AI-PRISM

D5.1– Task Analysis for Benchmarking and Design Requirements (I)

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Disclaimer

Acronyms and definitions

Acronym	Meaning
AOI	Areas of Interest
HTA	Hierarchical task analysis
MW	Mental Workload - an interaction between task requirements and the individual's capabilities or resources allocated to accomplish the task
SA	An individual's perception of environment and events around themselves with respect to time and space and the perception of the future state of these environmental elements and events
Self-efficacy	A personal judgment of how well one can accomplish a course of action. It allows the prediction if an individual can exhibit coping behaviour and how long they will sustain it while facing obstacles
Fatigue	Temporary impairment of functional efficiency (mental and/or physical) caused by mental strain. This inefficiency duration and strength depend on the intensity, duration and temporal pattern of the mental strain experienced. Recovery from fatigue is achieved by rest, however, fatigue like states (monotony, reduced vigilance, mental satiation) can be reduced by changing activity (ISO 9241-210)
PCB	Printed circuit board

Executive summary

User requirements were analysed and defined within five use cases in the AI-PRISM project. The initial processes were benchmarked for human factors involved in the use cases. Based on this information, this document reports and specifies operator psychological safety aspects necessary for successful adoption of AI-based robotics technology. Section 1 introduces the document and the need for this data collection. Section 2 describes the methodology used for data collection within the five use cases. The results are reported in Section 3, and finally Section 4 presents brief conclusions and future directions.

The AI-PRISM project

AI-PRISM will provide industrial users with **human-centred artificial intelligence (AI)-based solutions to create a more efficient, resilient, digital, sustainable and high-quality European manufacturing industry**.

To do so, we will develop an **integrated and scalable environment** with solutions adapted to dynamic and unpredictable manufacturing scenarios that require tasks that are difficult to automate and where speed and versatility are essential to meet users' needs. Furthermore, the solutions will be specific to semi-automated and collaborative manufacturing in flexible production processes and will not require specific robotic programming skills.

Our solutions ecosystem will have four main pillars:

1. **A human-centred collaborative robotic platform** oriented to ease hard-to-automate manufacturing tasks.
2. **A human-robot cooperative environment** powered by trustworthy AI.
3. **Social human-agent-robots teams' collaboration** — AI-based safety monitoring and robot control mechanisms to detect and avoid unsafe situations and ensure social and physical safety.
4. **An open-access network portal** to offer compliant infrastructure.

To evaluate our solutions' performance, transferability, scalability and large-scale deployment, we will perform demonstrations in real operating environments. Specifically, in **four user pilots involving key manufacturing sectors** — furniture, food/beverage, built-in appliances and electronics —, **types of robots and industrial processes that are difficult to automate, plus a generic demonstration facility.**

In addition to seeking quantitative improvements in the manufacturing sector, **AI-PRISM aims to use technological innovation to support a paradigm shift in which AI, robotics and Social Sciences and Humanities (SSH) are integrated into the manufacturing domain for the improvement of flexible production processes**, becoming a viable and widespread alternative for European factories.

During the next three years, **25 partners** from **12 countries** will join forces to make AI-PRISM a reality. From educational institutions to research and technology organisations, robot manufacturers, industries and use case providers; our interdisciplinary consortium brings together all the actors of the human-robot collaboration value chain and involves key experts in SSH, standardisation, exploitation, and dissemination.

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1. INTRODUCTION

The current data collection is part of the AI-PRISM project, and it is benchmarking five use cases from the human factors point of view prior to further technology introduction by the project. The project will implement and validate its technological solutions on five industrial use cases:

- VIGO – assembly of semiconductors. A precise positioning of small (1-2mm) semi-finished electronic components against a wire to be attached is performed manually by the operator.
- KEBA – testing of the printed circuit boards (PCBs). The testing of the assembled PCBs is performed manually by the operator. The tasks is a fast paced process requiring collection of the board from the collection stack, placement into the automated testing area, and upon completed testing depending on the result placement of the board either to successfully tested board stack or failed testing board stack.
- ANDREU WORLD – furniture manufacturing use case proposed two processes for the AI-PRISM project – painting and sanding. These both processes rely on skilled manual processes and given the variety of furniture models (shape, size, wood, etc.) requires operator experience and are hard to automate with conventional technology.
- ATHENIAN BREWERY – beverages production. At the facility, several processes are currently performed manually, and four processes were proposed for further investigation of the project for introduction of human-robot collaboration: Transportation of powder for brewing purposes, labelling of kegs, picking and assembly of pallets for customer orders, and sorting of the recycled glass bottles.
- SILVERLINE – home appliance manufacturer proposed hood use case. The hood assembly process consists of 12 steps and three steps of grounding test, visual inspection and labelling were proposed for the project.

1.1. AIMS AND OBJECTIVES

The aim of the current work was to identify impacts of current processes on operators' psychological safety.

The set of objectives needed to meet this aim are:

1. Benchmark current manual assembly processes to ascertain current sequence of physical and cognitive task steps and procedures.
2. Identify areas of retaining/increasing operator satisfaction and eliminating aspects of the process prone to high error rate and operator discomfort (physical and/or psychological)

In order to achieve these principal objectives, a corresponding two-stage methodology was employed. The first step was video analysis of the use cases were possible (due to internal regulations and contractor workforce Athenian Brewery use case were not able to provide video material, however assisted in extended physical visit). Second step was data collection with the eye tracker for further analysis of the processes. Both video analysis and eye tracking data was used for the initial task analysis to understand the process, and further implications on each use case are drawn on the triangulation of the task analysis, eye tracking data and interviews with the operator.

1.2. Research Approach

Social science research has established the importance of user centred research for the user increased acceptance (Pais et al., 2021) with task analysis often being the first step for in-depth understanding of the existing process. This analysis allows to capture human tacit and procedural knowledge of the existing process to determine necessary changes and improvements, i.e., innovation opportunities in the workplace. However, increasing collaboration not only between disciplines and industries, but also cross culturally, introduces the challenges of capturing language dependent knowledge.

