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Document Authors

Partners	Contributors
AIDIMME	María José Núñez, Javier Martín, Amparo Roca
AIRBUS	Manuel Oliva
COMAU	Jacopo Baldoni
ROYO	César Martín, César Taboas
SSSA	Lorenzo Grazi
IUVO	Giulio Proface
LMS	Nikos Dimitropoulos

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Document Approvers

Partners	Approvers
KIT-AR	Manuel Oliveira
HOLONIX	Eva Coscia

Executive Summary

The deliverable reports the current status of the ongoing evaluation studies. Consequently, it contains the insights into the initial evaluation studies carried out at each of the three industrial pilots, namely Airbus, COMAU and Royo Group, and the plan for the upcoming evaluation sessions, following the methodology reported in D7.1 Evaluation Methodology. A final version of the deliverable, with all the studies conducted along with analysis and discussion of results, will follow at the end of the project in M36.

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Acronyms

Acronym	Explanation
AR	Augmented Reality
VR	Virtual Reality
PI	Performance Indicator
EXOS-APO	Exoskeleton Service - Active Pelvis Orthosis
EXOS-UL	Exoskeleton Service - Upper Limb
WOS	Workplace Optimization Service
KIT	Knowledge in Time
SII	Shopfloor Insight Intelligence
OAST	Operator Awareness and Support Tool
STRE	Short Term Reasoning Engine
LTRE	Long Term Reasoning Engine

1. INTRODUCTION

WP7 is focused on the evaluation methodology and how to apply it to the different use cases at each of their three industrial premises. It reports the initial results of the analysis of the evaluation studies carried out. D7.2 is the introductory work which documents the preliminary steps into the evaluation of the HuMan solution. It encompasses the work performed in the three end-user evaluation tasks: T7.2 COMAU, T7.3 Airbus, and T7.4 ROYO, and most importantly the Evaluation Analysis and Insights tasks, T7.5, which collects and analyzes evaluation data from the three end users.

D7.2 also brings together the work performed in WP6, Integration and Validation in Pilots, and especially in D6.4 HuMan pilots, which corresponds to the testing of the HuMan services at the end user premises.

Finally, D7.2 presents concisely, and from the pilots point of view, evaluation sessions and opinions of the services to date, preceding the way to the final deliverable D7.3 which will include all final evaluations from this point on and until the end of the project.

1.1 PURPOSE AND SCOPE

The objective of this deliverable is to illustrate the work done to date, together with the future plans about assessing the HuMan solution which will serve in the above mentioned tasks as an instrument to perform a comprehensive final evaluation of the HuMan technological solutions at the three industrial plants.

Figure 1 - The three HUMAN industrial pilots

Before going further, it is important to give the reader some HuMan technical definitions taken from deliverable D1.4, Reference Architecture, which are used later in this document.

A HuMan service offers solutions for either short term or long term intervention requests. The level of support is regulated by interventions triggered by the HUMAN Core that takes into account the context as defined by relevant factors such as task, operator, time, etc.

A short-term intervention is an intervention with immediate impact in the workplace and on the operator, which is triggered automatically, whereas a long-term intervention is triggered when no short-term intervention is able to remove or mitigate the detected deviation, or when short-term interventions must be used continuously by a wide range of users. A long-term intervention always requires the intervention of a person, possibly an engineer or manager.

Long/short term decisions are those that are made to deliver the most appropriate intervention.

The Intervention Manager is part of the HuMan core and has three roles. These are detection, where the intervention manager analyses the signals triggered by the models to detect anomalies and deviations; reasoning where the intervention manager needs to reason what type of intervention is necessary and whether the context warrants triggering; and coordination in which in a particular instantiation of the HUMAN solution, there may exist a number of interventions, some with conflicting strategies to address a particular context. Therefore, the intervention manager is required to manage and coordinate the different interventions.

The following table gives a brief outline of each of the HuMan services currently being evaluated.

Table 1 - Description of the HuMan services

HuMan SERVICE	Description
Knowledge in Time (KIT)	KIT provides onsite support to the actions of operators. It is a short-term intervention that consists of an Augmented Reality (AR) system which will assist the operator by providing "in-time" cognitive support. This service will monitor the current progress of a worker, assess when the operator requires cognitive assistance, and provide it in the form of an augmented reality display.
Exoskeleton (EXOS)	The Exoskeleton Service is one of the services of the HuMan platform which is intended to support workers during some of the most physically demanding working activities. Its main objective is to deliver an intelligent assistance to the operators during repetitive and/or continuous tasks. Therefore, the goal is to reduce the physical stress or fatigue of workers and as a consequence to reduce possible work-related musculoskeletal diseases or injuries that can occur and, by doing so, increasing workers' well-being at work. The service consists on two different exoskeletons, namely an upper-limb (EXOS-UL) and a pelvic exoskeleton (EXOS-APO) and it also includes software modules to establish the integration between exoskeletons, wearable devices and the HuMan platform. On top of that, other components take place such as a broker-based communication system part of the HuMan core, and wearables for physiological monitoring of worker psychophysiological status and for interacting with the HuMan system, bieng this part of the sensing layer of HuMan. Within the project, there are two industrial use-cases where the EXOS are applied: Airbus and Royo. In the first case, the EXOS assists operators during operations requiring the worker to keep his/her arms elevated for prolonged time per shift; in the second case, the EXOS provides assistance to operators

	performing heavy load lifting operations. From the service point of view, the only component that differs one pilot from the other concerns the type of exoskeleton used to support the workers: Airbus' operators test an upper-limb exoskeleton (EXOS-UL), while Royo's workers test a pelvic exoskeleton (EXOS-APO).
Shopfloor Insight Intelligence (SII)	SII is a process mining service which uses all data collected by the HuMan system and services for exploratory data analysis. The purpose of data analysis with the SII is to support the long-term decision making regarding the work processes and the design of the workplace.
Workplace Optimization Service (WOS)	WOS is a HuMan service that is triggered as a long-term intervention, when short-term interventions are ineffective or inadequate, so as to make improvements in the workplace. This service promotes the collaboration of two actors, namely the workplace engineer and the operator. It utilizes Virtual as well as Augmented Reality in order to provide to the engineer all the necessary tools to simulate real manufacturing environments and processes, access them, modify the virtual workplace and check for the effectiveness of the modifications in terms of ergonomics, usability and efficiency. For better allocation of the workload, WOS is the outcome of two Tasks, namely: • Shop Floor Visualization and Simulation Service (T4.3) • Collaborative Workplace Design Tool T(5.5) The first one is the component of WOS that allows the immersion of the workplace engineer and the operator in a virtual shop floor. The module has two main modes, the simulation mode where the operator may perform the task, and the design mode where both actors are able to visualize and alter the layout of the workplace in a collaborative way. The changes can also be visualized and superimposed to the actual shop floor, using Augmented Reality, in order to perform clash analysis. The outcome of the second task is to provide the engineer all the necessary tools to be able to analyze the ergonomics, the usability and the efficiency of manufacturing environments, and check for improvement after the workplace redesign. The predominant functionality of this tool is the Spaghetti Diagram creation method, the ergonomic assessment as well as some auxiliary decision support tools that will support the engineer in the context of continuous workplace improvement. Within the project, WOS is applied to a reference use case from COMAU (assembly of a robotic wrist).

