



EVALUATION METHODOLOGY

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Executive Summary

The deliverable is the culmination of the work regarding the shaping of the validation preparation and execution in the three industrial scenarios, concretely, the execution of the validation and feedback to the IT partners for incremental improvement, the measurement of the usability and the impact on the business, and the reporting of results and lessons learnt. Consequently, WP7 defines the evaluation methodology along with the technologies to be used and the studies to be carried out at each of the three industrial pilots namely Airbus, Comau and Royo Group.

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Acronyms

Acronym	Explanation
AR	Augmented Reality
VR	Virtual Reality
JIT	Just-In-Time
PI	Performance Indicator
EXO	Exoskeleton
WOS	Workplace Optimization Service

1. INTRODUCTION

WP7 is focused on the evaluation methodology and how to apply this to the different trials at each of their three industrial premises, reporting later the results of the analysis.

D7.1 documents the evaluation of the HUMAN solution defining what forms of evidence will be used in order to evaluate the HUMAN performance and impact according to the assessment framework determined in D1.2. D1.2 will provide a generic framework for the whole project results, at different levels of hierarchy (worker, production line, factory, etc.), whereas this document elaborates on the Worker assessment level and provides performance indicators for each company. It is important to notice that D7.1 will not provide the specific performance metrics (evaluation mode) for assessment. It will rather provide an evaluation framework for deriving these metrics. Specific evaluation metrics will be defined when each company is evaluated.

Following T7.1, this deliverable will pave the way of the evaluation studies for testing, assessing and validating the scenarios of usage of the HUMAN solutions in the industrial trials. End users will be supported by an IT partner in preparing the environment and identifying the key elements to be used in the validation process. All processes to be executed will be detailed and all the documents and data to be used for configuring the system and execute these processes will be collected.

1.1 PURPOSE AND SCOPE

The objective of this deliverable is to illustrate the process of defining a methodology that will serve in the later tasks as an instrument to validate the HUMAN overall technological solutions in the three industrial plants.



Aerospace



Furniture



Automation
manufacturing



Figure 1 - The three HUMAN industrial pilots

The engagement of required industrial and technological partners for the implementation of this methodology in the three different real environments is a very important objective in the future scope in order to demonstrate how well this methodology measures the HUMAN solution.

All deliverables of WP7 are of type report and their dissemination level is confidential, so they are addressed only to the members of the consortium including the Commission Services.

1.2 RELATION TO OTHER HUMAN WORK PACKAGES AND TASKS

This deliverable is framed within the T7.1 activity and it is considered as the center point of the work package. As Figure 2 shows, 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. On the other hand, WP6 will output different customized instances of the HUMAN solutions that will have to be evaluated by the end users for the validation executed in T6.4. It is thanks to the T7.2, T7.3 and T7.4 that will apply the evaluation methodology formulated in T7.1 that developers will have the necessary feedback to release new improved versions of the instances that once again, will be put to test by the corresponding integration and deployment at the three industrial trials premises.

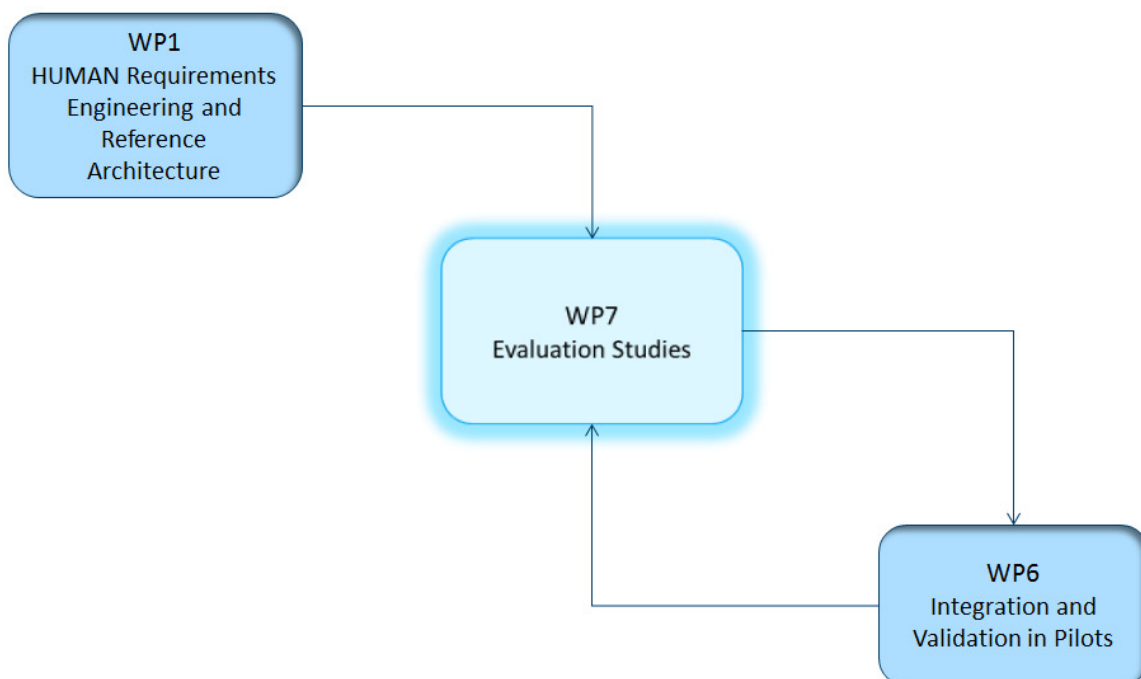


Figure 2 – Main relationship between WP7 and the other HUMAN WP

1.3 STRUCTURE OF THE DOCUMENT

This document is organized according to the main goals of task T7.1, which are:

- identification of the Objectives as a result of the user requirements gathered in WP1,
- identification of the involved actors in all scenarios,
- definition of the right forms of evidence that will serve to evaluate HUMAN performance and impact,
- and interpretation and validation of the measurements and their results.

For this purpose, the deliverable introduces the HUMAN methodology for evaluation of each trial identifying Objectives and Performance Indicators (PIs) definition. Then, it follows the evaluation of HUMAN performance with an introduction of all involved stakeholders leading to the forms of evidence used, such as the workers questionnaires. An interpretation of all the results obtained will be explained so the trials will be able to validate and evaluate their corresponding experimentations that will lead into the tasks 7.2, 7.3 and 7.4. Finally, the last chapters are dedicated to each trial namely Royo, Airbus, and Comau, where challenges, PIs, stakeholders and specific questionnaires are modeled into the final form of the pilots.

2. HUMAN METHODOLOGY FOR INDUSTRIAL TRIALS EVALUATION

2.1 HUMAN METHODOLOGY

As mentioned above, this deliverable documents the evaluation methodology, which is the foundation for the WP7. The methodology will be applied in consequent tasks 7.2, 7.3 and 7.4 at M13 where each individual trial will experiment the solutions developed within the technical work packages under their own use cases. These tasks will overlap with task 7.5, the evaluation analysis, which will start collecting and analyzing data early on (M18), and will finalize at the end of the project.