Task analysis (TA) methods are used in order to elicit, understand and represent the physical and cognitive steps an operator undertakes whilst completing a task (Stanton, 2006). This has been shown to be efficient to achieve a deeper understanding of the process and human cognitive steps involved (Tofel-Grehl & Feldon, 2013), as well as being successfully deployed in manufacturing (Johnson et al., 2019). Hierarchical Task Analysis is a popular and versatile human factors technique for deconstructing and analysing manual task activity. It is a systematic method for breaking down a task into its constituent parts as a nested hierarchy of goals, sub goals, operations and plans to show the step-by-step sequence of individual activities / operations necessary to meet the overall objective. The data needed to describe the task steps are collected via observations, demonstrations and interviews with operators who perform the task (subject matter experts), and by reviewing task documentation such as work instructions / standards and relevant technical information. By revealing each step of a task process the basic HTA breakdown reveals the distinction between physical and cognitive activities, which can then be used for other subsequent analyses. Yet, this method heavily relies on spoken language, and communicating via the interpreter introduces additional bias in particular when interpreter is familiar with the higher-level aspects of the process and unconsciously may introduce the interpretation of the answers by the operator from their own perspective.

The AI-PRISM project presents a two-step approach of engaging multicultural end users for robotic technology introduction in the manufacturing. The first step is video analysis of the process to determine which human factors might be key contributors to the existing processes. The second proposed step is process observation while the operators wear eye tracking glasses combined with several questions for the process clarification. This step allows to determine decision making points and visual attention sequence as well as provide a list of the human and cognitive factors involved in the process. The methodology reported in this deliverable will be presented in Section 2, with the results discussion in Section3 and Section 4 outlining the conclusions and future directions.

2. METHODOLOGY

2.1. Participants

Participants were recruited by the use case leaders asking for volunteers for the project data collection. Prior to data collection, participants were explained aims of the project, process of data collection and data usage, participants rights and potential harms and benefits of the procedure (Further described in D10.1). The use case leaders were assisting the communication between the user and the researcher by translating to the participants native language and English. Only participants gender and experience level were recorded for the initial data collection (Table 1).

Table 1: demographic information about participants in each use case

	VIGO	KEBA	ANDREU WORLD	ATHENIAN BREWERY	SILVERLINE
# participants	2	2	3	1	3
Gender	3 males	female/male	3 males	male	2 females, 1 male
Experience	Experienced & novice	Experienced & novice	Experienced	Experienced	Experienced
# processes	1	1	2 (painting and sanding)	3	3 stations in the same cell

2.2. Research Ethics

This research was approved by the Cranfield University Research Ethics Committee, and conducted in accordance with the Cranfield Research Integrity Policy, the British Psychological Society's Code of Human Research Ethics, and the General Data Protection Regulation 2018.

2.3. Procedure

The use case lead assisted the researcher for the interpretation in the participant's native language. Upon reading the informed consent and agreeing to take part in the data collection, the operators had a demonstration of the eye tracking glasses and further explanation about how they work. Participants were asked to wear the eye tracking glasses during the assembly and to verbalize the steps they were performing. The researcher asked questions regarding the process to gain more in-depth knowledge regarding what the operators were doing and why. After the assembly was completed, each operator was invited for a semi-structured interview.

2.4. Materials

2.4.1. Eye tracker

Participants' gaze was tracked via SMI Eye Tracking Glasses (SensoMotronic Instruments ETG 1.7). The eye-tracking data was analysed using SensoMotoric's BeGaze© eye-tracking analysis software, utilising the Area of Interest (AOI) semantic gaze mapping. The eye-tracking data was then examined in terms of dwell time (%) recorded within these AOIs. The number of dwell time was exported from the event statistics after all of the gaze events were mapped to the corresponding AOIs using the BeGaze software. In two of the use cases (Silverline and Keba) Tobii Eye Tracking Glasses 3 with Tobii Pro Lab analysing software were used, however the same approach was used as with SMI Eye Tracking Glasses.

2.4.2. Observations

Participants were asked to verbalize what they are doing during the assembly. The use case lead was assisting in translating the clarifying and probing questions from the researcher and answers from the operator. Furthermore, Andreu World use case data analysis was performed by coding behavioural data from the eye tracker with BORIS behavioural observation software.

2.4.3. Semi-structured interviews

The researcher asked the main five questions and then depending on the answer asked follow-up questions. The structured questions were: 1. What is the most difficult during the assembly; 2. Where potential errors can occur and how operators fix them; 3. What variation of the assembly does occur (novice vs experienced operators); 4. How long does the training take to be confident in the assembly? 5. Which aspects of the tasks are the most enjoyable?

3. RESULTS

3.1. VIGO

The heatmaps of the fixation times on three areas of interest: monitor used for calibrating the microscope, microscope, and the component provides some insight on how the process was approached and completed by two operators. The novice operator had a more spread fixation on the environment and wider dwell range compared to the experienced operator who was focused only on particular areas of the AOIs (Figure 2). Interestingly, the numerical comparison of the dwell times of these two operators indicate that although the novice operator had larger dwell times in all three AOIs (Figure 2C), the difference was the most evident in the microscope AOI.