Figure 2 summarizes all HuMan services in a diagram fashion. Notice that SKN, Social Knowledge Network, even though part of the HuMan solution, is not part of the evaluation, and therefore, it won't be tested by the end users. This is due to end users internet security policies to access internet outside their domains.

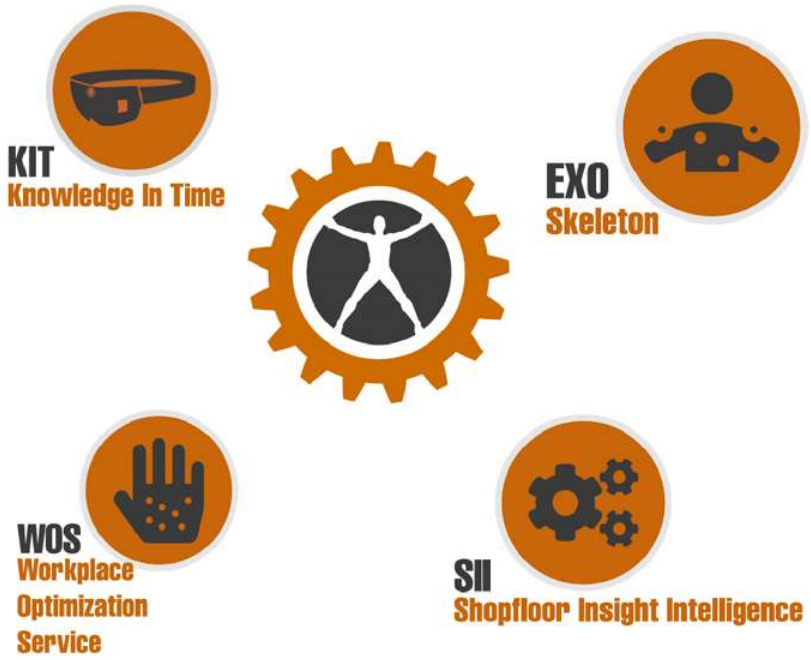

Figure 2 –Services integrated and deployed as part of the HuMan system to be evaluated by users.

1.2 RELATION TO OTHER HUMAN WORK PACKAGES AND TASKS

From the one side, this deliverable is framed within the T7.2, T7.3 and T7.4, from the other side it is also linked to T7.5. It gathers the work done to date for this work package, and as shown in Figure 3, both WP1 and WP6 are directly linked to WP7.

WP1 as requirements, user needs and framework package will provide a set of measurable PIs to assess the impact of the HUMAN solution that will filter down into the methodology devised here. Alternatively, WP6 will output different customized instances of the HuMan solutions that will have to be evaluated by the end users for the technical testing executed in task T6.4.

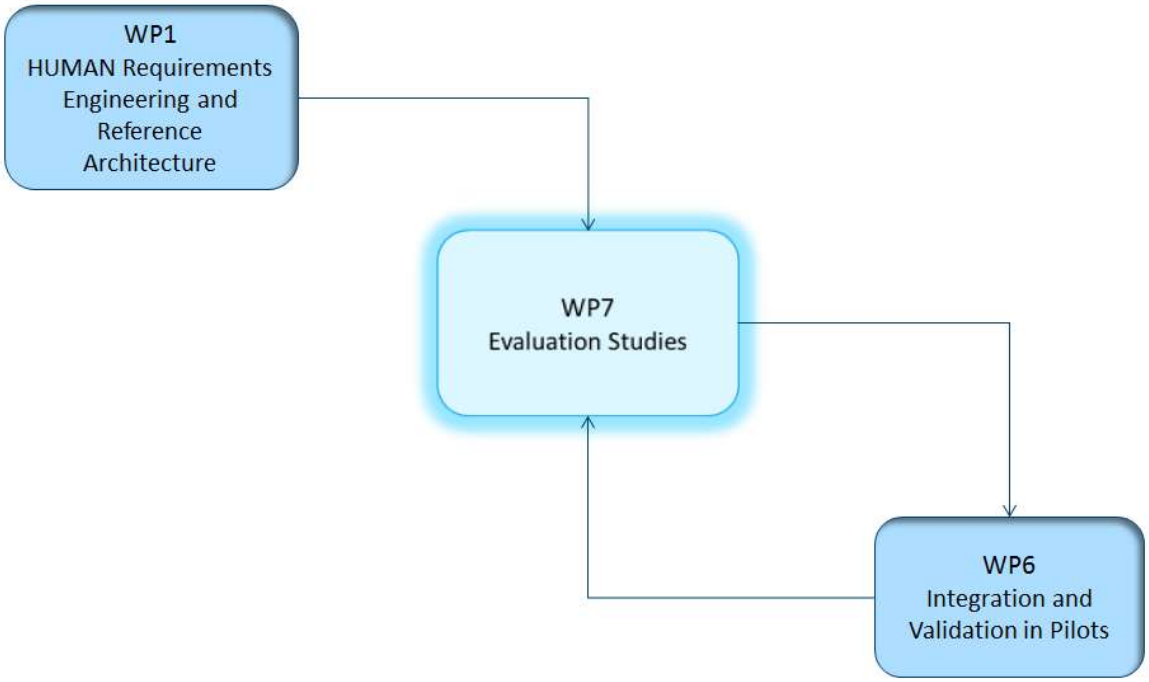

Figure 3 – Main relationship between WP7 and the other HuMan WP

1.3 STRUCTURE OF THE DOCUMENT

This deliverable is structured according to each end-user organization and gathers the primary results of WP7 tasks to date. It shows the current challenges and the current AS-IS situations that need to be addressed, identifying the problems to be solved, and the summary of the sessions by service held. In addition, plans for the final evaluations are described at the end of this deliverable.

2. REPORT OF THE EVALUATION RESULTS

This section documents the experimentations and evaluations of each of the end users to the date of submission of this deliverable. Different services are currently at different stages of evaluation since some of them have undergone more testing than others such as preliminary acceptance testing and UI usability testing.