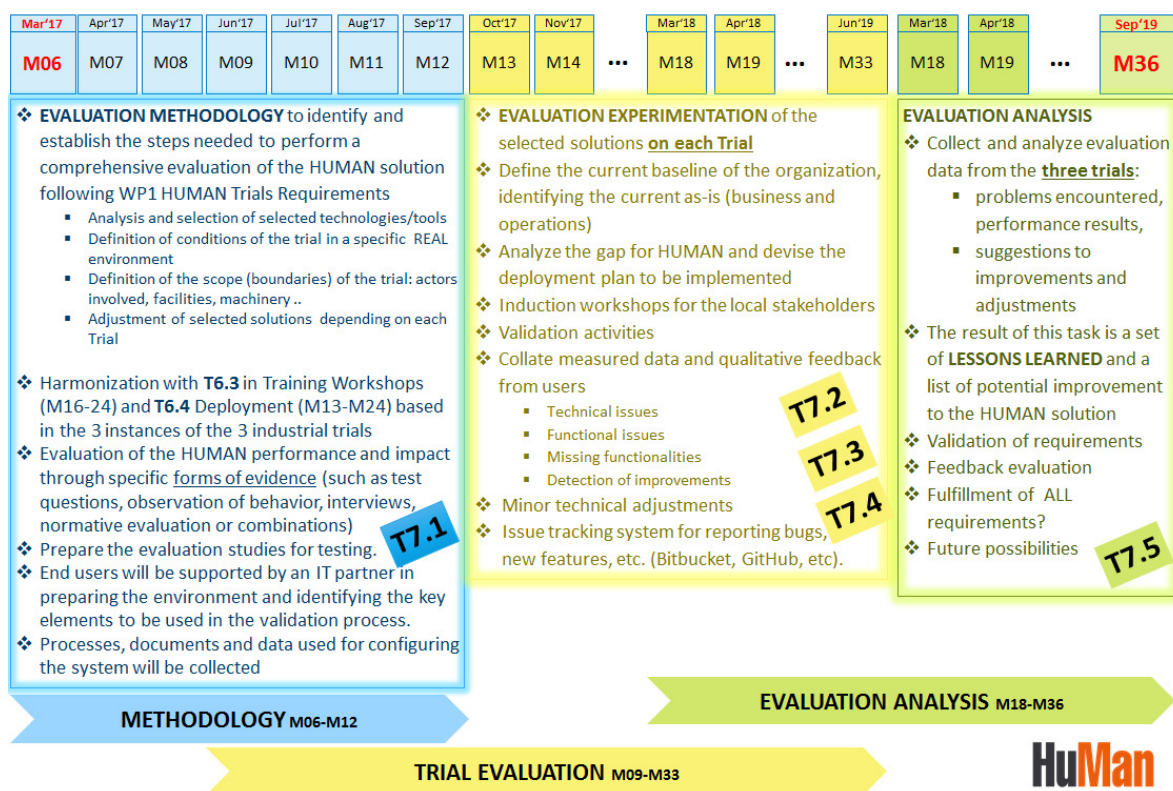


Figure 3 – Overall view of WP7

The methodology developed is based on a short-term comparison between the situation before (**AS-IS**) and after (**TO-BE**) applying the HUMAN technologies. “Situation” must be interpreted in a broader sense, since several experiences must be evaluated (trials) and performed in different manufacturing companies and work spaces, using different technologies, so that in each of them, the environment changes, and therefore, the objectives.

To define each situation in the most thorough way, Performance Indicators (PIs) will be used in all three trials. These PIs will be defined according to the Simplified ECOGRAI methodology.

The Simplified ECOGRAI method (Doumeingts, et al., 1995) is used for designing and implementing PIs.

The PIs are defined to provide an indication concerning the situation of the system in order to reach the assigned System Objectives and to facilitate the appropriate reaction. Therefore, the PIs values are connected to the nature of that objective. If a value does not evolve in the direction of the objective, it will be necessary to act on the drivers in order to modify the evolution. **Drivers are the HUMAN technologies to reach the objective in order to proper evaluate the PI defined.** There are three drivers that will be used in the experimentation and evaluation on each trial:

- Exoskeleton – EXO (includes wearable technologies such as smart watches, to monitor worker well-being)
- Augmented Reality – AR (may include breathing collector within the AR goggles to capture worker stress level)
- Virtual Reality – VR

A good advantage and characteristic of the ECOGRAI method is not only in the way to define the PIs, but also in the identification of the Drivers, which acts to reach the objectives. In ECOGRAI, the starting point is the identification of the Drivers through which to reach Objectives (arrow 1 between Objectives and Driver); the PIs then characterize the result of the Driver in reaching the objectives (arrow “1” between PI and Driver). In this way, it is possible to quickly determine where to act to improve the situation. The improvement is using the Drivers for reaching the PI, different from other methods which go directly to the PI.

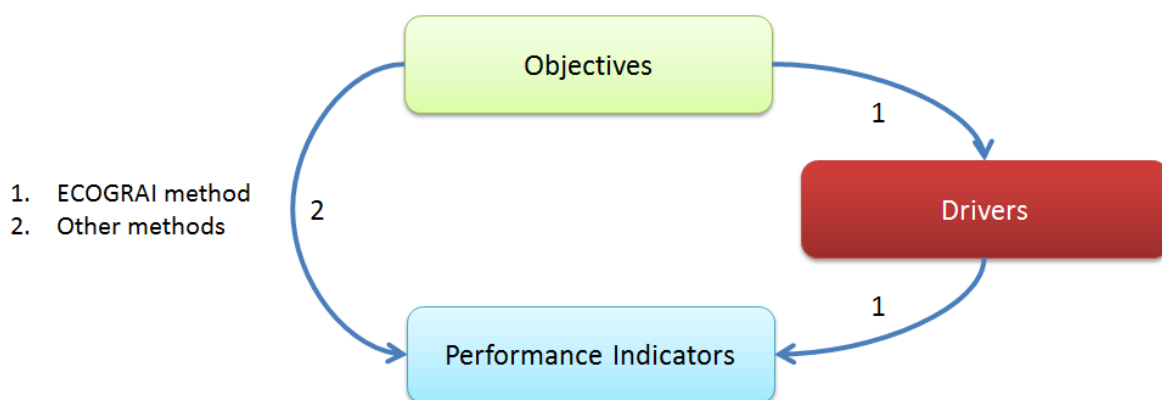


Figure 4 - The principles of Simplified ECOGRAI methodology

In conclusion, for HUMAN methodology, an **OBJECTIVE** must be:

- Clear, concise, (it means : "what the trial is trying to achieve")
- Including a dimension of performance (cost, time etc.) associated with a variation (increase, decrease, improve, etc.)
- Quantitatively or descriptively measurable being able to check whether the target is achieved
- Reachable
- Defined in a time period.

The PI can measure directly the achievement of the objective (result PI) or the trend/progress in the achievement of the objective (progress PI) and in this case the efficiency of the decisions.

A **PI** must be:

- easy to be interpreted, to put into work, to use or to exploit
- easily measurable, quantifiable
- representative of the objective of which it measures the reaching
- available at any time when one needs it renewed or changed, even disappear according to the circumstances.

The implementation of different technologies in the manufacturing shopfloors must be evaluated in order to check whether the initial target goals will be achieved. This "check system" must comply with the following requirements:

- ✓ Validate objectives / problems of each scenario and the indicated industrial deployment
- ✓ Validate PI calculation experimentally
- ✓ Define questionnaires or evaluation methods
- ✓ Validate questionnaires / methods experimentally

The goal to be achieved when implementing any technology on the shopfloor is to ease the work of the workers, so that it is:

- ✓ more comfortable (less physical and emotional strain),
- ✓ safer (reduced injuries and accidents),
- ✓ faster (improved productivity)
- ✓ better (with more quality).

