D6.5 White paper Report on best practices for HRC integration into production

Project ref. no.	H2020-NMBP-FOF-2018 Nº 820807
Project title	Safe and effective human-robot cooperation towards a better competitiveness on current automation lack manufacturing processes.
Project duration	1st November 2018 – 31st October 2022 (42 months)
Website	www.sharework-project.eu
Related WP/Task	WP6 / T6.1, T6.2, T6.3, T6.4
Dissemination level	CONFIDENTIAL
Document due date	31/10/2022 (M48)
Actual delivery date	31/10/2022 (M48)
Deliverable leader	STRANE INNOVATION
Document status	Draft

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 820807

Revision History

Version	Date	Author	Document history/approvals
1.0	04/10/2022	Aurélie Vonsy (STRANE)	Draft version circulated for internal review
1.5	07/10/2022	Tiffany Morisseau (STRANE)	Internal review
2.0	17/10/2022	Aurélie Vonsy (STRANE)	Draft version circulated to partners
2.0	25/10/2022	Tiffany Morisseau (STRANE)	Internal review
2.0	26/10/2022	Francesca Canale (STAM)	Review
3.0	28/10/2022	Alexandra Jaunet (STRANE)	Final complete version
3.0	28/10/2022	Project Coordinator	Submission

Executive Summary

This document reviews the best practices stemming from the Sharework project, contributing to a smooth cobot integration on the workplace from a human factors point of view. It was written based on four project's use cases and focuses on a number of success factors that were identified for all the use cases. Cobots are a costly investment that aim to reduce ergonomics issue, mental load and increase productivity. How the final users perform with them is thus a key element of successful integration. Any robot integration should be carefully prepared to make sure that the social terrain is ready, and that the technology can adapt to how the operators work (and not the other way around). Three indicators were measured in collaboration with the operators themselves: trust, situational awareness, and cognitive load. We also identified six key points for a successful integration, which focus on the integrator's location, the operators' expertise in the task, their perception of technology, the feeling of safety around the robot, how operator's feedback is addressed and the involvement of the management team.

NOTE: Front page and Executive summary will be published in the website for all deliverables

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Terminology and Acronyms

AR	*Augmented reality*
BAU	*Business As Usual*
HHC	*Human-human collaboration*
HRC	*Human-robot collaboration*
HRI	*Human robot interaction*
KPI	*Key performance indicator*
SAGAT	*Situational Awareness Global Assessment Technique*

1. Introduction

Since the early 2000s, consumption and economic behaviours have shifted from mass production and standardization to small series and customization. To face this new demand, the variety of products that a manufacturing system must deliver has dramatically increased, adding to ever-increasing complexity of manufactured systems (e.g.: cars have more and more electronic systems on board).

Consequently, the whole production process in a factory is often required to evolve, and operators must learn and adapt to these changes. New products and procedures often mean more complex information streams, which can in turn cause cognitive fatigue, along with physical efforts, among the employees.

In this context, more and more collaborative robots, or cobots, are being introduced in the workplace. These robots can perform low value-added tasks (e.g.: carrying heavy loads, which involves ergonomics issues) but also support to the operators in eliminating human errors involved in the manufacturing of several distinct products in a row.

This white paper aims to summarize the results of the human factor research in the Sharework project, together with the best practices that were identified for a better human-robot collaboration.

This report has been written using all available information at the time of publication. Noteworthily, the results of the experimentations run at the SEAT and ALSTOM facilities – run in late September 2022 – were not included.

2. Preparing and installing a collaborative robot in the workplace

2.1 Definition of a collaborative robot

There are several levels of collaboration between a robot and a human, described here below. The more collaborative the task, the more human factors must be considered.