Evaluation sessions may consist of one or more studies, each of which may entail multiple evaluation activities that need to be described in detail to allow for credible and realistic planning of the remainder months of the project. A complete service evaluation involves multiple stages such as data collection, technical testing, UX testing, formative evaluation and a final evaluation. Most of the sessions documented in this document are initial evaluation visits. Some of them have been a first contact between end user and service, and therefore they are excluded from this document since they cannot be considered experimentation sessions. The full comprehensive evaluation will fall under D7.3.

2.1 ROYO PILOT

ROYO is a multinational bathroom furniture manufacturing company with 9 assembly and packaging lines, sited in their 3 production facilities (3 different shop floors). The use case is concentrated in those production lines, where employees are working with different automation machinery. HuMan will try to facilitate the human-machine interaction, primarily to improve the quality of life and wellbeing of the workers.

For that purpose, ROYO's experimentation will be carried out with the following HuMan Services:

- KIT
- EXOS-APO
- OAST (officially started on the 1st December 2018 so no experimentations done so far)
- SII

2.1.1 CURRENT AS-IS TO BE SOLVED AND OBJECTIVES

Royo has two main areas at shopfloor that are the subject to the HuMan services test. The first area of interest is the **palletization area** where workers must move heavy boxes from the conveyor onto the pallets. Boxes come in a random fashion from different assembly lines, and are piled up and grouped onto the pallets manually. This is a perfect scenario for EXOS-APO and OAST.

The HuMan EXOS-APO service assists workers during the cumbersome task of piling boxes onto pallets, reducing the level of effort by the extensor spinae muscles. The **objectives** initially envisioned by this service are:

- Reduce the fatigue of the line workers
- Increase the speed of the line (improve productivity)
- Increase work periods in the workplace without the need to interchange positions
- Improve the comfort of workers while working in the palletized area

The palletization area is also the scenario where OAST will be applied. This tool will guide workers at the palletization area so as to find the right pallet and place the unit correctly on it, increasing his awareness of possible erroneously executed tasks. Thus, this will minimize the time needed to execute the task at hand, decrease the mental stress and physical fatigue of the operator. The **objective** envisioned by this service is:

- to improve worker conditions both physical and psychologically (reducing mental stress). The assessment is envisioned to be achieved thtough questionnaires as the component is not connected to the HuMan system.

The second area of interest for HuMan is the **assembly area**. For this area, the KIT and SII services are used. KIT service uses AR to offer workers wearing Microsoft HoloLens that results a step by step guidance on how to assemble furniture. All this data produced by KIT will be fed into the SII service which will perform process mining providing important analytics that will help to improve processes.

- The **objective** initially envisioned by these services is to reduce time of training (New workers or new products).

2.1.2 HELD SESSIONS

At the time of this writing, there have been three sessions to test the services at Royo premises: one initial for the exoskeleton service and two for the KIT service.

EXOS-APO SESSION 1:
Date: April 19-20, 2017.
Location: Royo Headquarters in Quart de Poblet, Valencia, Spain.
Partners involved: AIDIMME, SSSA, IUVO, and COMAU.

ROYO hosted a meeting with the aim of making a live demonstration of the current available exoskeleton prototypes, namely a full-active lower limb exoskeleton (APO) and a passive upper-limb exoskeleton (UL). It is worth noting that both exoskeleton prototypes APO and UL shown in this session were devices developed before and outside the framework of the HuMan project, and that were used just to show the working principles and potentiality of such devices. The final goal was to collect some technical and functional specifications for the development of the HuMan exoskeleton in Royo use-case scenario. The agenda included a presentation of current exoskeleton prototypes, a demo with Royo-AIDIMME team and workers, and a discussion on technical and functional improvements toward the HuMan exoskeleton and summary of the results.

The first day of activities was structured as follows:

- A brief description of the current exoskeletons. SSSA and IUVO did a presentation on the exoskeletons followed by a session of live demonstrations where Royo team members (also including a senior and experienced worker) tested both the lower and upper-limb exoskeletons.

- A visit of the plant in order to better understand where in the production line an exoskeleton would be applicable.
- A session of live demonstrations with workers working on the production line. At least three workers tested both the devices, while doing real working tasks (i.e. moving heavy boxes from the conveyor belt to the pallet at the palletization area, mounting components of bath furniture).

Figure 4 - A Royo employee testing the APO (pre-HuMan prototype)

The second day of activities included:

- A visit of another plant of Royo in order to have a better and overall vision of all the manufacturing processes performed in Royo factory.
- A discussion on technical and functional requirements and a summary of the results of the meeting.

This session was used as a requirement collection and a pre-validation of the device with the task to be carried out.The outcome of this session resulted on the final decision on which type of exoskeleton would be more useful and effective in Royo's industrial scenario. Indeed, it was clearly evident the most critical working activity, from the physical effort viewpoint, is related to the palletization area, where operators have to pile several boxes per shift into pallets. Therefore, it was decided that the EXOS applied to Royo's pilot would use would use a pelvic exoskeleton.

KIT SERVICE SESSION 1:

Date: January 15th, 2018.
Location: Royo Headquarters in Quart de Poblet, Valencia, Spain.
Partners involved: AIDIMME, UCL, Sintef, and HighSkillz.

The main purpose of this session was to assess the usability of the KIT service, but additionally, the session had the following two purposes:

- Test the usability of wearing the different sensors, namely the thermographic camera and Empatica[1].
- Collate sensor data.

The devices used in the study were the following:

- HoloLens[2]: a total of three devices are available, two by UCL and one by HighSkillz.
- Empatica: two devices from UCL.
- Myo: one device from UCL.
- Hero camera: one from Sintef, possibly with a tripod.
- Thermo-Camera: one from UCL, with the supporting structure to attach to a HoloLens.

The data collated were:

- HoloLens: head orientation.
- Eye tracker: eye movements.
- Empatica: blood volume pulse, galvanic skin response, 3-axis accelerometer data.
- Myo[3]: EMG (Electromyography) muscle movements.
- Video: contextual information.
- Thermo-Camera: breathing temperature.