These factors can be obtained objectively, getting significant results whenever there is plenty of time for both experimentation and evaluation. They can be obtained under a subjective perspective in shorter periods of time, then the obtained results can be later verified with objective methods.

With this in mind, **two main general principles** will be applied:

- A. The subjective perception of the use of technologies by the stakeholders is very important to evaluate the HUMAN solution. This is because an objective evaluation would mean to require long periods of time which are not available in the use case companies due to their daily activities. A hypothesis that must be validated, is the positive reinforcement that has favorable attitude to the use of technologies on people. That is, if a worker believes that the use of technology will improve some or all aspects to be evaluated, then it is possible that that worker's perception will be positive after its use.
- B. The objective measurement of the results must be considered short term, which can hinder getting reliable measurements of some factors related especially with the physical well-being of the workers. For instance, complete measures see unrealistic since the use of some technologies at the workplace is limited to small periods of time during a complete shift. Therefore, the possibility to design specific experiments that will reproduce the effects of the extended use of the evaluated technologies within a short period, will be considered.
- ➔ Based on these principles, and considering the requirements to be satisfied, the proposed methodology includes the following results: **BEFORE (AS-IS)** technology implementation.

Table 1 – What, who and expected results before (AS-IS) implementation

WHAT	WHO	EXPECTED RESULTS
Identification of stakeholders by the technical partners	technical partners + trial companies	List of involved personnel, indicating name, position, trial related task (supervision, use of technologies, others) Work procedures NO HUMAN technologies Registered data about the activity
Identification of the specific objectives to achieve, or results to demonstrate, with the use of the technologies in each pilot	technical partners + trial companies	Objectives list or results to achieve in the trial
Conduct project knowledge test and the results that must be expected from the implementation of technologies	responsible personnel from each of the pilot companies.	Average score
Conduct workers attitude survey	responsible personnel from each of the pilot companies.	Average score

Record the activities carried out at the workplaces where technologies will be implemented	Trial companies staff	Report about how things are done before HUMAN
records of the results gathered during the process	Trial companies staff	information that will support the calculation of the associated indicators to the objectives prior to the experimentation

→ **AFTER (TO-BE)** technology implementation:

Table 2 - What, who and expected results after (TO-BE) implementation

WHAT	WHO	EXPECTED RESULTS
Questionnaires to gather the subjective perception of the workers on the use and results from the technologies' use	the workers who have used the HUMAN technologies	Average score
Record of the activity developed in the workplaces during the technology implementation	Trial companies staff	Report about how things are done after HUMAN
Record of the results obtained in the improved process	Trial companies staff	information that will support the calculation of the associated indicators to the objectives after the experimentation

2.1.1 IDENTIFICATION OF OBJECTIVES

The pilot responsible company must execute the identification of the objectives or results to be achieved by the use of the HUMAN technologies. The following criteria must be considered in order to identify the objectives:

- Identify objectives / problems that need to be resolved within each trial. They have to be defined in full detail: what they are, to whom they affect, the effects on the people or on processes or products, etc.
- From these objectives, determine from 0 to 10 where 0 is barely has influence and 10 is has strong influence, the influence level each one has on the following four **Performance Categories**:

- Health. "State of complete physical, mental, and social wellbeing, and not merely the absence of disease or infirmity." World Health Organization. Occupational Health and Safety aims to apply measures and develop the necessary activities for the prevention of risks arising from work.
 - Communication. Effective communication is essential for organizational transformation and is considered critical to achieve employee engagement and their satisfaction at work. Every manager need timely and useful information to take right decisions; when the data is incomplete, deficient or inadequate, affect engagement, attitude, satisfaction, employee performance and all areas of the organization¹
 - Productivity. Productivity measures the efficiency of a person, process, or machine to convert inputs into products or services. It is measured from the product/service units produced and the resources used to manufacture them.
 - Quality. Quality in manufacturing, in the HUMAN sense, means an absence of defects in the manufactured products. Defects are defined by the rules specified within each company, or by its own clients. Precision is found inside the parameters measured to determine the quality level of a product. It is to fulfil a determined value within some known tolerances. Normally, precision can reference dimensional variables, color adjustments, quantity of defects, etc.
- This evaluation will be conducted at least by five technicians, two from the technical partner, and three from the pilot company, obtaining an average value in the end.
 - The Performance Categories whose influence is 5 or above, must be quantified numerically through the associated PIs, both in the as-is, and the to-be situation after the experiment (target value). If the current and target value can be determined through historical data, they will be acquired. Otherwise, a data capture period, prior to the experimentation start, will be devised. This period will be as long as needed (no less than one month), so that the data are significant enough. If a factor cannot be objectively quantified, questionnaires will be used to assess the subjective perception of the users and the people involved in the pilot companies.

2.1.2 PERFORMANCE INDICATORS (PIS) DEFINITION

PIs must be defined for each of the Performance Categories previously mentioned (health, communication, productivity and quality), with at least one PI per factor. Only significant objectives must be considered, namely those with a score greater than 5.

The indicators to be defined must have the following characteristics:

- They will be obtained by objective measurements whenever possible. These measurements can be made on the products (e.g. quantities), the processes (e.g. times), the persons (e.g. number of movements) or the environment (e.g. used space).

¹ "La Motivación, Comunicación y Actitudes de los Empleados como Elementos Fundamentales en la Organización". Noris de la Cruz.

- Since it is possible that some value could be obtained from the workers opinion, and therefore, adding a certain degree of subjectivity, the assessment must be performed through a written questionnaire in which each evaluated worker assigns numerical values to the parameters being measured (e.g. indicate from 0 to 5 the level of fatigue, the ease of use, etc.).
- The PI value must be obtained as an average of several observations, at least three.

A list of reference indicators can be found in D1.2 Assessment Framework and Methodology, which documents the requirements elicited and describes the methodology for monitoring and ensuring their traceability. D1.2 is to be submitted on month 15 (December 2017).

Since the methodology must be able to evaluate the experimentation of any technology within HUMAN, the procedures and questionnaires must be adjusted to each use case. The technical partners responsible to implement the technologies in each pilot, must adapt the process so that it captures the specificities of each pilot.

On each Trial Evaluation all PIs defined will have their own **Performance Metrics** (Evaluation Modes) to calculate the performance of the PI.

2.1.3 STAKEHOLDER IDENTIFICATION

In this document, the word “Stakeholder” denotes both involved persons in the process, and other organizational elements (work procedures, technology, IT solutions, etc.) affected by the selected technologies implementation.

In order to identify the involved persons, the following criteria must be considered:

- Workers from the workplace/section/area of the pilot company where technology is going to be implemented will be considered. Even though the technology could be used by a limited number of workers, all that perform the same tasks at the workplace/section/area are involved.
- Supervisor/section team leader, and the safety/risk prevention manager are considered.
- Other persons that could be involved and whose participation in the evaluation must be decided by the use case company, according to their implication in the evaluated activities:
 - internal providers or internal clients of the workers directly involved,
 - workers from other shifts (when tests are not being conducted in other shifts).