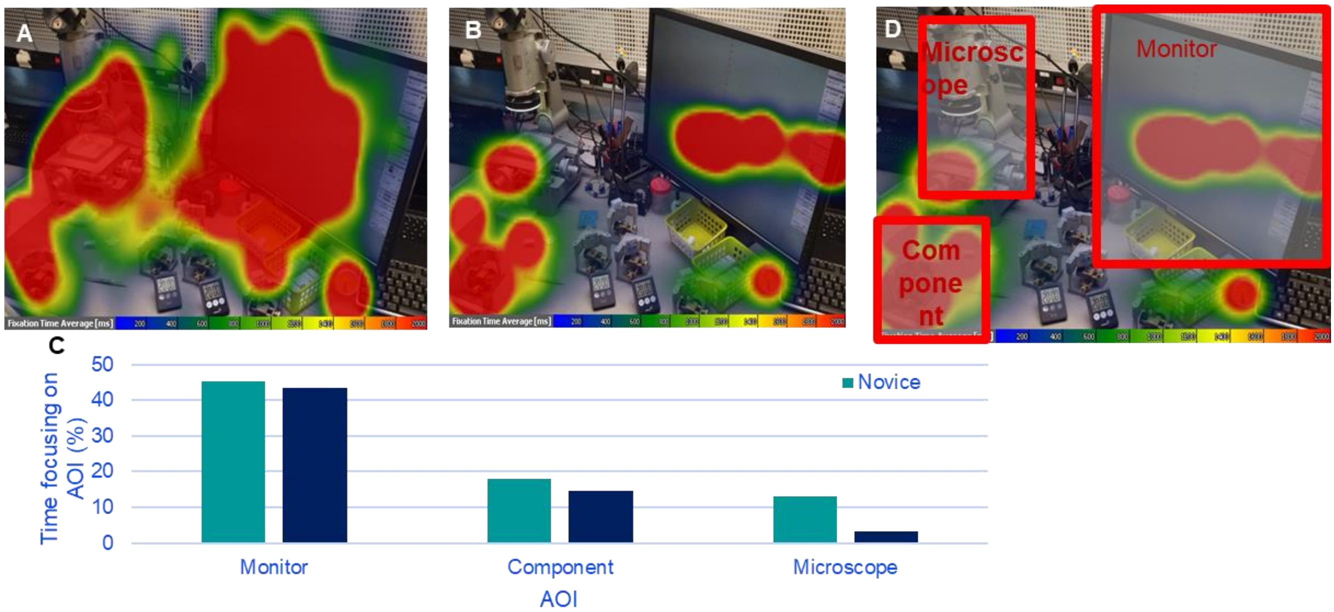

Figure 1: Eye tracker results: heat map of dwell time for (A) novice operator, (B) experienced operator. (C) plotted statistics of fixation time (%) in these AOI as a function of operator experience. (D) defined Areas of Interest

These results combined with the follow up interviews of the operators to provide an opportunity to explain their eye tracker results provided some insight on how the assembly is approached by different experience operators. The novice operator explained that he was looking more at the microscope than he expected due to difficulty in manipulating the adjustments and positioning the lens. Furthermore, he indicated that looking on the computer screen (monitor) he was not always certain if he was looking at the right place and therefore the gaze was more spread out. The experienced operator on the other hand was twice as quick as the novice operator and more importantly his gaze focused on only certain aspects of the screen, while the microscope was manipulated without paying visual attention to the adjustments (tactile information from the environment). Both operators indicated that the most mental focus was on computer screen as it allows to determine if the electronic component is placed correctly and if the metal wire is be glued properly. The more experienced operator explained that although the task itself is not difficult, the process requires a great level of precision and responsibility as if errors are made, there is no way to fix them – the electronic component gets scraped.

The discussion with the operators allowed to determine that during the assembly situation awareness and mental workload might be impacted depending on automation steps introduced. Furthermore, although physical discomfort is minimal according to the operators, the current process might have influence on the eye strain due to long periods of working in front of the computer screen and great focus on the precise details. Finally, the operators being in charge of the process and, in particular, the experienced operator having his own routines (i.e. pre-arranging components ready for the wire to be glued, and then gluing several at the same time) can have an impact on the perception or job responsibilities and roles - job satisfaction and self-efficacy are organizational factors to be tracked throughout technology introduction.

3.2. KEBA

KEBA use case followed the same approach as with Vigo, however, here the Areas of interest were defined as follows: PCB board, board test area, scanner, board stack, and primary and secondary monitors (Figure 2 D). The heatmap and fixation time on AOIs indicate that novice user compared to the experienced user spent more time fixating on all AOIs, but mainly on the monitors (main and secondary screen), also the on board test area. While the experienced operator had hardly any fixations on the scanner location, the novice user spent around 5% of fixation time in this AOI.

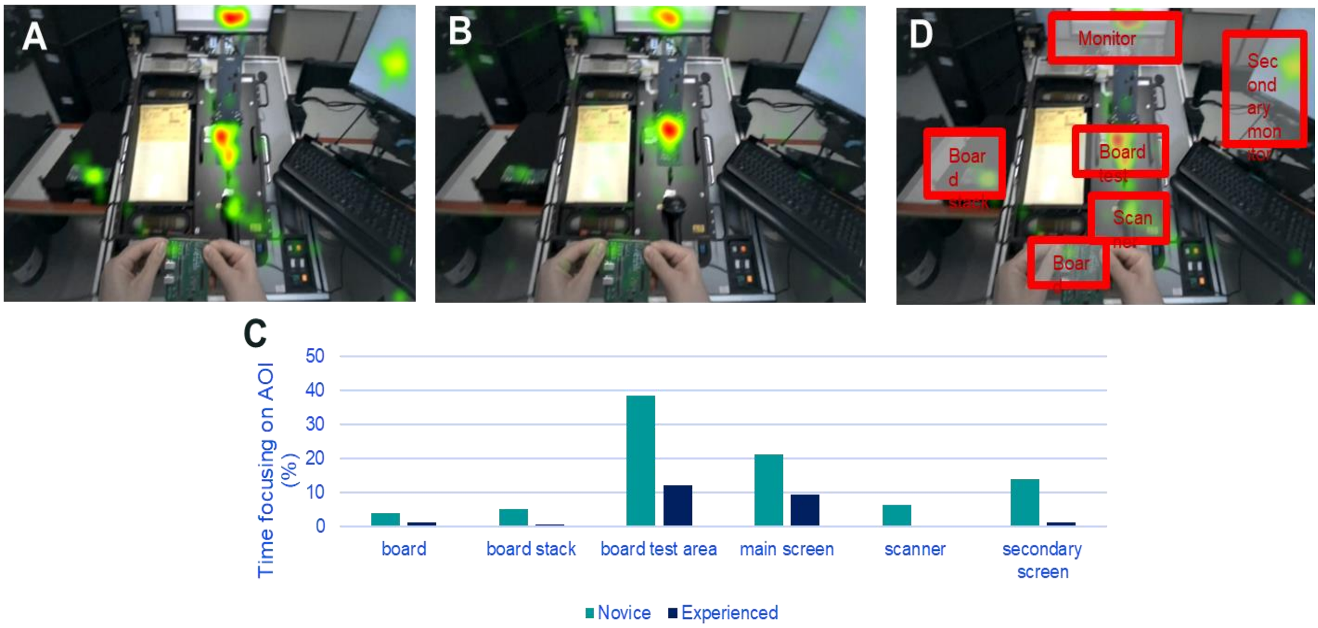

Figure 2: Eye tracker results: heat map of dwell time for (A) novice operator, (B) experienced operator. (C) plotted statistics of fixation time (%) in these AOI as a function of operator experience. (D) defined Areas of Interest