Every participant underwent the experiment with the two configurations of the devices, with the distinguishing factor being the thermographic camera. The study required each participant would undergo two evaluation sessions, one for each configuration of the devices. The participants experienced the KIT service as “Normal” where the participant was asked to assemble three units without constraints on time, and “Stress”, where a stressor was used to induce stress and anxiety to the participant. The study showed that:

- The physical setup involved gearing a participant with the devices. In addition, the participant was walked through some of the key features of the interaction mode.
- At the end of each unit pre-assembled, the participant was asked to fill the stress scale.
- The total time duration of a study session was 75 minutes (1.15hours) with a buffer of 15m, so total is 1.5hours.
- All participants underwent the study with configuration A and then with configuration B of the devices.
- The condition related to interaction mode was counterbalanced

[1] https://www.empatica.com/research/e4/
[2] https://www.microsoft.com//hololens
[3] https://support.getmyo.com/hc/en-us

Figure 5 – Royo worker testing the KIT service at the work area

A total of six subjects were necessary for the study, divided into two groups. One group was allocated to the mornings and the other group to the afternoons. The subjects were of mixed experience in assembly of furniture. The work area consisted of a table with the necessary surface area to allow each participant to carry out the pre-assembly of the furniture. The work area had the assembly area in the middle, with the sides being used for the different parts. The participant focused on the pre-assembly, thus the supply of parts and the removal of the unit once pre-assembled was done by someone. This person assisting the participant was either from Royo or AIDIMME.

KIT SERVICE SESSION 2:

Date: April 10th, 2018.
Location: Royo Headquarters in Quart de Poblet, Valencia, Spain.
Partners involved: AIDIMME, UCL, Sintef, and HighSkillz.

The main purpose of this session was very similar to the previous one, but this time using a more mature KIT service.

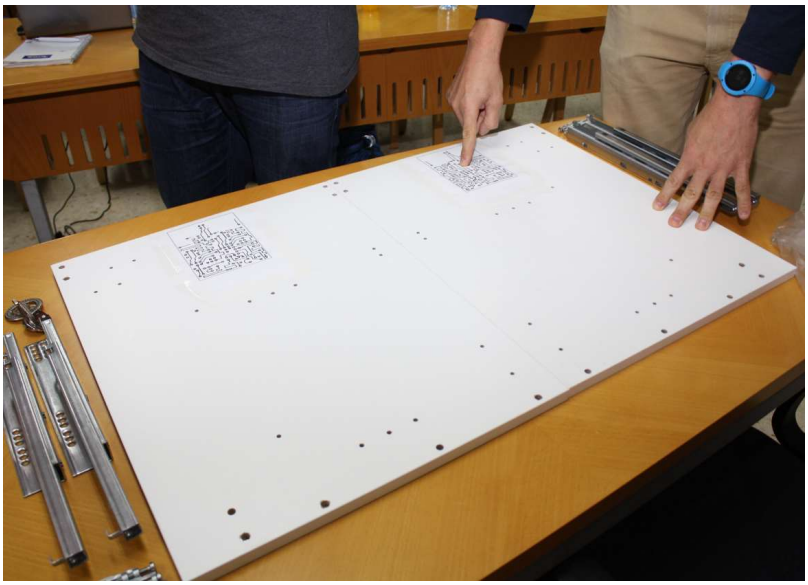

Figure 6 – Initial setup of the the work area for the KIT service session 2

2.2 AIRBUS PILOT

Airbus is an international pioneer in the aerospace industry. Airbus is leader in designing, manufacturing and delivering aerospace products, services and solutions to customers on a global scale. HuMan project is developed within the Airbus Defense and Space in Spain sites. The use cases are focused in the areas of aircraft assembly to help operators within their daily tasks by improving their wellbeing and human machine interaction.

For that purpose, Airbus experimentation will be carried out with the following HuMan Services:

- KIT-AR
- SII
- EXOS-UL

2.2.1 CURRENT AS-IS TO BE SOLVED AND OBJECTIVES

The particularity of aircraft products at Airbus is the low production rate of deliveries (less than 800 per year) and the high complexity to manage the production. The number of parts per aircraft is around 700.000 and the interaction between the different areas (engineering, production, services) is also very complex. Aircraft production at shopfloor requires a big effort to keep the line under constant progression and providing help to operators becomes a key aspect to consider.

AIRBUS use case for the exoskeleton is focused on assembly operations where the operator physical stress is impacting the upper body. Examples of this are drilling or clamping operations where the operator has to keep their arms in high positions for long periods of time during a shift. These types of operations do not require lifting heavy elements, just tools such as screwdrivers or scissors.

The **objectives** initially envisioned by this service are:

- Reduce fatigue of the line workers

- Reduction of operation execution
- Increase work periods in the workplace without the need to interchange positions
- Increase well-being of the workers
- Improve workers engagement

2.2.2 HELD SESSIONS

At the time of this writing this deliverable, there have been two sessions to test the EXOS-UL service at Airbus premises: one initial for requirements and use cases and another for the exoskeleton service. No sessions for KIT-AR have taken place yet.

EXOS-UL SERVICE SESSION 1:
Date: March 20-22, 2018.
Location: Airbus, Tablada site, Seville, Spain
Partners involved: AIDIMME, Holonix, SSSA, IUVO, Airbus.

The main purpose of this session was to preliminary test and assesses the usability of the EXOS. During this session, the following components were used and tested:

- the upper-limb exoskeleton developed by IUVO and SSSA;
- The software service to integrate the EXOS-UL with the HuMan Core, developed by HOLONIX;
- the wearables for physiological data collection (Empatica E4) and for communication (Huawei Smartwatch 2) and the sensing layer to collect them from these devices developed by HOLONIX;
- an app installed on the smartwatch, to provide suggestions to the worker and receive feedback, developed by HOLONIX;
- the broker-based communication (MQTT).

The main objectives were therefore:

- test the usability of using the wearables and wearing the exoskeleton during normal working activities;
- check that the integrated system works in the real environment.

Three male workers (age: 44 ± 7.2 years) volunteered to participate to the testing session.
Each worker was introduced to the experimental session with proper and detailed explanation given by SSSA-IUVO-Holonix team members about the following aspects:

- goal of the test;
- how the exoskeleton works;
- how the whole system works (notifications from the system through the smartwatch, change of the assistance level from the exoskeleton).

Then, the worker was allowed to familiarize with the exoskeleton by performing some operations in order to learn how to use it and profit from it.
Since at the time of this experimental session the Intervention Manager was still on development, the output of the Intervention Manager (i.e. the suggestion to change the level of assistance

delivered by the exoskeleton) was decided by the experimenters; in this way the communication between the HuMan system and the worker was tested, however.

Based on the job schedule of each worker, three different operations were performed:

- operation #1: passing cables in the upper part of the fuselage,
- operation #2: riveting with a light tool,
- operation #3: upper panel assembly inside the cockpit.

Figure 7 – Airbus operator working with the EXOS-UL.

At the end of the testing session, the worker filled some standard and ad-hoc questionnaires about:

- perception of the task load (NASA TLX);
- usability of the exoskeleton (System Usability Scale, SUS);
- technical questions:
    - wearable devices (adoption, notifications and feedback),
    - exoskeleton (comfort, usability, effectiveness).

Questionnaires were then administered to the workers involved in the experimentations. See Appendix A.