Other elements that must be considered to evaluate the impact of the HUMAN technologies are:

- Written work procedures or methods. These will have to be gathered since they can support the subsequent data capture.
- Available technology. Equipment and tools not developed in the HUMAN project used by each worker needs to be detailed, in those cases where any IT system being used normally is included. The responsible company must assess whether this technology can have an influence or not on the pilot results. If it has, it would have to be indicated along with its reasons.

- Data obtained as a result of the activity. The way to capture data that reflects the results of the activity must be identified (working times, product quality, unexpected stops, etc.). These data will be used to tangibly evaluate the experimentation results (improvements achieved). If there are no relevant data records, the responsible organization must contemplate a gathering system to get the data that is feasible for the pilot company.

2.1.4 DOCUMENTS AND WORKERS OPINIONS

Key documents (questionnaires, surveys, tests, etc.) will be defined to have enough information from the workers, before and after performing the experimentation, in order to evaluate the obtained results, and to gather information that allows improving the technologies from a “usability by the workers” point of view.

BEFORE the experimentation begins, three types of documents will be used to obtain information directly from the workers and accounted personnel:

1. Project knowledge test and what to be expected from the implementation of technologies filled in by the responsible people of each pilot company before the experimentation. The objective of this test is to identify the expectations of the managerial staff of the pilot company regarding the project results. It must capture both HUMAN general objectives knowledge and the experimentation to be carried out at shopfloor. It must be fulfilled by at least four people at each company: one person from high management, one operations manager, one HR manager, and one safety and health manager. Questions should be addressed so that they can be scored from 0 to 5. If the average score is less than 4, an informative/formative action must be carried out.
2. Attitude survey of the experimentation participant’s stakeholders. This questionnaire should capture, previous to the experimentation, the inclination and motivation of the workers to the application of new systems that will ease the involved tasks. It has to be a simple and easy-to-answer questionnaire, with numerical values (0 to 5), and that reflects the following aspects: satisfaction with current work, participation in improvement processes, previous experiences in improvement processes, perception on possibilities to reduce fatigue (or improve quality, productivity, etc.), current motivation to face new work procedures, etc. The results obtained from this questionnaire will be taken into account to gauge the results of the subjective perception after the experimentation.
3. Activity record that is developed in the workplaces where the technologies and obtained record of results in the process will be implemented. This record has a double aspect:
 - On one side, questionnaires that allow to easily gathering how things are done before HUMAN must be defined. Fulfillment of these questionnaires must be done by direct observation, and must be filled in for all workers involved in the task, whether they later participate in the HUMAN experimentation or not. The questionnaire must reflect: movements done by the worker, tools used, load handling, documentation lookup, enquiry with supervisors, cooperation with other workers, etc.

- On the other side, and depending on the quantified objectives, several actions must be created in order to obtain information that will support the calculation of the associated indicators to the objectives prior to the experimentation. These actions can be based on registers filled in by the workers, IT registers, or, in the worst case, registers filled in by direct observation.

AFTER the experimentation of the HUMAN technologies, **two types of documents** will be used:

1. Record of the activity developed during the implementation of the technology in the workplaces, and record of the obtained results in the improved process. To capture this information, the same documentation used before implementing HUMAN could be used.
2. Questionnaire to capture the subjective perception of the workers on the application of the technologies used and the related results. This questionnaire must be prepared so that it reflects the subjective perception of each worker, but quantified through numerical grading scales (0 to 5). The questionnaires will be completed by the workers who have used the HUMAN technologies. Questions must capture the following aspects:
 - Reduction of fatigue feeling: awkward movements, load handling, movements, tools use, etc.
 - Reduction on the need to rest
 - Task completion swiftness
 - Improvement in processes of control of process or product
 - Increase of work efficiency
 - Stress
 - Other specific aspects of the implemented technologies.

2.2 INTERPRETATION AND VALIDATION OF RESULTS

In order to implement the evaluation process, the following schema summarizing the methodology for gathering the opinions of the workers is presented:

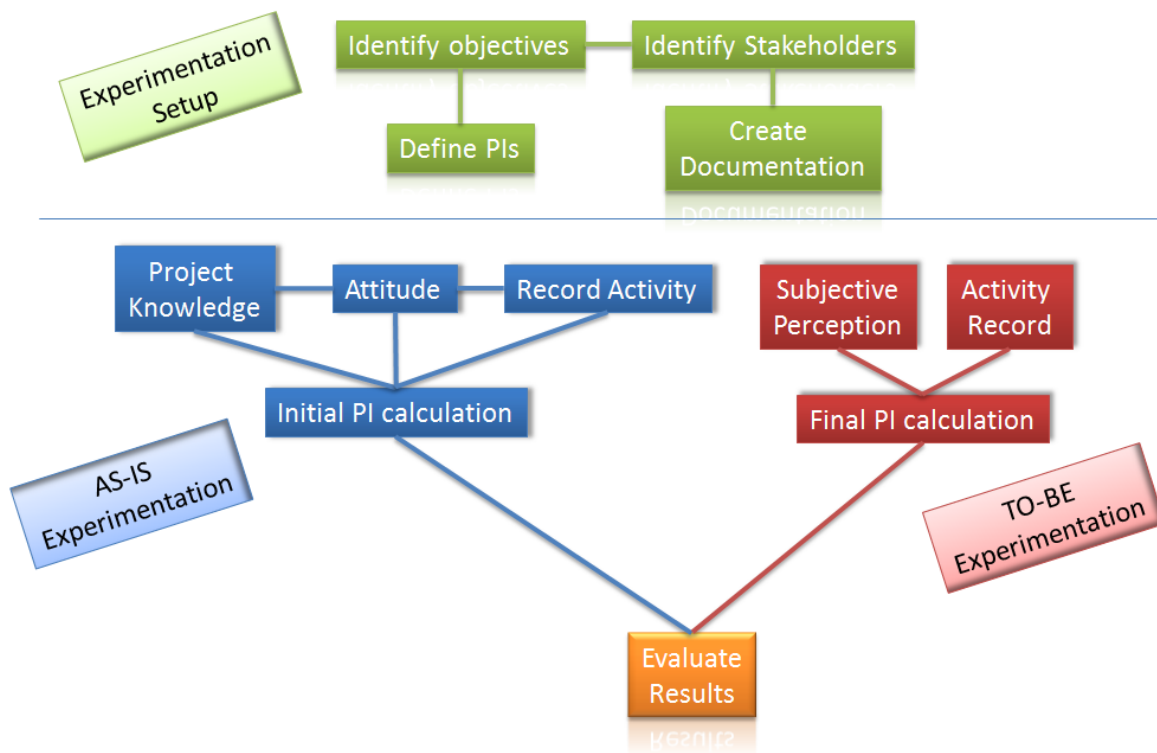


Figure 5 - Evaluation Process Schema

NOTICE that the complete method needs to be applied to a specific use case as well as a real test needs to be carried out. Otherwise, it will be difficult to foresee any outcome.

However, these results must be put into context according to the information obtained before the experimentation since there exist strong interrelationships among several elements of the evaluation system. Specifically, the following effects must be considered:

- The influence of an indifferent, or even negative attitude that the stakeholders could have with the technology to be evaluated, must be taken into account.
- Negative effects on the results of the project could derive if the knowledge of the project objectives is limited, as well as if they are not resolved adequately before the experimentation begins.
- There has to be a guarantee that the activity records before, during and after the experimentation are carried out in a homogeneous manner (same persons, same method, etc.). Otherwise, the results could be affected.