The semi-structured interviews with the operators provide some explanation for these results. The novice operator explained that it would be useful to have some kind of auditory notification when the testing of the board is done. This is highlighted by greater fixation duration on both monitors, while for the experienced operator the test time became habituated and they knew once the test should be completed and in the meantime were looking around, checking documentation. Furthermore, the novice explained that removing the board from the test area was not straightforward "you need to know where to grab the board, as the sides of the board are covered with sealant, and it is difficult to get a good grip to remove the board". In addition, placing the board on the testing area required some procedural knowledge as the board needs to be at an angle to fit the pins first and then the rest of the board. Finally, the novice operator also indicated that once you scan the board, the testing area cover needs to be closed very quickly, otherwise the testing will indicate failure. This explains greater fixation duration on the scanner AOI. In fact, although the experienced operator was efficient on this step, the novice operator needed several attempts to get the right speed of scanning and closing the cover.

Further discussion with the experienced operator about the task indicated that the operator values the self-efficacy aspect of the task "knowing when the board fails and finding the cause of it is important". Although there are support technicians to help with fails, whenever the operator observes a fault, they triy to figure out what is the reason – is it really the board, or the machine needs fixing (might be the pin not working, dusty, etc.). During the observation, the testing failed 5 times, and the operator managed to fix the failed process 3 times. This indicated procedural knowledge of the task and also satisfaction with their own work once this level of knowledge is achieved. Considering other aspects of the task, the operator indicated that they enjoy the process and learning about different processes around the facility (over several years they have been trained on several different processes). However, the independence and self-efficacy aspect was very important. Yet, what the operator finds difficult in the process is the fluctuation of production intensity – sometimes it is busy, sometimes it is less busy. Having a constant flow, operator explained, would be their preference as they would get used to it better.

Overall, the discussion with the two operators indicated that the most error-prone parts of the process are placing and removing the board, and scanning. The process relies on the procedural knowledge and visual inspection. Yet, the self-efficacy of being able to fix some of the fails and independence on the process were important aspects contributing to operator satisfaction and need to remain with future technology development.

3.3. ANDREU WORLD

During the use case visit, two processes were observed: the painting and sanding processes. One operator was observed while completing the painting process, and two operators during the sanding processes. The chair production is completed over several stages, and the products are automatically transported on the assembly line between the stages.

3.3.1. Painting

In the painting stage, the operator is located in the painting section isolated from the rest of the factory (to contain the spray paint). In this section there are two assembly lines, and the operator is located in between them. Using a spray, the operator applies the initial layer of paint on the products. The task is dependent on visual information and experience about the shape and form of the product to be aware of the paint coverage and movement. The interview with the operator after the observation indicated that due to the assembly line being low, the operator needs to bend for some components, and this put a strain on his back. Yet, the operator explained that this does not cause long term discomfort. The main aspects new operators need to learn and be aware about are dependent on the experience: (i) the shape of the component and drip; (ii) different wood soaks the paint differently, and therefore the spraying needs to be either lighter or repeated several times for greater coverage. The hierarchical steps involved in the process are described below:

1. Starting the computer and following the specifications for the next batch (colour, component)
2. Preparing the environment (paint etc.)
    a. Preparing the spray:
        i. Removing the previous colour from spray with water – *procedural knowledge*
        ii. Colour sample matching to the selected paint – *visual information, and procedural knowledge*

3.Painting the chair

    a. Turning the chair upside down – procedural information
    b. Spray from top to bottom but also follow the component shape (starting from left side highest point, and following down and then up to the right-side highest point – *procedural knowledge, visual information*
        i. Rotate the chair to cover all the sides – *procedural knowledge*
        ii. Repeat the steps until even colour matching sample is achieved (3 spins) – *visual information, tacit knowledge and experience*

4. Compare the legs with the colour sample (but only close over)
5. End of the processes and start on next component (chair)

3.3.2. Sanding

In the sanding stage, there were multiple operators working at the same area. During the time of observation there were 4 operators, and two of them were interviewed and their eye-tracking data was collected during the sanding process. This was followed with an interview of the operator. The collected data revealed that the process heavily depends on the visual and tactile information to determine if the quality of the finished product is acceptable. However, the process to achieve this relies on an array of movements. As the eye-tracker data has revealed, ten motions/steps were performed for the observed aspect (Table 1), and the further analysis was performed by coding different hand motions used in the sanding process, including the count and time they were used.

Table 2: description of different motions in the sanding process

Motion	Description
1 finger sensing	Tactile information about the sanding needs on a small, usually narrow area. This sensing is very brief and used to confirm the surface smoothness
2 finger sensing	Tactile information about further precision of the sanded process. normally used on a small narrow surface area
Palm sensing	Tactile information about sanding quality on a large flat area, such as the length of the chair leg
Circular motion	Sanding process motion performed in order to blend in the sanding area with the rest of the component. Minimal force is applied.
Long stroke	Sanding strokes along the length of the surface, applied with medium force on the long areas.
Short stroke	Sanding strokes along the length of the surface, applied with medium force on the hard to reach areas (near joints and corners), and secondary purpose is for more sanding requiring areas applied with greater force.
Scraping	Removal of the bumps and other defects from the component prior to completing the sanding
Paint touch-up	Surface areas which were sanded to the extent where colour inconsistencies are visible are normally touched up with paint to allow further consistent painting process
Tool usage	Removal of the bumps and other defects from the component prior to completing the sanding by using sanding stones of various gradient
Cloth cleaning	Cleaning of the component from dust to allow better visual inspection to finalise the product

Although both operators were observed while completing sanding on different components (the shape of chairs differed), the main similarity was that both processes used long strokes while sanding and cloth cleaning the most (Figure 3).