Other specific questions were asked to participants in order to understand if the technological solutions proposed were well received by the workers. The feedback provided by workers was then used to refine the development of the service. A set of questions was asked for each wearable . Each set covers aspects related to the acceptance of the wearable, i.e. its adoption by the user, and the type of notifications and feedback it provides back. An example of such questionnaires is listed below:

ADOPTION

- Do you think that the wearable device could interfere with your normal working activity?

- Do you think that the wearable device could raise safety issue along your normal working activity?
- Would you accept to wear it for the whole duration of the shift?
- Did you feel uncomfortable with them? YES/NO
    - If YES: when? After how much time?

NOTIFICATIONS and FEEDBACK

- Is the notification mechanism adequate to be perceived during the normal working activity?
- Do you have suggestions to improve it?
- Would you accept to have further interaction with the system through the smartwatch, for example to communicate that you are going to put on/put off the EXO, that you need assistance, that you have completed an activity?
    - If NO, why?
    - If YES, which mode of interaction would you accept?
        - Interacting with an app, touching the screen
        - Voice command

- Would you like to provide feedback to the system on the usage of the EXO using the smartwatch? YES/NO
    - If YES: When?
        - Immediately after having finished the task, also through the smartwatch
        - Before living work, better on a smartphone

The questionnaires measuring worker's perception about comfort, usability, and effectiveness of the upper limb Exoskeleton were administered and can be found in Appendix A.

Tests carried out in the two sessions where performed at the Airbus C295 IFA and A400M HTP aircraft areas showing the high interest by the operators and managers in such device. Although some tests showed in the first EXOS session that for tight or enclosed areas the device was not valid due to the difficulty of movements, for other roomier areas, the experience was qualified as of very helpful by operators and managers. The tests were not performed as in a day to day real situation and also because the tasks where not of a long duration it was not possible to determine if an operator would need the service to trigger the exoskeleton. In this case, a researcher simulated the trigger manually in order to tell the operator to start using the exoskeleton. This trigger was recognized by the operator and turned on the exoskeleton to support him during the task.

The outcomes of the questionnaires distributed among the workers were used by the technical partners to evaluate the current status of the EXOS and then to identify which could be the next development steps in order to improve the system tested at this phase of the project.

In particular, the ad-hoc questionnaires were specifically used, for each of the devices used (i.e. the Empatica, the smartwatch and the exoskeleton), to have feedbacks related to the possibility of adopting these devices during normal working activities. These feedbacks also included the usability and effectiveness of the technology presented.

2.3 COMAU PILOT

Comau is a leading company in the industrial automation field at a global level. Combining innovative engineering solutions with easy-to-use, open automation and enabling technologies. Their use case focuses on the simplification and personalization of the access and worker contributions to instructions and details on the tasks to be performed.

For that purpose, Comau's experimentation is to be carried out with the following HuMan Services:

- KIT
- WOS
- SII

2.3.1 CURRENT AS-IS TO BE SOLVED AND OBJECTIVES

COMAU has a low volume production with high mix and variability of parts to be assembled; therefore the areas of improvement can be divided in 5 main groups:

1. Increase guidance for the operators while performing their tasks.
   Several operations are customized for every variant of product.
2. Improve the accessibility of information throughout the workflow.
   Assembly procedures are written on paper and it takes time to find the right information at the right time.
3. Create assembly sequences driven by the customization level required by the different operators.
   Assembly procedures are standard and do not adapt to the different needs of the operators or the stress level of the particular worker.
4. Create a training material on the job tool.
   One of the most common sources of errors in the assembly phases are connected with inexperience of newbies.
5. Improve the process of optimization of the workplace through Augmented Reality.
   Optimization activities are usually implemented on the finished work station. Augmented Reality tools can improve the process and reduce possibility of errors.

The **objectives** that COMAU wants to address by applying the WOS and KIT services are:

- Non-Conformity rate reduction: The Non-Conformity rate is the principal KPI that is used to assess the performance of the production line. It is affected by all the events that shape the assembly process and it is the main parameter used to assess the quality level in the Manufacturing area.
- NVAA reduction: NVAA stands for Non Value Added Activities, and its measurement is obtained using Spaghetti Charts that map the movements of the operator in the assembly station.
- MURI-MUDA scores improvement: Improvement in measurements of posture and ergonomics are important factors in order to determine health related issues.

2.3.2 HELD SESSIONS

There has been one session to test the WOS service at the COMAU premises.

WOS SERVICE SESSION 1:

Date: 5-7 November 2018.
Location: COMAU premises, Turin, Italy.
Partners involved: LMS and COMAU.

The main purpose of this session was to conduct a training workshop as well as perform preliminary tests, in order to access the usability of WOS and receive feedback to improve the service.

The devices used in this study were the following:

- Oculus Rift headset: one device from LMS
- Oculus hand controllers: two devices from LMS
- Oculus sensors: three devices from LMS
- Microsoft Kinect sensor: one device from LMS

A total number of ten (10) subjects participated to this study, divided into two groups; operators' group and engineers' group. Five (5) workers and five (5) engineers participated to this study, testing the currently developed components of WOS. Two questionnaires were prepared by LMS and filled in by the subjects, one for the workers and one for the engineers.

Day one (5 November 2018)

The first day was dedicated to setup the demo. Two colleagues from LMS performed the demo setup, placing all the necessary sensors to the appropriate positions and calibrated all the sensing equipment.

Day two (6 November 2018)

On the second day the operators tried WOS. As mentioned before, five (5) operators tried WOS and provided their feedback through the form of questionnaires and verbal feedback. Each of the operators had about one (1) hour to assign to the testing session (five hours in total).

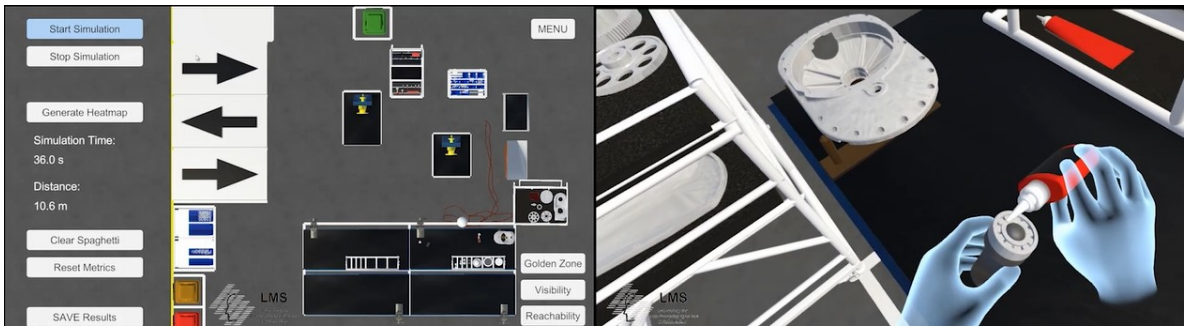

Figure 8 - Virtual reality WOS experimentation

Initially, LMS provided a detailed explanation regarding the goals of the experimental session.

