to perform the correct operations.
### 5.3.4 R3 with respect to the use cases

<table>
<thead>
<tr>
<th>Use case</th>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use case 1</strong></td>
<td>For each operator, the presence of severed or missing fingers will be assessed based on prior information.</td>
<td>The HMI will adapt the interaction mode (e.g. size and number of buttons to be simultaneously pressed) to accommodate the presence of operators with severed or missing fingers.</td>
<td>Guided procedures will be defined, to help operators with severed or missing fingers to follow complex procedures (e.g. avoid the need to simultaneously pressing several buttons by means of a sequence of questions).</td>
</tr>
<tr>
<td><strong>Use case 2</strong></td>
<td>For each operator, blindness or deafness will be assessed based on prior information. The INCLUSIVE system will also evaluate, off-line, the level of the blindness or deafness.</td>
<td>The HMI will utilize different interaction means, to accommodate different kinds of physical impairments. In particular, voice recognition and synthesis technologies will be utilized for allowing the interaction for blind operators, taking into account the constraints related to the industrial environments, such as high levels of noise (i.e. positioning of microphones, filtering). Regarding deaf operators, the HMI will be utilizable by means of touch screens (or standard PCs), only, i.e. without the need of sound elements and voice recognition.</td>
<td>Guided procedures will be defined, to help physically impaired operators to follow complex procedures. In particular, guided procedures based only on voice recognition and synthesis will be implemented to let blind operators follow the procedures without the need of any additional information. Guided procedures will also be implemented utilizing visual information only (e.g. no sound alarm), for assisting deaf operators.</td>
</tr>
<tr>
<td><strong>Use case 3</strong></td>
<td></td>
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</tr>
</tbody>
</table>
5.4 R4: The system can be used by people with low computer skills

In this section we detail how the three pillars will address the requirement R4.

5.4.1 Measure

The INCLUSIVE system will include an assessment tool, to be performed off-line, for profiling the operators based on their actual skills in the use of computers and related technologies.

5.4.2 Adapt

Based on the assessed level of computer skills of the operator, the INCLUSIVE system will adapt the HMI. This adaptation will consist in utilizing, for operators with low computer skills, natural and intuitive interaction modes that do not require specific knowledge (e.g. file management is automatically handled by the HMI). Furthermore, code writing will not be necessary for those operators.

5.4.3 Teach

The INCLUSIVE system will include a teaching module that will guide operators with low computer skills to perform the required operations in an intuitive manner. An industrial social network app will be implemented for giving the possibility, to operators with low computer skills, to request assistance from more computer-skilled colleagues, when necessary.

5.4.4 R4 with respect to the use cases

<table>
<thead>
<tr>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use case 1</strong></td>
<td>The level of computer skills of the operators will be assessed using an off-line tool.</td>
<td>Based on the assessed level of computer skills of the operators, information will be provided by the HMI in a sufficiently natural and intuitive manner. At the same time, the operator will be allowed to interact with the system in a sufficiently natural and intuitive manner.</td>
</tr>
<tr>
<td><strong>Use case 2</strong></td>
<td>The level of computer skills of the operators will be assessed using an off-line tool.</td>
<td>Based on the assessed level of computer skills of the operators, information will be provided by the HMI in a sufficiently natural and intuitive manner. At the same time, the operator will be allowed to interact with the system in a sufficiently natural and intuitive manner. Manual code writing will not be necessary, for operators with low computer skills.</td>
</tr>
</tbody>
</table>
### Use case 3

The level of computer skills of the operators will be assessed using an off-line tool.

Based on the assessed level of computer skills of the operators, information will be provided by the HMI in a sufficiently natural and intuitive manner. At the same time, the operator will be allowed to interact with the system in a sufficiently natural and intuitive manner, possibly exploiting speech recognition and synthesis, that will be designed taking into account the constraints related to the industrial environments, such as high levels of noise (i.e. positioning of microphones, filtering).