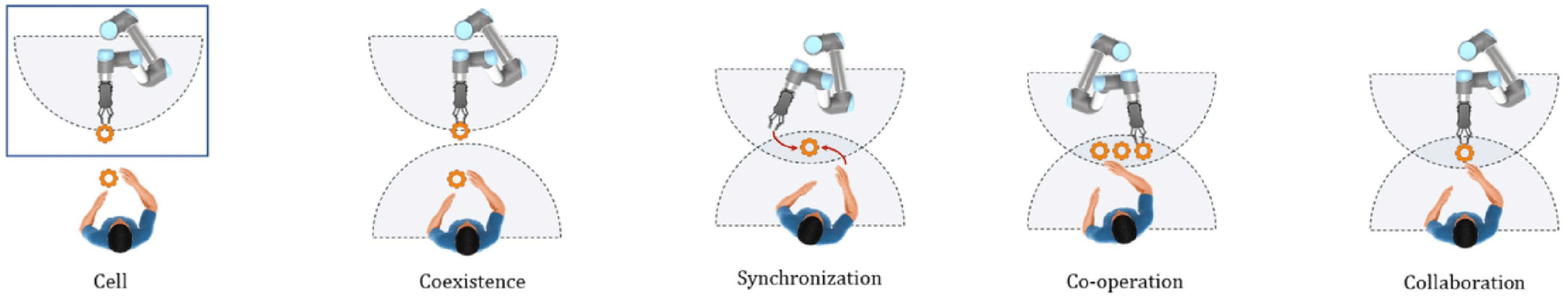

Figure 1: Levels of engagement between human and robot based on time and space sharing (Malik & Bilber, 2019)

Low Human factors impact on production

High Human factors impact on production

The robot operates in a closed environment (or cage) and moves only when the cell door is closed, and no human is in its operating area. There is no collaboration.

The robot does not have a physical cell or cage, there is colocation without interaction between the operator and the robot, as they do not share a workspace

The operator and the robot share a workspace but only one of the interaction partners is present in the workspace at any given time.

The operator and the robot share the same workspace, at the same time, but they do not work simultaneously on the same product or component and do not have the same tasks.

The operator and the robot work in the same workspace, on the same product or component and they share the same goal with reciprocal consequences (the actions of the robot influence the operator and vice versa).

One of the main benefits a cobot brings to the workplace is the increased efficiency of both the human and the robot. With cobots being able to perform more tasks more rapidly, workflows are completed faster – with the added benefit of human insight, thanks to the collaborative nature of the process.

2.2 What are the advantages of a cobot for industries?

A robot (including a cobot) generally represents a significant investment for a company, and its function should thus be carefully studied.

In all cases, the integration of a robot aims to relieve human operators in their work, as it can lift heavy weights without ergonomic issues and without the physical and mental fatigue caused by the repetition of the same movement all day long. On the other hand, a robot may not have the human's efficiency to detect visual defects or "feel" the product's quality associated with years of experience.

Examples of manual tasks that could be replaced by a robot or a cobot

- Palletization of the same items over several days
- Sanding parts with a sand blaster (heavy and straining)
- Positioning of heavy standard parts
- Application of tape on a set path

If the task is very repetitive (for example, the same movement over several months), it may be interesting to look at a caged robot integration to relieve altogether the operator of the task. However, if the task at hand is complex, the cost of a caged robot can rapidly soar, as automation is time consuming and equipment price rises with complexity.

In such cases, a cobot may be a good solution in terms of time and costs: the task can be split between the robot and the human operator, so as to reduce the complexity of the cobot's task.

A cobot is also a suitable alternative to a caged robot in case of small areas, as it only requires a limited amount of space and can be mounted on wheels to move from line to line, while a caged robot, by definition, cannot share its workspace with operators and has a fixed position.

Risks of a mismanaged cobot integration

The introduction of a cobot on the workplace includes many human factors related risks, including[1]:

- a perceived threat towards job security, fear of being replaced
- a perceived loss of job control, fear of being monitored
- lower perceived influence, feeling of worthlessness

In the worst cases of cobot integration, workers may misuse the robot, leading to a strong increase in maintenance and productivity costs.

[1] See Sharework deliverable D6.2 for a detailed description of these risks.

Below are two tasks that benefited from automation during the Sharework project.