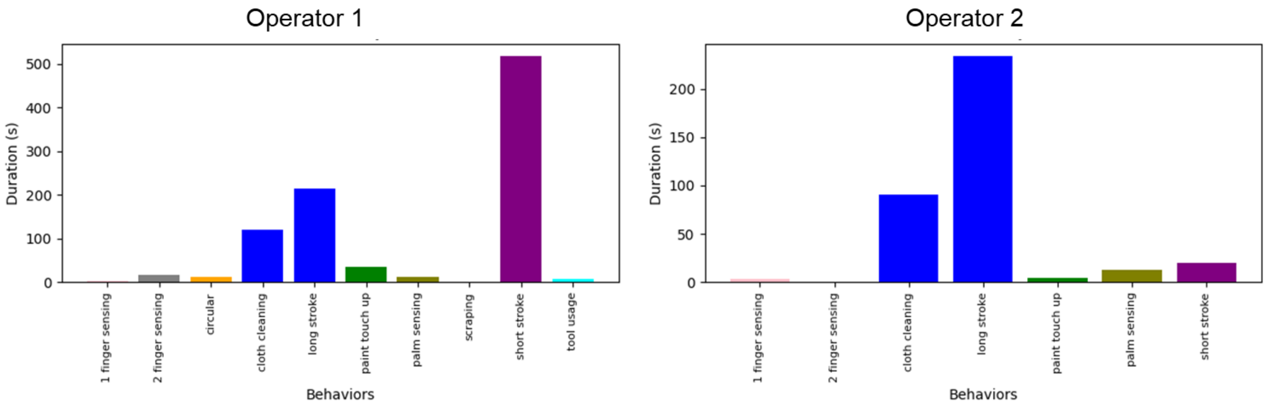

Figure 3: observation action coding for both operators. The figures include the count how often each action was performed during the observed process.

Furthermore, plotting the actions against the time indicated how the different steps and motions are distributed over time and what is needed at the beginning of the process and how it evolves nearing the completion of the component. This data is plotted in Figure 4. Operators start with long strokes to cover all the surface area of the component they are working on, with shorts strokes mainly left for the corners and where the parts are attached. However, the more they complete the task the greater tactile sensing is incorporated (1 finger, 2 fingers or with the palm – depending on the surface area where the imperfections are potentially observed). The final stages of the completion consist of fixes of tool usages (sanding stones for greater imperfections, scraping of bumps, and touching up the fixed areas with colour to enable even painting during the next stage of the assembly process).

Even though the process heavily relies on tactile and visual information, the operators discussed that experience and knowledge about the wood type, different cuts, and even colours is essential. In fact, both operators previously have worked on antique furniture restoration, and they indicated that knowledge about the wood is important in the current job. In discussion on the training of new employees, operators indicated that if there is only one component, the training does take several months to learn (around two or three months), however, as the company has hundreds of products, the learning process can take a year or more. Operators indicated that the main priority in this station is the quality of the product. Some components can take 30 minutes, others 60 minutes, however, the most difficult aspect is knowing when to stop and ensuring that high quality is achieved. Considering the difficult aspects of the process both operators indicated that corners and joints are the most difficult as even surface sanding is harder to achieve, and also depending on the polish they might need to use additional tools (scrapping) to remove the excess material. In the figures these areas are indicated by greater short stroke motion usage, where operators were applying greater force or smaller surface area.