Guided procedures will be defined, to help operators to perform the operations required for the changeover of the format parts required by the individual containers, and for fault analysis and recovery, without the need for specific computer skills. An industrial social network app will give the possibility, to operators with low computer skills, to receive assistance from colleagues that have those skills.

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### 5.5 R5: The system enforces the correct procedures

In this section we detail how the three pillars will address the requirement R5.

#### 5.5.1 Measure

The INCLUSIVE system will measure the performance of the operators, in terms of mistakes and execution time. Based on these measurements, it will be possible to assess if the procedures are correctly followed.

#### 5.5.2 Adapt

Based on the performance measurements, the INCLUSIVE system will adapt the HMI. In particular, if the operator is not following the procedures in a correct manner, the information displayed in the HMI will be adapted to enforce correct execution.

#### 5.5.3 Teach

Guided procedures will be provided by the INCLUSIVE HMI, to ensure that correct procedures are followed. Furthermore, an industrial social network app will be developed, and will provide operators with the possibility of asking other colleagues for assistance in following the correct procedures.
<table>
<thead>
<tr>
<th>Use case 1</th>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness of the procedures will be assessed measuring the execution time, and the kind of errors that are made by the operators.</td>
<td>Adaptive guided procedures will be implemented, to enforce the correct execution of the procedures, when errors have been detected.</td>
<td>Augmented reality techniques will be implemented to prevent errors in the procedures. Augmented reality will be implemented using wearable devices (e.g. smart glasses) or tablets, and will be used to show to the operators, while they are working, the information that is currently contained in the manual.</td>
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</table>

<table>
<thead>
<tr>
<th>Use case 2</th>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness of the procedures will be assessed measuring the execution time, and the kind of errors that are made by the operators.</td>
<td>Adaptive guided procedures will be implemented, to ensure the correct parameter tuning, suggesting possible correct values when errors have been detected.</td>
<td>Augmented reality techniques will be implemented to prevent operators from following wrong procedures in problem solving. In particular, wearable devices (e.g. smart glasses) will be used to suggest the operators the correct sequence of actions to be performed to solve a specific problem. Moreover, the HMI will suggest common solutions, based on history of actions (e.g. the correct angle to be used for bending a certain part), to avoid mistakes in the procedures to be followed (e.g. wrong selection of tools, wrong thickness of material, low air pressure, etc.).</td>
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</table>

<table>
<thead>
<tr>
<th>Use case 3</th>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness of the procedures will be assessed measuring the execution time, and the kind of errors that are made by the operators.</td>
<td>Adaptive guided procedures will be implemented, to enforce the correct execution of the procedures, when errors have been detected.</td>
<td>Utilizing feedback from the machine, guided procedures and confirmation procedures (e.g. “Are you sure?”) will be implemented to prevent dangerous situations, when possible errors have been detected.</td>
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</tbody>
</table>
5.6 R6: The operator feels satisfied from the interaction experience

In this section we detail how the three pillars will address the requirement R6.

5.6.1 Measure
The INCLUSIVE system will exploit data collected by means of questionnaires to assess the level satisfaction of the operators when interacting with the system.

5.6.2 Adapt
The INCLUSIVE adaptation module will be designed in order to maximize the satisfaction of the operators, when interacting with the system. This will be achieved by means of an iterative design procedure, where the adaptation module will be refined based on the feedback from the measurement of satisfaction.

5.6.3 Teach
The INCLUSIVE system provides the operators with guided procedures that, together with augmented reality techniques, will ensure them good performance, even in the presence of difficulties (such as physical/cognitive impairment, low skills, etc.). Thus, achieving a successful performance, the satisfaction level is expected to be high.