Goizper use case: Automation of the rotation of the turntable for quality check

Description of the task without the robot:

- changing the turntable position by a few degrees by rotating a shaft on the side of the box
- checking the contact inside the box by looking through the holes located on another side of the box
- repeating this task every few degrees of rotation until the whole table is checked

Description of the task with the robot:

- getting positionned to check the contact through the two holes
- ordering the rotation of the table (two levels of speed available)

Figure 2 : Goizper use case without cobot

Figure 3 : Goizper use case with cobot

SEAT use case: Automation of the moving and positioning of a car hood

Description of the task without the robot:

- two operators required to carry the hood (about 30 kg) from the storage jig to the working area
- one operator carries most of the weight of the hood and adjusts its position while the other holds it and screws it to the car structure (2 screws on the right, 2 on the left)

Description of the task with the robot:

- one operator controls the robot's tasks with AR and a smart watch
- the operator can adjust the hood's position with the AR display or with the watch, and screws it effortlessly, as all the weight is held by the robot

Figure 4 : SEAT use case without cobot

Figure 5 : SEAT use case with cobot

2.3 Key points before integrating a robot

Before any implementation of a cobot, an evaluation assessing the maturity of the whole ecosystem in the factory (operators, technology, management, social context) should be performed.

The **USUS model**, proposed by Weiss et al. (2009), is a useful tool for such evaluation. It identifies 4 pillars to build a successful HRI:

- Usability is the indicator of how a product can be used by specific users to perform a task with effectiveness, efficiency, and satisfaction.
- Social acceptance is the readiness of the targeted group to use the technology to accomplish the designated tasks.
- User experience is the way users interact with the product, how it feels in their hands, how well they understand the system, and how easy it is to use.
- Social impact describes "all effects the introduction of robotic agent consequences for the social life of a specific community (taking into account cultural differences) in terms of quality of life, working conditions and employment, and education."

A robot that is difficult to handle for a novice (that is, with no previous experience with a robot) will require further modifications on the user experience to ensure optimal use and collaboration. In such case, including the workers in the design of the user interface is a critical step to gain acceptance and trust. This will be the topic of section 3 "Best practices to ensure acceptability and acceptance of a robot in the workplace".

Regarding social aspects, management may also have to ensure that operators' fears are addressed, along with any question they may have about the system. For instance, cobots may be perceived as a threat to their working conditions and employment, with the fear of being replaced at some point.

If one of these pillars is not proven strong enough (the robot itself, its functions, the industrial environment, or a combination of the three), there is a risk that human-cobot interactions in that context will not be as successful as expected.