Other factors to be considered when gathering conclusions on the experimentation results are the following:

- Precision degree when obtaining data to calculate the PIs. If there are confusions doing this, it is recommended to get the data from two different sources.
- In the questionnaires with subjective assessments (e.g.: with values in a 0 to 5 scale), is possible that each person could have a different perception of the scale values. To avoid this,

it is necessary to explain the meaning of each value with common words, so each person can understand their meaning.

3. ROYO TRIAL

ROYO is a multinational bathroom 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 aims at facilitating the human-machine interaction, primarily to improve the quality of life and wellbeing of the workers. With that goal achieved, different benefits for the pilot company will follow such as an increment in production, etc.

ROYO's experimentation is conceived to be carried out with the following **Drivers** :

- **Exoskeleton - EXO.** To be used at the palletization area where workers must move heavy boxes from the conveyor onto the pallets. Boxes come in a random fashion and must be piled up and grouped onto the pallets manually. The HUMAN exoskeleton for hip-trunk assistance would assist workers during this tiring task with the ultimate goal to reduce the level of effort by the extensor spinae muscles. The HUMAN exoskeleton will be a light-weighted exoskeleton capable to provide an assistive torque around the hip-lumbosacral articulations. The HUMAN exoskeleton will be easy to don/doff and adjustable to match different anthropometries.



Figure 6 – Early tests with an available prototype of exoskeleton at the palletization area in ROYO.

- **Augmented Reality - AR.** To be used in the assembly area of the plant. HUMAN AR is a service in the form of delivering the required information to the operator when they need it. The system will be aware when the worker needs assistance, giving the operator the control to turn it on or off whenever the information is required or not.
- **Virtual Reality - VR.** At the time of the writing of this deliverable, VR is to be used in the palletization area. The idea is to optimize this place so workers have all the information about incoming boxes. As previously commented above when speaking about the exoskeleton, these heavy boxes travel on the conveyor and have to be manually put onto the pallets. They arrive in a random fashion and must be piled up and grouped onto the pallets manually. VR needs to address this and provide help by offering useful information to the workers about the type of box, items, pallet, etc.

3.1 OBJECTIVES IDENTIFICATION, INFLUENCE AND ASSOCIATED PI PER DRIVER

DRIVER 1 - EXO

Table 3 – Royo Objective identification and associated PIs for Driver EXO

OBJECTIVE	PERFORMANCE INDICATOR
I Reduce fatigue of the line workers	Level of Exertion index: Calculated using the Borg Scale of Perceived Exertion. The Borg Scale takes into account the fitness level of the individual: It matches how hard he/she feels. It is a “relative” scale. The scale starts with “no feeling of exertion,” which rates a 6, and ends with “very, very hard,” which rates a 20. Moderate activities register 11 to 14 on the Borg scale (“fairly light” to “somewhat hard”), while vigorous activities usually rate a 15 or higher (“hard” to “very, very hard”). Dr. Gunnar Borg, who created the scale, set it to run from 6 to 20 as a simple way to estimate heart rate—multiplying the Borg score by 10 gives an approximate heart rate for a particular level of activity. (see Table 5)
II Increase speed of the line (improve productivity)	Level of Performance Index: Calculated according to the number of boxes (B) that are piled up every day, and the time needed (T). In order to take into account the weight and size of the boxes, a scale factor (SC) is defined: <ul style="list-style-type: none"> ○ Heavier box > 24 kg: 1 ○ 24 kg > box > 20 kg: 0,90 ○ 20 kg > box > 15 kg: 0,80 ○ 15 kg > box > 10 kg: 0,70 ○ Box < 10 kg: 0,60

$$\text{So the } KPI = \frac{B \times SC}{T}$$

Volume. Weight > Volume is better than Weight < Volume.

III	Increase work periods in the workplace without the need to interchange positions	Bio parameters (breathing, sweating...) Data coming from sensors monitoring the stress levels of workers can assess their ability to perform their tasks with consistence and high quality standards
IV	Increase well-being of the workers	MURI-MUDA analysis. Measurements of posture and ergonomics are important factors in order to determine health related issues. This PI measures the influence of posture and the ergonomics in the generation of “MUDA” or waste, which in this case it could lead to the presence of more defects than usual, to the reduction of the level of production, or to the need to interchange the operator from his/her workplace.
V	Improve workers opinions about the palletized area	Subjective assessment questionnaire. This questionnaire deals with ergonomics related matters at workplace, the feeling of fatigue, the suitability of the auxiliary equipment to support daily work activity, ambient conditions, etc. 10 questions from 0 to 5.

Influence of the objectives on the Performance Categories:

Table 4: Royo Objectives vs. Performance Categories for driver EXO

PERFORMANCE CATEGORY	I	II	III	IV	V
Health	10	3	3	10	4
Communication	0	0	0	0	6
Productivity	8	10	8	8	6
Quality	7	5	8	4	7

0 = barely has influence – 10 = has strong influence

Table 5 - The Borg Scale of Perceived Exertion

How you might describe your exertion	Borg rating of your exertion	Examples (for most adults <65 years old)
--------------------------------------	------------------------------	--

None	6	Reading a book, watching television
Very, very light	7 to 8	Tying shoes
Very light	9 to 10	Chores like folding clothes that seem to take little effort
Fairly light	11 to 12	Walking through the grocery store or other activities that require some effort but not enough to speed up your breathing
Somewhat hard	13 to 14	Brisk walking or other activities that require moderate effort and speed your heart rate and breathing but don't make you out of breath
Hard	15 to 16	Bicycling, swimming, or other activities that take vigorous effort and get the heart pounding and make breathing very fast
Very hard	17 to 18	The highest level of activity you can sustain
Very, very hard	19 to 20	A finishing kick in a race or other burst of activity that you can't maintain for long

DRIVER 2 - AR

Table 6 - Royo Objective identification and associated PIs for Driver AR

OBJECTIVE	PERFORMANCE INDICATOR
I Reduce time of training (New workers or new products)	Time spent with the aid of glasses and the traditional way to increase productivity reducing training time
II Reduce mistakes of assembly line (Mix up pieces, sequence, etc.)	Number of assembly models wrong or units containing a defect in material or workmanship.
III Improvements on current models	Percentage of products A with faults, claims or re-processes, Products A: references that add up 60% of total sales
IV Impact on low-runner products	Percentage of products C with faults, claims or re-processes, Products C: references that have a rotation of less than X units per month
V Increase Safety (Accidents. Wrong movements with hands, tools, etc.)	Number of accidents in the work area over a specific time period

Influence of the objectives on the Performance Categories:

Table 7 - Royo Objectives vs. Performance Categories for driver AR

PERFORMANCE CATEGORY	I	II	III	IV	V
Health	2	2	7	0	10
Communication	8	6	10	3	3
Productivity	10	8	10	10	8
Quality	8	8	8	7	7

0 = barely has influence - 10= has strong influence

DRIVER 3 – VR

Table 8 - Royo Objective identification and associated PIs for Driver VR

OBJECTIVE	PERFORMANCE INDICATOR
I Improve planning/organization of the palletization area.	Number of orders loaded daily
II Improve information interchange with palletization area workers.	Number of information inputs received by workers per hour. An information input is data received related to work to be done (package information, orders, pallets, etc.)
III Reduce unnecessary waiting periods	Maximum time between packages. Longest time that elapsed between two consecutive packages in a workday.
IV Reduce response time before unexpected problems	Reduction of delay time by problem. Measured as the rate between the accumulated delay time due to problems occurred in the line and the number of total problems through a measured time period (at least a workday) / number of problems
V Improve the confidence of the worker when making decisions since they have real time information.	Time to prepare a pallet

Influence of the objectives on the Performance Categories:

Table 9 - Royo Objectives vs. Performance Categories for driver VR

PERFORMANCE CATEGORY	I	II	III	IV	V
Health	8	2	4	2	7
Communication	5	10	10	10	5

Productivity	10	7	10	8	7
Quality	7	8	3	8	6

0 = barely has influence - 10= has strong influence

3.2 STAKEHOLDERS

The following involved persons are considered:

- Workers that perform piling and palletizing tasks: A, B, C, D and E.
- Management staff: Section Chief shift 1, Section Chief shift 2, Safety Manager; Operations Director.
- Other personnel: Shipping Fork-lift operator, Packer shift 1, Packer shift 2.