This was followed up by a training session were operators received visual and verbal instructions on how to:

- Mount and use the Virtual Reality hardware
- Interact with the Virtual Environment
- Perform the simulation

Then, each of the operators put on the VR equipment and got familiarized with the virtual environment. Each of them performed a virtual assembly of a robotic wrist, with the LMS colleagues, at the role of the engineer, guiding them through the whole process. Finally, questionnaires were filled in by the operators. See Apendix A.

The same procedure was followed for each of the operators (each subject tested WOS individually).

Day three (7 November 2018)

Five engineers tried WOS and provided their feedback through the form of questionnaires and verbal feedback. Each of the engineers had about one hour to perform the testing session (five hours in total). Initially, LMS provided a detailed explanation regarding the goals of the experimental session. This was followed up by a training session were engineers received visual and verbal instructions on how to:

- Use the assessments and tools of WOS
- Use the engineer's user interface (UI)
- Mount and use the Virtual Reality hardware
- Interact with the Virtual Environment
- Perform workplace redesign inside the Virtual Environment

Then, a person from LMS, at the role of the operator, performed an assembly simulation while the engineer observed him using the engineer's UI. Following, the engineer put on the VR equipment and got familiarized with the virtual environment. After that, he performed a virtual redesign of the workspace. Finally, a questionnaire for engineers was filled in. See Apendix A.

The same procedure was followed for each of the engineers (each subject tested WOS individually). Feedback in general was positive both performing assembly simulations and virtual redesign of the workplace in order to improve the process of optimization of the workplace.

3. NEXT STEPS FOR FINAL EVALUATION

As stated before, D7.2 captures evaluation sessions and opinions of the services as of December 2018. It was in this date when the inclusion of a new tool called the Operator Awareness and Support Tool (OAST) was introduced in HuMan. It is already mentioned in the Royo's pilot and has not undergone any testing. It will be used and evaluated by Royo and its objective is to provide cognitive support to the operators working in the palletization area. After assessing the current status at the ROYO's palletization area, where workers are not aware of the type of boxes that is arriving through the conveyor belt or for delays at previous production stages, the need to support these workers was identified.

This tool monitors what is happening on the final section of the production line and provides real-time information to the operators regarding the correct placement of the boxes to the appropriate pallets. Information provided consists of the following:

- type of expected units
- way of stacking
- destination warehouse
- delay of units.

This helps workers by eliminating waste and reducing errors and stress.

In addition, a template for gathering data to be used in the upcoming evaluation sessions for each service by end user has been created. It serves as an excellent base to connect the use cases with the service owners when setting the service evaluation.

An **evaluation study** is associated to a site visit and may correspond to one or more stages (see point 2) since one could do technical testing, UX testing and formative evaluation. However, the final evaluation must be done in a dedicated site visit. The template considers a description of the final study to be carried out, a collection of all the studies yet to be done, described in sufficient detail to elaborate a plan that can be followed, the impact measures expected, and finally the actual plan to conduct the final evaluation of the service.

The studies will consist on a service owner meeting with the corresponding end user in order to evaluate its service. For instance, Royo has OAST whose service owner is LMS, therefore, the template to follow will be ROYO-LMS-OAST. The following table shows the current ten studies that need to happen to fully evaluate HuMan at the three end users.

Table 2- End user / service owner evaluation sessions

END USER	SERVICE OWNER	SERVICE
ROYO	IUVO/SSSA	EXOS-APO
	LMS	OAST
	KIT-AR	SII

	UCL	KIT
AIRBUS	IUVO/SSSA	EXOS-UL
	KIT-AR	KIT-AR
	KIT-AR	SII
COMAU	KIT-AR	SII
	UCL	KIT
	LMS	WOS

3.1 EVALUATION PROCESS TEMPLATE

The template has been handed out to all actors involved in the evaluation process and it is to be filled with all details involving such assessment. From there, meetings are being scheduled, and final results will end up into D7.3. Notice that each of the ten templates is customized for the current instance to be evaluated. The generic template is detailed below.

- **TEAM**

This is the part that captures who is involved in the study and who is the team leader. The team leader is the contact person for WP7 leaders to follow-up on a regular basis.

- **STUDY DESCRIPTION**

This description corresponds to the final evaluation and it should start with a paragraph describing what the study consists of.

- **SYSTEM DESCRIPTION**

This part describes the overall needs for the system setup.

- **ENVIRONMENT FOR EVALUATION**

This is where a definition of the environment where the service is going to be executed and evaluated takes place: workplace, workers to be engaged, activity(ies). It is important to state any constraints.

- **STATUS OF THE EVALUATION STUDY**

Describes what stage of the evaluation of the service is in, specifying what has already been done and what is missing.

- **EVALUATION STUDIES**

A list the different evaluation studies that are yet to be done. Each subsection should correspond to one study.

❖ **EVALUATION STUDY**

A short description of the study and which stages of the service it encompasses (e.g.: data collection only; or data collection, technical testing and formative evaluation)

- **GOALS**: Goal definition to be achieved with this service based on the needs and objectives set by the end user.
- **PARTICIPANT POOL**: A check of type, defining whether skilled or non-skilled, and number needed. Needed for each participant: sex, age, …
  - ❒ Total number of Managers:
    - Skilled:
    - Non-skilled:
  - ❒ Total number of Operators:
    - Skilled:
    - Non-skilled:
- **DATA COLLECTION (DEVICES):** A full list of all devices needed.
  - ❒ Empatica E4:
    - Number:
    - Type of data and explain why:
  - ❒ Huawei Smartwatch 2
    - Number:
    - Type of data and explain why:
  - ❒ HoloLens
    - Number:
    - Type of data and explain why:
  - ❒ EXO-UL
    - Number:
    - Type of data and explain why:
  - ❒ EXO-APO
    - Number:
    - Type of data and explain why:
  - ❒ Myo
    - Number:
    - Type of data and explain why:
  - ❒ Hero
    - Number:
    - Type of data and explain why:
  - ❒ Thermo-Camera
    - Number:
    - Type of data and explain why:
  - ❒ Eye-tracker
    - Number:
    - Type of data and explain why:

❒ Video
- Number:
- Type of data and explain why:

❒ Oculus Rift
- Number:
- Type of data and explain why:

- **QUANTITATIVE EVALUATION:** A description of the data that is captured.