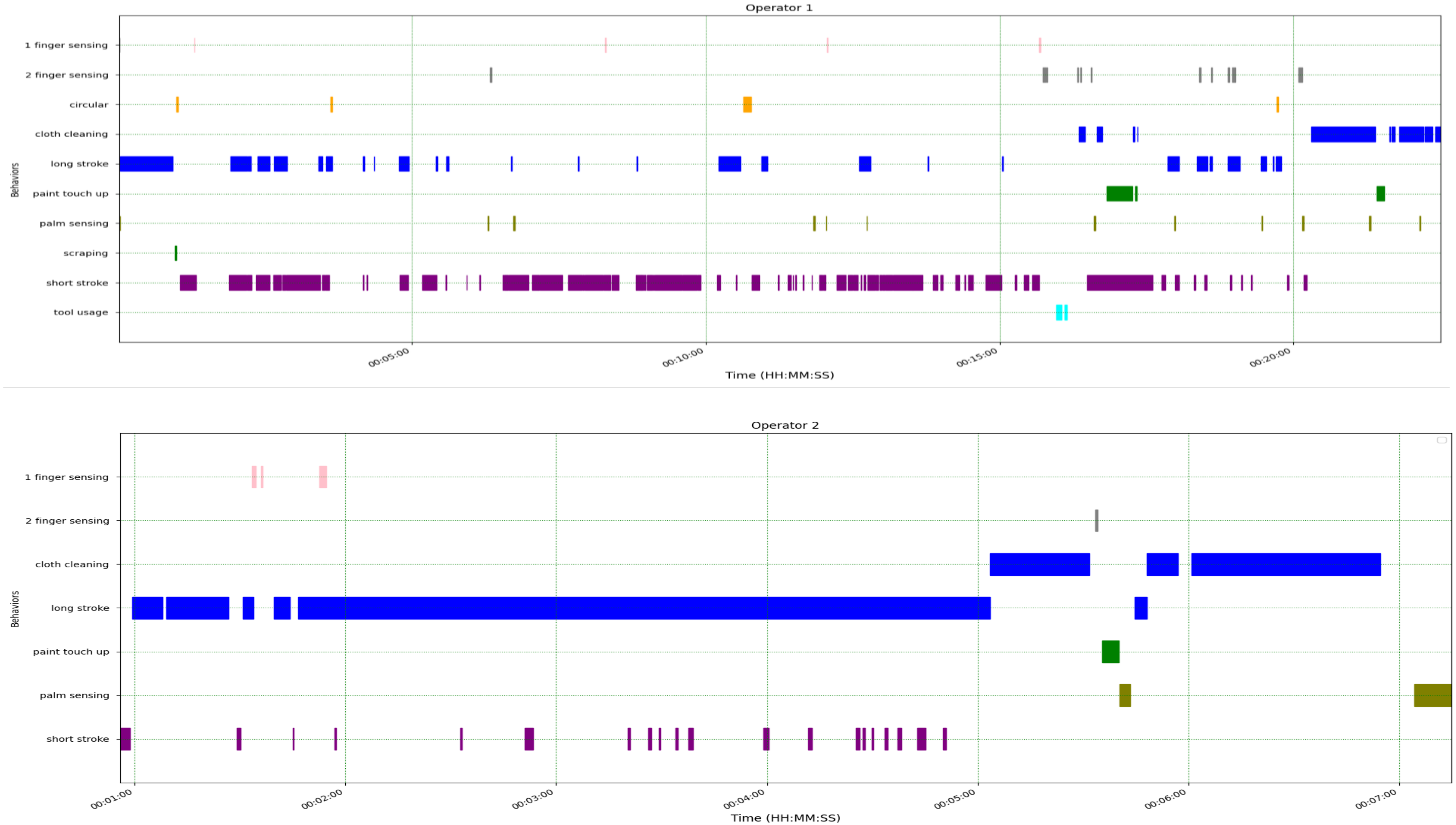

Figure 4:: observation action coding for both operators over the time. The figures indicate the change of motions from start to finish of the sanding of a component.

3.4. ATHENIAN BREWERY

The visit to Athenian brewery consisted of observation of four processes:

1. Sorting
2. Picking
3. Transporting the powder (if inhaled, carcinogenic)
4. Labelling kegs

3.4.1. Picking

The picking process consists of operators receiving the list of pallets of different products (glass bottle crates, can crates or kegs). Unsorted pallets are placed at the end of the warehouse, and once assembled (sorted according to the customer orders) they are moved to the front of the warehouse. This manual process relies on visual information: picking the right boxes according to the order list and placing them on the assembly pallet. Furthermore, the process is physical as beer crates can weight around 15 kg, and barrels between 30 and 50 kg. The operators are trained on safe lifting and there are posters reminding how to lift heavy objects to prevent musculoskeletal injuries.

3.4.2. Sorting crates

For the sorting process operators needs to sort out through crates with mixed beer bottles and collect same-type bottles in the same crates. The facility receives 13 different types of beer, however, there are 7 different types of bottles (the same bottles might be used for different beers). This line relies on subcontractor work, and, from talking with the use case leader, this process is the main bottleneck for increasing production as it is difficult to get enough employees working on this process.

The sorting area consist of 6 work cells and an automated assembly belt in the middle. A single work cell has crates of sorted glass bottles on the left and right, and in the middle a pallet of mixed bottles which needs to be sorted out. Some bottles come with metal caps still on, and operators needs to remove these. As the pallets with mixed crates are kept outside, they can be filled with rainwater and also during winter months with temperatures falling below zero, the glass can become weaker and can shatter in an operator's hands. Due to this, operator wear protective gloves and long-sleeved clothes. Once the crates are assembled with the same type of bottles, they are lifted on the assembly belt and moved for further sorting.

The work pace on this process is fast. Operators receive 2 months training: initially they need to complete 8 pallets per hour, and after a 2-month training period, 16-18 pallets per hour. Quality checks are performed on 5 crates per day (during the training period, one crate per hour).

The process outlined potential issues for the human factors: operators working in these conditions have to deal with potentially shattered glass, water from the bottles, and also manually lifting the crates onto the assembly belt. Although this is not a cognitively difficult job, the emotional and physical impact is substantial and is reflected in workforce shortage on this process.

3.4.3. Transporting

For the brewing process, different powders and substrates are used in the process. One of the powders if inhaled might be carcinogenic and the manufacturing company put forward this process as a potential use case.

The powder for the brewing process is kept in paper bags, which potentially can cause leakages. Although operators wear masks to protect them from inhaling the dust and powder, the potential danger remains.

The operator normally puts paper bags on the conveyer belt which transport it to the semi-sealed machine (the machine is cased with transparent plastic) the machine cuts the bag in half and mixes the powder. While the observation was performed, the machine was broken, and the operators were performing the task manually. The lifting of the bags is performed manually and is repeated once a day/when the new batch of brew is being produced. For each new batch of brew, the operator had to lift 10-12 bags to mix the powder and start the brewing process.

During this process, operators are dealing with the dust particles in the room constantly, and although the machine is glassed off, it is not completely sealed. Therefore, the future of this process should include consideration how to improve not only lifting of the bags, but minimising operator presence in the vicinity.

3.4.4. Label sticking

The final process observed for this use case was label sticking. Once the kegs are filled in, the operator needs to connect the plugs with the tube for the beer, and label each keg. The process was observed while the operator was wearing the eye tracker with four areas of interest: the plug, the operator’s hand, the barrel surface and the barrel opening. The fixation duration analysis was performed on the three steps of the process: (i) attaching the plug, (ii) fixing the pipe, and (iii) sticking the label (Figure 5).