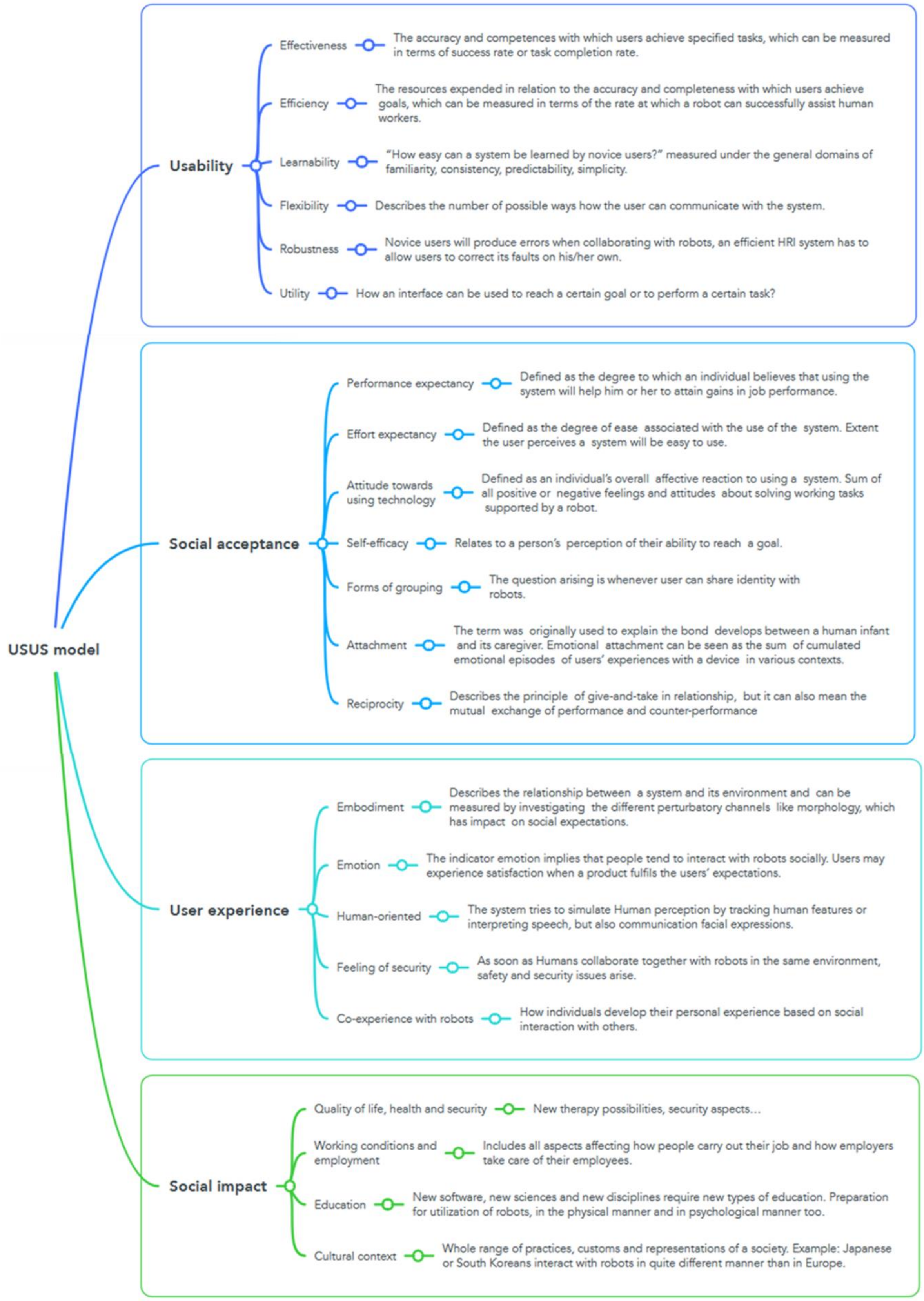

Figure 6 : the USUS model, adapted from Weiss et al. (2009)

2.4 Measuring HRC performance: useful KPIs

In order to achieve optimal HRC, 3 KPIs were defined at the beginning of the Sharework project[2], based on a literature review on social neurosciences, psychology and anthropology: trust, cognition and situational awareness. For each of them, we identified a suitable measurement methodology.

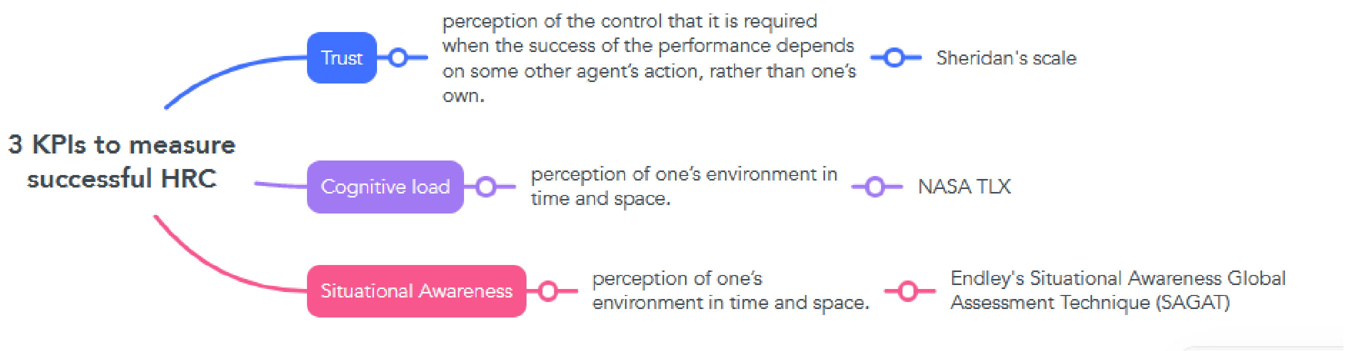

Figure 7 : the 3 KPIs used in Sharework

The first of these KPI is **trust**. For its evaluation, we used Sheridan's scale (1988, 2019), defined as follows**.**