Written work procedures:

- Safety and risk prevention recommendations.

Available technology:

- None used.

Data obtained from IT tools or manually as a result of the activity performed:

- Daily number of boxes loaded (SAP)
- Weight of each box (SAP)
- Number of daily orders and contents for each one (SAP)
- Daily incidences report (Manually)
- Prevention service reports (Manually)

3.3 QUESTIONNAIRES

PROJECT KNOWLEDGE TEST

Mark only one answer per question: (Keep in Spanish)

1- El proyecto HUMAN persigue como objetivo principal:

- a- Mejorar la opinión del trabajador sobre la empresa
- b- Aumentar la calidad de los productos
- c- Mejorar la productividad
- d- Aumentar el bienestar del trabajador en su puesto de trabajo

2- La experimentación que se realizará en la empresa tiene como objeto:

- a- Mostrar las tecnologías aplicables en una empresa
- b- Probar que las tecnologías consiguen los objetivos deseados
- c- Mejorar la productividad
- d- Validar los resultados teóricos que ya se han obtenido

ATTITUDE STAKEHOLDERS PARTICIPANTS SURVEY (keep in Spanish)

Line workers

Asignar un valor de 0 a 5 a cada afirmación. 0- Desacuerdo, 5- Totalmente de acuerdo.

- 1- Mi puesto de trabajo actual requiere poco esfuerzo físico
- 2- Mi puesto de trabajo actual requiere poco esfuerzo mental
- 3- Preferiría estar en otro puesto de trabajo
- 4- Participo activamente en procesos de mejora cuando la empresa lo demanda
- 5- Me gusta aportar mejoras en mi puesto de trabajo
- 6- Dispongo de los medios adecuados para realizar mi trabajo

...

Management:

Asignar un valor de 0 a 5 a cada afirmación. 0- Desacuerdo, 5- Totalmente de acuerdo.

- 1- El trabajo en la línea requiere poco esfuerzo físico
- 2- El trabajo en la línea requiere poco esfuerzo mental
- 3- Participo activamente en procesos de mejora cuando la empresa lo demanda
- 4- El personal de la línea sugiere mejoras con frecuencia
- 5- La tecnología utilizada en la línea es la más adecuada para conseguir buenos resultados
- 6- Los trabajadores de la línea disponen de los medios adecuados para realizar su trabajo

...

ACTIVITY RECORD

Exoskeleton

Describe through direct observation the following aspects of the working activity:

1. Workers that take part in the piling task.
2. Specify the sequence of movements that each worker makes considering that the standardized movements are:
 - leg bending,
 - simultaneous two-leg bending,
 - trunk torsion,
 - waist turn,
 - back bending.
3. Number of repetitions for each movement over a standard period of time (five minutes, fifteen minutes, half an hour, etc.).

4. Movements (number and distance walked) that workers make at the workplace over a standard period of time.
5. Height of the stacked line.
6. Hand position when picking up each load. Indicate differences according to the box weight.

Obtain the following information from the SAP system or manual records.

1. Number of boxes prepared daily per shift.
2. Weight distribution of the boxes: quantity of boxes that weight less than 10kg, between 10 and 15 kg, between 15 and 20 kg, more than 20 kg.
3. Stacking distribution per time zones: stacked box quantity average, each hour during regular work shift (X boxes from 8 to 9, Y boxes from 9 to 10, etc.)
4. Enumerate the registered incidences for the last six months, and its appearance rate.

4. AIRBUS TRIAL

AIRBUS experimentation is conceived to be carried out with the following **Drivers** :

- **Exoskeleton - EXO.** To be used in working tasks where workers have to drill, clamp and rivet a high number of screws per shift. These operations are done on different aircrafts parts (e.g. the fuselage and tail) and in all these operations workers have to keep their arms elevated for prolonged times, in some cases even while holding tools. The HUMAN exoskeleton for shoulder assistance would assist workers during these tiring tasks with the ultimate goal to reduce the level of effort by the shoulder and upper-arm muscles. The HUMAN exoskeleton will be a light-weighted exoskeleton capable to provide an assistive torque around the shoulder flexion-extension articulations. The HUMAN exoskeleton will be easy to don/doff and adjustable to match different anthropometries.
- **Augmented Reality - AR.** To be used in the assembly area of the plant. HUMAN AR is a service in the form of delivering the required information to the operator when they need it. The system will be aware when the worker needs assistance, giving the operator the control to turn it on or off whenever the information is required or not.

4.1 OBJECTIVES IDENTIFICATION, INFLUENCE AND ASSOCIATED PI PER DRIVER

DRIVER 1 – EXO

Table 10 - Airbus Objective identification and associated PIs for Driver EXO

	OBJECTIVE	PERFORMANCE INDICATOR
I	Reduce fatigue of the line workers	See Royo case for Borg Scale.
II	Reduction of operation execution	<p>1) Level of Non-Conformity rate. Non-Conformity rate is the main PI 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.</p> <p>2) Time to complete operations. The reduction of time to complete operations is the most immediate parameter that gives feedback about the productivity of an assembly line</p>
III	Increase work periods in the workplace without the need to interchange positions	<p>Bio parameters (breathing, sweating...) Data coming from sensors monitoring the stress levels of workers can assess their ability to perform their tasks with</p>

			consistence and high quality standards
IV	Increase well-being of the workers		MURI-MUDA analysis. Measurements of posture and ergonomics are important factors in order to determine health related issues.
V	Improve workers engagement	Workers survey	

Table 11: Airbus Objectives vs. Performance Categories for driver EXO

PERFORMANCE CATEGORY	I	II	III	IV	V
Health	10	3	3	10	0
Communication	0	0	0	0	10
Productivity	6	8	8	6	3
Quality	9	8	8	7	3

0 = barely has influence - 10= has strong influence

DRIVER 2 - AR

Table 12 - Airbus Objective identification and associated PIs for Driver AR

OBJECTIVE	PERFORMANCE INDICATOR
I Increase guidance for the operators while performing their tasks	1) Level of Non-Conformity rate. Non-Conformity rate is the main PI 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.
II Improve the accessibility of information throughout the workflow	Time to complete operations. The reduction of time to complete operations is the most immediate parameter that gives feedback about the productivity of an assembly line
III Create assembly sequences driven by the customization level required by the different operators	Time to complete operations. The reduction of time to complete operations is the most immediate parameter that gives feedback about the productivity of an assembly line
IV Increase work periods in the workplace without the need to interchange positions	Bio parameters (breathing, sweating...) Data coming from sensors monitoring the stress levels of workers can assess their ability to perform their tasks with

consistence and high quality standards

V Improve workers engagement Workers' survey

Influence of the objectives on the Performance Categories:

Table 13 - Airbus Objectives vs. Performance Categories for driver AR

PERFORMANCE CATEGORY	I	II	III	IV	V
Health	2	2	5	8	0
Communication	10	10	10	3	10
Productivity	10	8	10	8	3
Quality	10	8	8	3	3

0 = barely has influence - 10= has strong influence

4.2 STAKEHOLDERS

The following involved persons are considered:

- Manufacturing Management
- Manufacturing Engineering Management.
- Product Quality
- Health and Safety Manager
- Shopfloor workers.