Type of Questionnaire:

❒ Quality:
❒ Usability:
❒ Training:
❒ Comfort:
❒ Effectiveness:
❒ Load:
❒ Exertion:
❒

Interviews (Feedback from users about adoption while experimenting with the service)

- **PROCEDURE:** How the evaluation is going to take place, filling the table with the corresponding activities needed taking into account duration, conditions, service status, and supporting material. This description is similar to an evaluation paper where the procedure is described with timings.

Time (min)	Activity	Conditions	Service status	Support material

- **DEPENDENCIES**: What HuMan system dependencies are needed.

❒ CORE
❒ Empatica
❒ Smart Watch
❒ Short-term Intervention
❒ Intervention
❒ Long-term Intervention
❒ Data repository

- **SCHEDULE**: A Gantt chart of the study, with the key activities and delimited in time.

❖ **IMPACT ASSESSMENT**

Impact stating by defining the pre/post status before/after the service. The idea is to follow what is in D7.1 where the methodology developed is based on a short-term comparison between the situation before (AS-IS) and after (TO-BE) applying the Service. The PIs are defined to provide an indication concerning the situation of the system in order to reach the assigned Objectives (defined by the user) and to facilitate the appropriate reaction. Therefore, the PIs values are connected to the nature of that objective which in the end is the problem(s) that need to be resolved within your trial.

- Pre-questionnaire (AS-IS)
- Post-questionnaire (TO-BE)
- Performance Indicators

OBJECTIVE	PERFORMANCE INDICATOR
1	
2	
3	
4	

Performance results and Impact (overall assessment of the service in the framework of the pilot).

4. SUMMARY AND CONCLUSIONS

Most of the services have not undergone any validation yet. Just preliminary visits to have an overall view of the plants to see the actors involved and tasks being performed. Plans are already underway to complete all HuMan service evaluations by the end of the project.

The following table complements the table above and summarizes briefly all evaluation studies and their current status.

Table legend:

DC: Data Collection
TT: Technical Testing
UXT: UX Testing
F: Formative
FE: Final Evaluation

Table 3 - Status and planning for each evaluation study

END USER	SERVICE OWNER	SERVICE	Status of validation	Involved Activities	Expected ending date
ROYO	IUVO/SSSA	EXOS-APO	Preliminary tests done. TT, UX done for EXO	Wearable Setup TT Setup data collection experiment STRE DC data collection STRE (without exo) DC data collection (with exo) DC Training of STRE Fatigue model Testing of STRE + IM at Royo TT, F Final evaluation + training workshop FE	18th May
	LMS	OAST	Ongoing	Data Collection and technical Testing TT UX testing and formative evaluation TW, UX, F Final Evaluation FE	26th July
	KIT-AR	SII	Ongoing	Demo (attract interest) Formative evaluation UX, F Development activity Final evaluation and training workshop	31st July
	UCL	KIT	Ongoing	meeting UCL and SUPSI data collection with experiment analysis of existing data collated analysis of new data collated training of STR model integration of STR formative evaluation F development activity	19th July

				final evaluation and training workshop FE	
AIRBUS	IUVO/SSSA	EXOS-UL	Ongoing	Lab test of STR TT Setup data collection experiment STRE DC Data capture without Exo DC Data capture with Exo DC Training of STR model Testing of STR at Airbus F Final evaluation and training workshop FE	30th April
	KIT-AR	KIT-AR	Ongoing	Use case workshop Creation of use case Data collection with experiment DC Formative evaluation F Development activity Final evaluation and training workshop FE	22nd July
	KIT-AR	SII	Ongoing	Final integration TT Production data DC Demo (attract interest) Formative evaluation UX, F Development activity Final evaluation and training workshop FE	26th July
COMAU	KIT-AR	SII	Ongoing	Demo (attract interest) SII/Comau Formative evaluation SII/Comau Development activity SII/Comau Final evaluation FE SII/Comau	16th July
	UCL	KIT	Data capture for error recognition done.	Training of model Find replacement for sealant Development activity Formative evaluation F Development activity Final evaluation and training workshop FE	12nd July
	LMS	WOS	Ongoing	Formative evaluation F Final evaluation and training workshop FE	5th July

5. APPENDIX A

For the ease of reading, this section gathers most of the questionnaires used during the initial experimentations carried out at the end users premises.

NASA Task Load Index test

The NASA TLX test was administered to workers after the evaluation session, in order to assess the task after the use of the **EXOS-UL**.

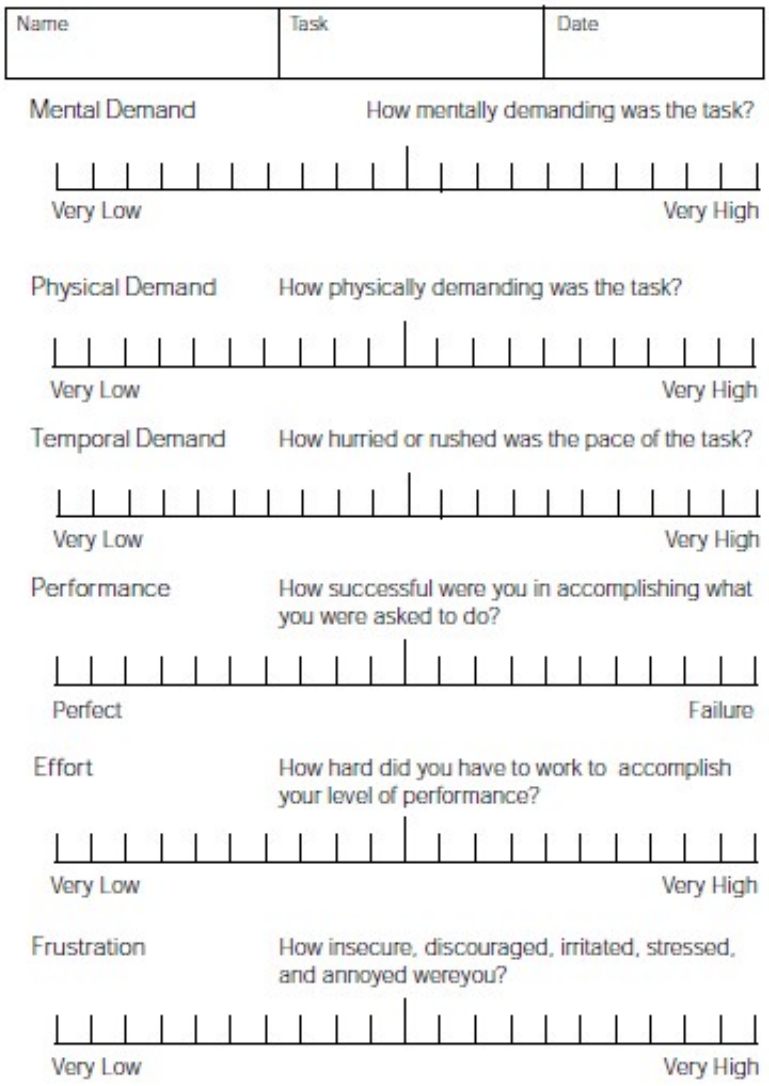

Figure 9 – NASA Task Load Index questionnaire used during Airbus EXOS-UL experimentation

System Usability Scale (SUS) questionnaire

The System Usability Scale provides a "quick and dirty", reliable tool for measuring the usability of a system. It is a simple, ten-item attitude Likert scale giving a global view of subjective assessments of usability of a system. It has been distributed to workers after the evaluation session to rate their perception of the usability of the EXOS and of the interaction with the wearables.