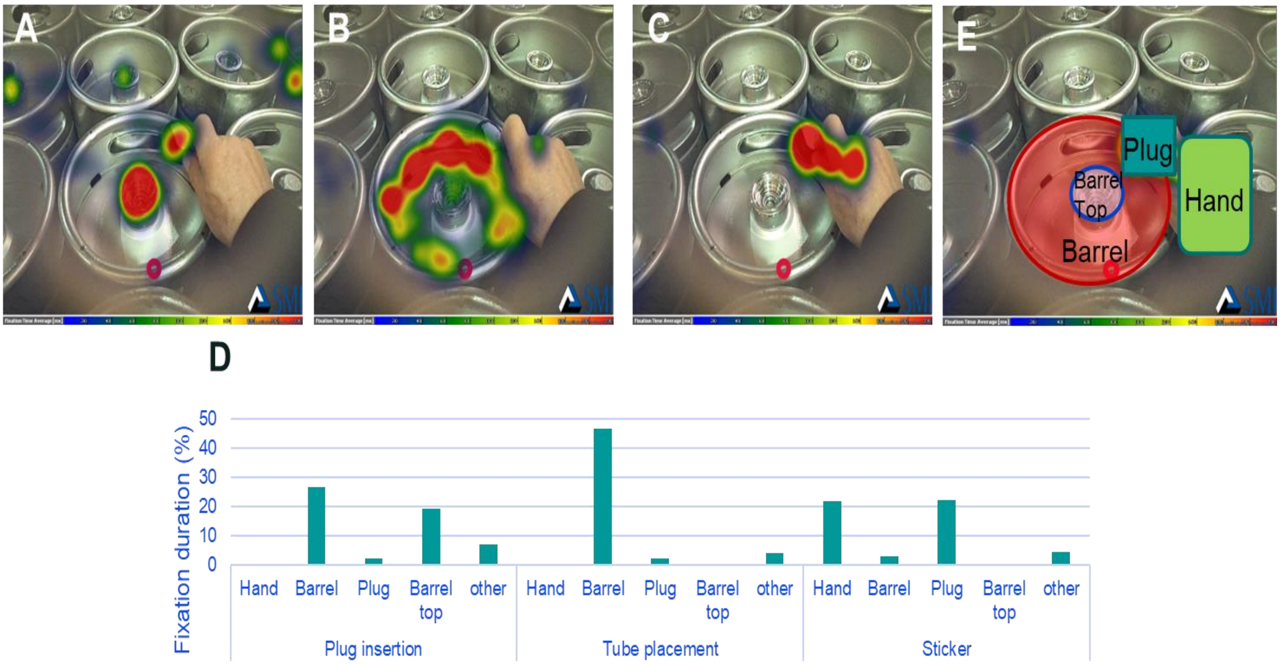

Figure 5:: Eye tracker results: heat map of dwell time for (A) attaching the plug, (B) placing the pipe, (C) sticking the label. (D) Plotted statistics of fixation time (%) in these AOI as a function of process stage. (E) Defined Areas of Interest

The heatmap revealed great reliance on visual information in each step as operator gaze rarely went outside the AOI locations. However, the interview with the operator also indicated that completion is dependent on procedural knowledge. While attaching the cap, operators need to locate the pin in the opening and insert the plug diagonally starting from the pin. Furthermore, the insertion of the tube around the top of the keg is also dependent on the pin location. The final stage of sticking labels requires dexterity to speed up the process as the operator utilises all 4 fingers and attaches the labels simultaneously.

3.5. SILVERLINE

The proposed process in the SILVERLINE use case was the extractor fan grounding, visual inspection, and labelling. Each process is performed by one operator within the same workcell and, although eye tracker data was collected on all three processes, further investigation was performed on grounding and visual inspections processes.

3.5.1. Grounding testing

The operator for this process collects the component from the automated moving assembly belt and performs grounding test as well as positioning labels inside the component (hood) corresponding to the model and make. For the eye-tracking analysis six AOIs were defined: the component; inside the component, the plug (mainly used for ground testing and then to tie the lead), the scanner for the label scanning), and the testing screen.

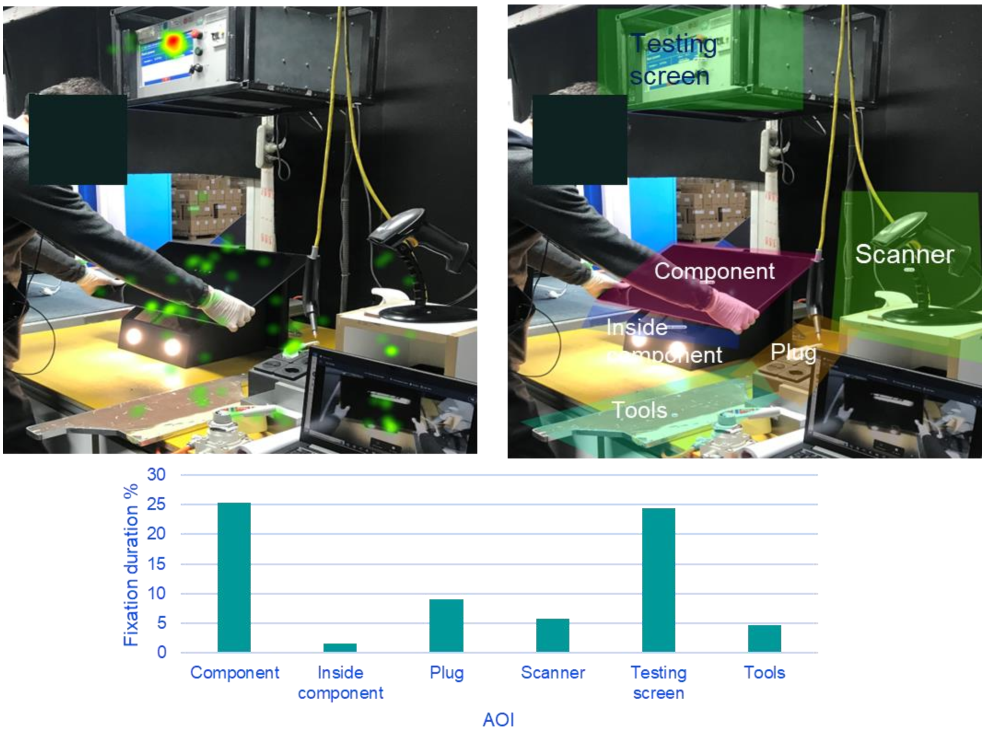

Figure 6: Eye tracker results: (top left) heat map of fixation time (bottom) Plotted statistics of fixation time (%) in these AOI. (top right)) Defined AOIs

The fixation durations reveal that the operator spends a similar amount on the visual inspection of the component (component AOI) as well as confirming the results of the grounding test (Testing screen). The focus on the inspection of the inside of the component, and plug (inserting electrical plug for testing), as well as scanning the label required less visual attention and focus from the operator.