Written work procedures:

- Safety and risk prevention recommendations.

Available technology:

- None used for exoskeleton
- Manufacturing execution system for augmented reality.

Data obtained from IT tools or manually as a result of the activity performed:

- Number of daily orders (SAP)
- Non conformities report (SAP)

4.3 QUESTIONNAIRES

These questionnaires will be used for the exoskeleton and the augmented reality use cases

Project Knowledge Test

Evalua los mas importantes objetivos del sistema implementado en HUMAN

	Completamente de acuerdo				Totalmente en desacuerdo
<i>Mejorar la productividad de las estaciones involucradas</i>					
	1	2	3	4	5
<i>Mejorar la calidad en las estaciones involucradas</i>					
	1	2	3	4	5
<i>Mejorar la satisfaccion de los trabajadores</i>					
	1	2	3	4	5
<i>Mejorar la seguridad e higiene en los puestos de trabajo</i>					

Qué esperas de estas pruebas iniciales

	Completamente de acuerdo				Totalmente en desacuerdo
<i>Validar y proporcionar feedback a los socios tecnológicos para una mejora incremental</i>					
	1	2	3	4	5
<i>Medir la usabilidad y el impacto en el negocio</i>					
	1	2	3	4	5
<i>Reportar los resultados y las lecciones aprendidas</i>					

- **Record of the activities**

During a period of 2 months prior to the experimentations, all the relevant PIs will be stored and detailed for the chosen work-stations.

- **Questionnaire to capture the subjective perception of the workers**

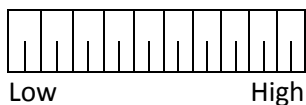
In order to evaluate the subjective perception of the workers during the application of the technologies proposed:

1. SUS (System Usability Scale) → after the use of HUMAN system

	Completamente de acuerdo				Totalmente en desacuerdo
<i>Creo que usaria este sistema con frecuencia</i>					
	1	2	3	4	5
<i>Es un sistema innecesario y complejo</i>					
	1	2	3	4	5
<i>Pensaba que el sistema era facil de usar</i>					
	1	2	3	4	5
<i>Creo que necesitaria el soporte de un tecnico para usar este sistema</i>					
	1	2	3	4	5
<i>Las funciones de este sistema están bien integradas</i>					
	1	2	3	4	5
<i>Habia demasiadas inconsistencias en el sistema</i>					
	1	2	3	4	5
<i>Imagino que la mayoría de las personas aprenderian a usar el sistema muy rapidamente</i>					
	1	2	3	4	5
<i>El sistema es muy engorroso de usar</i>					
	1	2	3	4	5
<i>Me siento muy seguro usando el sistema</i>					
	1	2	3	4	5
<i>Necesito aprender muchas cosas antes de poder trabajar en este sistema</i>					

2. NASA Task Load Index → before and after the introduction of the HUMAN system

Demanda Mental



Cuanta actividad mental y perceptiva era. ¿Era una tarea facil o exigente, simple o compleja?

Demanda fisica



Cuanta actividad fisica era requerida. ¿Era facil o exigente, pausada o laboriosa?

Demanda Temporal



Cuanto stress temporal sentiste durante la ejecucion de las tareas.

Performance



Como crees que ejecutaste las tareas. ¿Estabas satisfecho con tu rendimiento?.

Good

Poor

Esfuerzo



Cuanto esfuerzo (mental y fisico) te requirió para conseguir realizar la tarea.

Frustracion



Como de inseguro, irritado, estresado frente a seguro, contento, relajado te sentiste durante la tarea.

5. COMAU TRIAL

COMAU experimentation is conceived to be carried out with the following **Drivers** :

- **Augmented Reality – AR.** To be used in the assembly area of the plant. HUMAN AR is a service that delivers the required information to the operator when they need it. The system will understand when the worker needs assistance, giving the operator the control to turn it on or off whenever the information is required or not.
- **Virtual Reality – VR.** To be used in the design phases of the workplace in order to anticipate the insurgence of ergonomic and productivity problems. This technology will help the Manufacturing Engineering team in simulating and testing the work station before its actual implementation in the plant, enhancing the participation of the workers to the process of design that leads to the creation of their own workplace.

5.1 OBJECTIVES IDENTIFICATION, INFLUENCE AND ASSOCIATED PI PER DRIVER

DRIVERS – AR and VR

Table 14 – COMAU Objective identification and associated PIs for Driver AR and VR

	OBJECTIVE	PERFORMANCE INDICATOR
I	Increase guidance for the operators while performing their tasks: Several operations are customized for every variant of product	Non-Conformity rate: The Non-Conformity rate is the principal PI 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.
II	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	Time to complete operations: The reduction of time to complete operations is the most immediate parameter that gives feedback about the productivity of an assembly line Bio parameters (breathing, sweating...) Data coming from sensors monitoring the stress levels of workers can assess their ability to perform their tasks with consistence and high quality standards
III	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	Bio parameters (breathing, sweating...) Data coming from sensors monitoring the stress levels of workers can assess their ability to perform their tasks with consistence and high quality standards

IV Create a training on the job tool: One of the most common sources of errors in the assembly phases are connected with inexperience of newbies	Non-Conformity rate: The Non-Conformity rate is the principal PI 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.
V 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	NVAA measurement: Measurements obtained using Spaghetti Charts and other methods are important to assess the level of productivity of the line MURI-MUDA analysis: Measurements of posture and ergonomics are important factors in order to determine health related issues.

All stakeholders are potentially affected by the improvement of these aspects that may lead to reduced non-conformities, stress levels for the workers and level of quality of the job.

Please note the following:

- Objectives I through IV are achieved via the AR driver that assists the worker while operating.
- Objective V is the only one that uses driver VR.
- PIs number 1, 2 and 3 will be used to evaluate AR.
- PIs number 4 and 5 will be used for the evaluation of VR.