System Usability Questionnaire

		Strongly disagree				Strongly agree
1	I think that I would like to use this system frequently.	1	2	3	4	5
2	I found the system unnecessarily complex.	1	2	3	4	5
3	I thought the system was easy to use.	1	2	3	4	5
4	I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5	I found the various functions in this system were well integrated.	1	2	3	4	5
6	I thought there was too much inconsistency in this system.	1	2	3	4	5
7	I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8	I found the system very cumbersome to use.	1	2	3	4	5
9	I felt very confident using the system.	1	2	3	4	5
10	I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

Figure 10 – System Usability Scale questionnaire used during Airbus EXOS-UL experimentation

Worker's perception about comfort, usability, and effectiveness for the EXOS-UL service

A	***Comfort of the exoskeleton***	**Very low**	**Low**	**Medium**	**High**	**Very high**
	How do you rate the level of comfort of the device?	**1**	**2**	**3**	**4**	**5**
	Do you think you would wear it for the entire shift?	**1**	**2**	**3**	**4**	**5**
	How do you rate the perceived weight of the device?	**1**	**2**	**3**	**4**	**5**
	Is the don procedure easy and fast enough?	**1**	**2**	**3**	**4**	**5**
	Is the doff procedure easy and fast enough?	**1**	**2**	**3**	**4**	**5**

B	*Usability of the exoskeleton*	Very low	Low	Medium	High	Very high
	The lighting LEDs are well visible?	1	2	3	4	5
	The buttons are easy to reach and press?	1	2	3	4	5
	Are the visual feedbacks provided by the LEDs enough?	1	2	3	4	5
	Do you think that the information from the exoskeleton received is enough?	1	2	3	4	5
	Is the time needed to change the assistance too long?	1	2	3	4	5
	Do you think it is a useful device?	1	2	3	4	5
	If in future you can have the possibility to use this device every day, do you think you would like to use it?	1	2	3	4	5

C	*Effectiveness of the exoskeleton*	Very low	Low	Medium	High	Very high
	Is the exoskeleton helping in performing the job?	1	2	3	4	5
	How do you rate the physical support?	1	2	3	4	5
	Is the change of assistance well perceivable?	1	2	3	4	5
	Do you think that the level of physical support is enough to perform the job?	1	2	3	4	5

Questionnaire for Operators about the WOS service.

1. How long have you been working on this assembly station?
    a. 0-1 years
    b. 1-2 years
    c. 2-3 years
    d. More than 3 years
2. What, if any, of these Virtual Reality devices have you heard of?
    a. Google Cardboard
    b. Microsoft HoloLens
    c. Oculus Rift
    d. Samsung Gear VR
    e. HTC Vive
    f. PlayStation VR
    g. None of the above
    h. Other (please specify):

3. Have you used Virtual Reality equipment before?
    a. No
    b. Yes (if yes, please specify which device have you used)

4. How easy did you get familiar with the virtual environment – interactions?
    a. Extremely easy
    b. Very easy
    c. Somewhat easy
    d. Not too easy
    e. Not at all easy

5. How realistic did you find the visualization of the Virtual Environment compared to the actual one?
    a. Extremely Realistic
    b. Very Realistic
    c. Somewhat Realistic
    d. Not to Realistic
    e. Not at all Realistic

6. How realistic did you find the user interactions with the Virtual Environment?
    a. Extremely Realistic
    b. Very Realistic
    c. Somewhat Realistic
    d. Not to Realistic
    e. Not at all Realistic

7. How realistic did you find the assembly procedure using this software?
    a. Extremely Realistic
    b. Very Realistic
    c. Somewhat Realistic
    d. Not to Realistic
    e. Not at all Realistic

8. How satisfied are you with this software's ease of use?
    a. Extremely satisfied
    b. Very satisfied
    c. Somewhat satisfied
    d. Not to satisfied
    e. Not at all satisfied

9. How satisfied are you with the look and feel of this software?
    a. Extremely satisfied
    b. Very satisfied
    c. Somewhat satisfied

d. Not to satisfied
e. Not at all satisfied

10. Did you face any kind of discomfort during the testing session?
    a. No
    b. Yes (if yes, please specify)

11. Do you have any thoughts on how to improve this software?

Questionnaire for Engineers for the WOS service

1. How long have you been working as a workplace engineer?
    a. 0-1 years
    b. 1-2 years
    c. 2-3 years
    d. More than 3 years

2. How satisfied are you with this software's ease of use?
    a. Extremely satisfied
    b. Very satisfied
    c. Somewhat satisfied
    d. Not to satisfied
    e. Not at all satisfied

3. How satisfied are you with the look and feel of this software?
    a. Extremely satisfied
    b. Very satisfied
    c. Somewhat satisfied
    d. Not to satisfied
    e. Not at all satisfied

4. Would you change anything related to the graphical user interface of this software?
    a. No
    b. Yes (is yes, please specify)

5. How satisfied are you with the ability to collaborate with other users on this software?
    a. Extremely satisfied
    b. Very satisfied
    c. Somewhat satisfied
    d. Not to satisfied
    e. Not at all satisfied

6. How satisfied are you with the current number of supported assessments?
    a. Extremely satisfied

b. Very satisfied
c. Somewhat satisfied
d. Not to satisfied
e. Not at all satisfied

7. How satisfied are you with the current implementation of the supported assessments?
    a. Extremely satisfied
    b. Very satisfied
    c. Somewhat satisfied
    d. Not to satisfied
    e. Not at all satisfied

8. Would you add any kind of new assessments?
    a. No
    b. Yes (if yes, please specify)

9. How possible would it be to use this service instead of the current procedures?
    a. Extremely possible
    b. Very possible
    c. Somewhat possible
    d. Not to possible
    e. Not at all possible

10. Do you have any other thoughts on how to improve this service?