3.5.2. **Visual inspection**

The second stage in the workcell is the visual inspection of the component. The operator inspects the component for any physical faults (scratches, damages, dents) inside and outside of the component. For this reason, the AOIs were defined as the top of the component, sides of the component, front and back of the component, and the inside of the component (Figure 7). The fixation durations show that the operator spends most of the time inspecting the top of the component, followed by inside inspection. Although the inspection relies heavily on visual information, is also reliant on tactile sensing, in particular around the component edges.

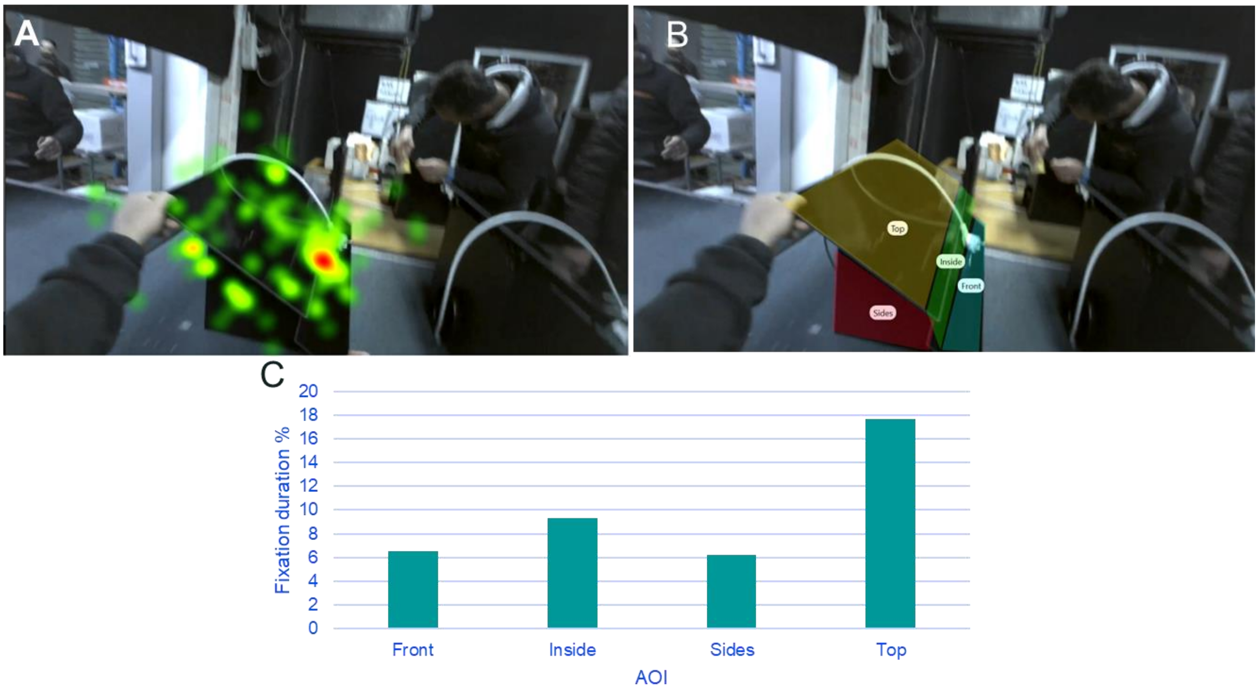

Figure 7:Eye tracker results: (A) heat map of fixation time (B)) Plotted statistics of fixation time (%) in these AOI (E) Defined AOIs

The analysis of two work processes indicate that although within the same work cell some steps are being duplicated which might be increasing the workload for the operators. For example, both the grounding test and visual inspection spent the most time inspecting the top of the component. Including this step only in one process might allow the operators to utilise their time for other tasks increase efficiency and allow operators to specialise on other processes.

4. CONCLUSIONS AND FUTURE WORK

The discussed use cases outlined the main human factors and psychology aspects involved in each use case. The majority of the use cases involve physical discomfort and mental stress. Although in the majority of use cases these two are related, tackling the physical aspect is likely to improve mental pressures experienced by being exposed to potentially unhealthy and unpleasant elements. Furthermore, the use cases indicated the importance of the operator's feeling of self-efficacy and satisfaction with their work. Although this directly impacts on the job performance, it also has an impact on organizational commitment and affect workforce sustainability.

The following steps include the data collection via psychometric questionnaires to assess their individual, cultural and social aspect affecting technology engagement. The proposed list of questionnaires corresponding to the factors outlined in the use cases is as follows: General trust in technology questionnaire (Ejdys, 2018), Situation awareness (Taylor & Selcon, 1990), Trust, organizational commitment and personal need scale (Cook & Wall, 1980) , Physical discomfort scale (Corlett & Bishop, 1976), Mental workload NASA TLX (Hart & Staveland, 1988), Technology Readiness scale (Rose & Fogarty, 2010) and the Self-efficacy scale (Schwarzer & Jerusalem, 1995).

Finally, the final stage of user engagement is development of the workshop to explore what solutions could be made for the existing uncomfortable aspects of the process. The plan is included in deliverable D10.1. As the operators are non-native English speakers with varying degrees of English proficiency, the workshops are being designed to rely on minimal verbal information and provide hands-on activities with visual props to encourage the development of the solutions. The developing workshops are being based on work conducted for developing visual signage (Eimontaite, 2022; Gwilt et al., 2018) and using LEGO to increase stakeholder buy-ins (de Saille et al., 2022). This approach has previously been successfully used for the intermediary between robotics engineers and shopfloor operators, resulting in greater user acceptance of the new processes (Eimontaite et al., 2022) as well as an impact on greater trust in human-robot interaction (Cameron & Collins, 2021). Thus, the expected outcomes of the engagement programme are: (i) increased level of user engagement and acceptance of the new processes; (ii) increased technology readiness levels and greater trust in automation, and (iii) more transparency in the changes of the processes and assembly resulting in greater organizational commitment.

ANNEX A: References

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