Table 15 - COMAU Objective identification and associated PIs for Driver AR

PERFORMANCE CATEGORY	I	II	III	IV	V
Health	0	0	0	0	5
Communication	0	0	4	4	0
Productivity	10	8	10	8	8
Quality	10	8	7	10	8

0 = barely has influence - 10= has strong influence

5.2 STAKEHOLDERS

The following involved persons are considered:

1. Workers involved in the target work-stations.
2. Management:
 - a. Plant Manager
 - b. Manufacturing Management
 - c. Manufacturing Engineering Management
 - d. Safety Manager
 - e. Product Quality

5.3 QUESTIONNAIRES

- **Project Knowledge Test**

1. Dai una valutazione ai seguenti obiettivi del Sistema implementato all'interno di HUMAN. (Give an evaluation to the most important objectives of the system implemented inside HUMAN)

	Forte disaccordo (Strongly disagree)				Forte accordo (Totally agree)
Migliorare la produttività delle postazioni coinvolte <i>(Improve Productivity of the involved work stations)</i>					
Migliorare la qualità del lavoro delle postazioni coinvolte <i>(Improve the quality of work in the involved work stations)</i>					
Migliorare la soddisfazione dei lavoratori coinvolti <i>(Improve the satisfaction of the involved workers)</i>					
Migliorare le condizioni di sicurezza dei lavoratori coinvolti <i>(Improve health and safety conditions in the workplace)</i>					

2. Quali output ti aspetti da queste sessioni di test? (Which outputs do you expect from these initial tests?)

	Forte disaccordo (Strongly disagree)				Forte accordo (Totally agree)
Eseguire la validazione delle soluzioni proposte e dare un feedback ai partner di progetto che si occupano di IT. <i>(Execute the validation and provide feedback to the IT partners for incremental improvement)</i>					

Dimostrare che le tecnologie proposte riescono a raggiungere gli obiettivi proposti durante il Workshop di inizio progetto (Novembre 2016) <i>(Prove that the proposed solutions may reach the objectives defined during the Workshop held in Comau on November 2016)</i>					
Misurare l'utilizzabilità e l'impatto delle tecnologie proposte sulle attività dell'azienda. <i>(Measure the usability and the impact on the business)</i>					
Raccogliere risultati e lezioni imparate <i>(Report results and lessons learnt)</i>					

- **Record of the activities**

During a period of 2 months prior to the experimentations, all the relevant PIs will be stored and detailed for the chosen work-stations.

- **Questionnaire to capture the subjective perception of the workers**

In order to evaluate the subjective perception of the workers during the application of the technologies proposed:

3. SUS (System Usability Scale) → after the use of HUMAN system

	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 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

Italian translation to be used with the operators:

1. Penso che mi piacerebbe utilizzare questo sistema frequentemente

1	2	3	4	5
---	---	---	---	---

2. Ho trovato il sistema complesso senza che ce ne fosse bisogno

1	2	3	4	5
---	---	---	---	---

3. Ho trovato il sistema molto semplice da usare

1	2	3	4	5
---	---	---	---	---

4. Penso che avrei bisogno del supporto di una persona già in grado di utilizzare il sistema

1	2	3	4	5
---	---	---	---	---

5. Ho trovato le varie funzionalità del sistema bene integrate

1	2	3	4	5
---	---	---	---	---

6. Ho trovato incoerenze tra le varie funzionalità del sistema

1	2	3	4	5
---	---	---	---	---

7. Penso che la maggior parte delle persone potrebbero imparare ad utilizzare il sistema facilmente

1	2	3	4	5
---	---	---	---	---

8. Ho trovato il sistema molto scomodo da utilizzare

1	2	3	4	5
---	---	---	---	---

9. Ho avuto molta confidenza con il sistema durante l'uso

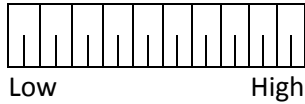
1	2	3	4	5
---	---	---	---	---

10. Ho avuto bisogno di imparare molti processi prima di riuscire ad utilizzare al meglio il sistema

1	2	3	4	5
---	---	---	---	---

4. NASA Task Load Index → before and after the introduction of the HUMAN system

Mental Demand



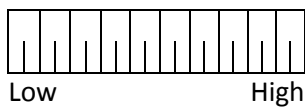
How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand



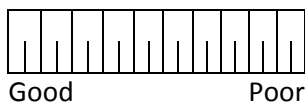
How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand



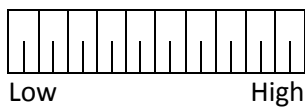
How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance



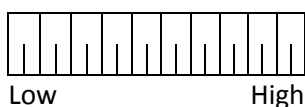
How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Effort



How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration



How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Italian translation:

Impegno mentale richiesto

Quanto era mentalmente impegnativo il compito?

Molto basso

Molto alto



Impegno fisico richiesto

Quanto era fisicamente impegnativo il compito?

Molto basso

Molto alto



Impegno di tempo richiesto

Quanto pressante era il ritmo di esecuzione del compito?

Molto basso

Molto alto



Prestazione

Quanto sei riuscito a portare a termine ciò che ti è stato richiesto di fare?

Perfetto

Fallimento



Sforzo

Quanto duramente hai dovuto lavorare per arrivare al livello della prestazione che hai raggiunto?

Molto basso

Molto alto



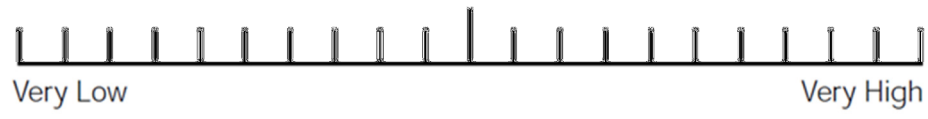
Frustrazione

Quanto ti sei sentito insicuro, scoraggiato, irritato, stressato ed infastidito

Molto

basso

Molto alto



6. NEXT STEPS

D7.1 as the outcome of the task 7.1 continues in time with the three industrial pilot evaluation activities, namely tasks 7.2, 7.3 and 7.4. These parallel tasks deal with a main common goal, the evaluation of the HUMAN system in the three real scenarios of the pilots. Each one of them will have a current organization baseline definition, analyze the gap for HUMAN, devising a deployment plan, create workshops for local stakeholders, and most importantly, validate and gather feedback from these stakeholders.

T7.5 will pick all this up and analyze all the data captured from the three pilots along with problems encountered, performance results, and impact. Suggestions for improvements will also be assembled. The results of this final WP7 task will be a set of lessons learned and a list of potential improvements to the HUMAN solution.

7. REFERENCES

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8. APPENDIX I - PI specification sheet

Template for detailing the PI information and gathering its main characteristics, the PI specification sheet is used following the ECOGRAI methodology.

Table 16 - PI specification sheet (generic template)

Performance Indicator ID (Pilot_PI(x)) – PI title (e.g. Pilot_PI2 – Number of improvement suggestions from workers)	
Evaluation mode (Performance metrics)	Explanation of the formula or way to measure the PI.
Objective	The objective connected to the PI. (e.g. <i>To increase the worker's competence</i>)
Target audience	To whom (service / person) the value of PI is addressed. (e.g. <i>worker at shop floor</i>).
Driver	HUMAN technology to be applied
PI nature	Quantitative or Qualitative
Information source	The information (data) source(s) needed to calculate the PI.
AS IS Value	Value of the "PI" during a period before the Driver implementation (e.g. <i>10</i>)
TO BE Value	Value of the "PI" during a period after the Driver implementation (e.g. <i>12</i>)
Required evolution (Target)	The value of the PI which is necessary to reach. (e.g. <i>13 (an increase of 30 percent)</i>)
The owner (Who measures)	Person responsible of the domain in which the PI is
Period	The interval of time to evaluate the value of the PI. This interval should be significant according the evolution of the system. The period depends on the evolution of the system (if the evolution is important, the period of evaluation decreases).
Actions to react depending on the PI value	Action (on the concerned driver) that the owner takes to evolve in the right direction.