5.6.4 R6 with respect to the use cases

<table>
<thead>
<tr>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use case 1</strong></td>
<td>The satisfaction of the operators will be assessed using questionnaires to collect data from the operators after the execution of tuning operations on the woodworking machines, and of routine maintenance operations.</td>
<td>The design of the adaptation procedures will be performed in an iterative manner, refining it based on the measured satisfaction of the operators.</td>
</tr>
<tr>
<td><strong>Use case 2</strong></td>
<td>The satisfaction of the operators will be assessed using questionnaires to collect data from the operators after controlling a robot to bend a standard metal part, and replacing a malfunctioning tool.</td>
<td>The design of the adaptation procedures will be performed in an iterative manner, refining it based on the measured satisfaction of the operators.</td>
</tr>
<tr>
<td><strong>Use case 3</strong></td>
<td>The satisfaction of the operators will be assessed using questionnaires to collect data from the operators after performing changeover of the format parts required by the individual containers, and fault analysis and correction.</td>
<td>The design of the adaptation procedures will be performed in an iterative manner, refining it based on the measured satisfaction of the operators.</td>
</tr>
</tbody>
</table>
5.7 R7: Interaction with the system generates a low level of stress for the operators

In this section we detail how the three pillars will address the requirement R7.

5.7.1 Measure

The INCLUSIVE system will exploit real-time measurements of physiological indicators (e.g. heart rate, galvanic skin response, skin temperature and adrenaline level), to assess, on-line, the level of cognitive workload and stress of the operator. This information will also be complemented by data collected with questionnaires, to measure the overall stress level generated by the interaction with the system.

5.7.2 Adapt

Based on the assessed level of cognitive workload and stress of the operator, the INCLUSIVE system will adapt the HMI. In particular, in case of high level of stress, the HMI will provide a simplified interaction system, including guided procedures, with the aim of reducing the stress itself.

The design of the adaptation module will be performed in an iterative manner, utilizing the measured level of stress of the operators as a feedback, with the objective of reducing it as much as possible.

5.7.3 Teach

The INCLUSIVE system provide the operators with guided procedures that, together with augmented reality techniques, will reduce the cognitive workload, without affecting the performance in the operations.

Furthermore, these procedures will avoid the need of presence of supervisors, which is a common source of stress.

An industrial social network app will also be developed, that can be used for obtaining assistance from colleagues in case of difficulties: this will lead to avoiding several causes of stress related to failures.

5.7.4 R7 with respect to the use cases

<table>
<thead>
<tr>
<th>Use case 1</th>
<th>Measure</th>
<th>Adapt</th>
<th>Teach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The cognitive workload of the operators will be assessed, based on measurements of physiological indicators taken while executing tuning operations on the woodworking machines, and when executing routine maintenance operations. These measurements will be complemented by data collected with questionnaires, to assess the overall stress level, both on-line and off-line.</td>
<td>The design of the adaptation procedures will be performed in an iterative manner, refining it based on the measured stress level of the operators. Moreover, on-line assessment of stress and cognitive workload will be used for adapting the HMI, simplifying the interaction system (e.g. introducing guided procedures) when the stress level is too high.</td>
<td>Augmented reality techniques and guided procedures will support the operators, providing them with live information while performing operations. This will reduce the cognitive workload, and subsequently the stress level, during the interaction with the system.</td>
</tr>
<tr>
<td>Use case 2</td>
<td>The cognitive workload of the operators will be assessed, based on measurements of physiological indicators taken while controlling a robot to bend a standard metal part, and when replacing a malfunctioning tool. These measurements will be complemented by data collected with questionnaires, to assess the overall stress level, both on-line and off-line.</td>
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</tr>
<tr>
<td>Use case 3</td>
<td>The cognitive workload of the operators will be assessed, based on measurements of physiological indicators taken while performing changeover of the format parts required by the individual containers, and while performing fault analysis and recovery. These measurements will be complemented by data collected with questionnaires, to assess the overall stress level, both on-line and off-line.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Use case 2</th>
<th>The design of the adaptation procedures will be performed in an iterative manner, refining it based on the measured stress level of the operators. Moreover, on-line assessment of stress and cognitive workload will be used for adapting the HMI, simplifying the interaction system (e.g. introducing guided procedures) when the stress level is too high.</th>
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</thead>
<tbody>
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<td>The design of the adaptation procedures will be performed in an iterative manner, refining it based on the measured stress level of the operators. Moreover, on-line assessment of stress and cognitive workload will be used for adapting the HMI, simplifying the interaction system (e.g. introducing guided procedures) when the stress level is too high.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use case 2</th>
<th>Augmented reality techniques and guided procedures will support the operators, providing them with live information while performing operations. This will reduce the cognitive workload, and subsequently the stress level, during the interaction with the system. An industrial social network app will also be developed, to provide assistance to operators in the case of difficulties.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use case 3</td>
<td>Guided procedures will support the operators, providing them with live information while performing operations. In this way, the presence of supervisors will not be necessary, even for operators with low level of experience. This will reduce the stress level, while reducing the cognitive workload on the operators. An industrial social network app will also be developed, to provide assistance to operators in the case of difficulties.</td>
</tr>
</tbody>
</table>
6 Target users

The INCLUSIVE project aims at providing technological solutions for compensating workers’ limitations (e.g. due to age or inexperience), while taking full advantage of their experience. The results achieved in the project will be evaluated considering the following user groups:

- **Elderly**: people in the last years of their work life. Generally, these workers have a large experience in the traditional industrial processes, but are not familiar with modern computerized devices and, then, have difficulties in utilizing modern automatic machines that come with complex HMIs.

- **Disabled**: people with physical impairment and limited cognitive abilities. Such limitations introduce difficulties in the use of complex automatic machines. Therefore, in order to reduce these difficulties, it is important to take into account their special needs.

- **Inexperienced**: this class of users includes people with low level of education, limited expertise in the use of automatic machines and/or computerized HMI, and lack of experience in the industrial processes.

The following table shows how the considered use cases target the user groups under consideration.

<table>
<thead>
<tr>
<th>Use case 1</th>
<th>Use case 2</th>
<th>Use case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elderly</strong></td>
<td>The system will be evaluated with users with different age</td>
<td>The system will be evaluated with users with different age</td>
</tr>
<tr>
<td><strong>Disabled</strong></td>
<td>The system will be evaluated with physically impaired users, specifically considering users with missing fingers</td>
<td>The system will be evaluated with operators with different education level, ranging from Level 1 to Level 5A according to the ISCED 1997 standard</td>
</tr>
<tr>
<td><strong>Inexperienced</strong></td>
<td>The system will be evaluated with users with different level of work experience and, if available, with customer-personnel with different level of experience on current technology and HMIs from KHS</td>
<td></td>
</tr>
</tbody>
</table>
7 Conclusion

This deliverable defines the system requirements for the INCLUSIVE project. Those requirements have been defined based on the analysis of three industrial use cases that are representative of a wide variety of relevant industrial situations in Europe.

For each use case, specific representative scenarios have been analyzed. As a result, main issues related to current HMI systems have been obtained, referring in particular to elderly, disabled and inexperienced operators. Starting from these issues, system requirements are derived, as an abstraction of the user needs, and define what issues the INCLUSIVE system will tackle.

The analysis of the use case and the description of the system requirements will be the basis for the subsequent definition of the INCLUSIVE system specification, at system and at module level, that will be collected in Deliverable D1.3.
8 References

[1] SCM Manual, Tuning of the tools warehouse
[2] SCM Manual, Tuning of the worktable area components
9 Annex 1

The accompanying video shows a machine center for woodworking by SCM. Specifically, procedures for tuning worktable area components, alarm recovery and tool changeover, both automatic and manual, are shown. The video has been taken during a visit to the SCM showroom by some partners of the INCLUSIVE Consortium.