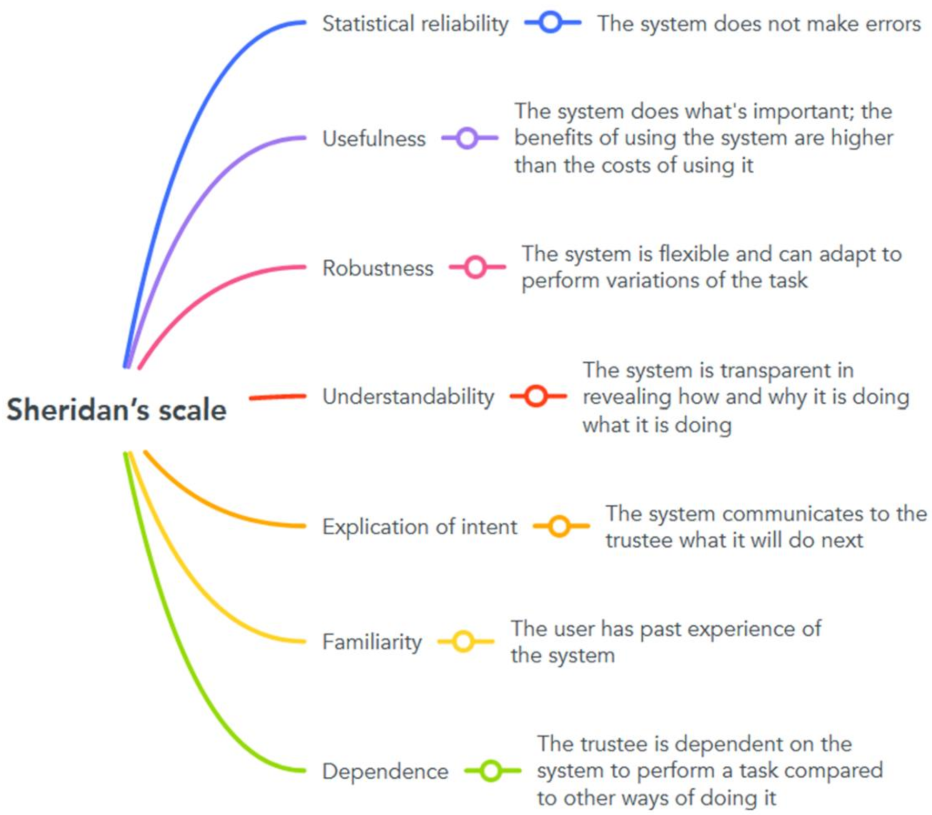

Figure 8 : Sheridan's scale, adapted from Sheridan, T. B. (2019).

[2] See Sharework deliverable D6.1.

Cognitive load is related to the amount of attentional or working memory resources needed to solve a task. Cognitive load is very subjective and depends both on the complexity of the task and on the individual (a worker with more expertise will experience less cognitive load than a novice). In Sharework, we chose the NASA TLX scale (Colligan, et al., 2015), available in annex, to evaluate this KPI.

Finally, **situational awareness (SA)** is the perception of one's environment in time and space. To measure this KPI, we used Endsley's Situational Awareness Global Assessment Technique (SAGAT) (Endsley, 1987). Endsley identified three levels of SA:

- Perception: one can see its environment and its movements
- Comprehension: one can recognize patterns and understand how its environment will affect one's goals
- Projection: one can extrapolate from perception and comprehension future states of the system in movement.

An assessment of these 3 KPIs should be performed before and after the cobot's integration, to measure the impact of the robot on the operator.

In the Sharework use cases, we used set questionnaires for all the use cases and observed the operators while they were performing their tasks, only asking questions during short interruptions. The initial KPI evaluation was realised with the "business as usual" scenario (without the robot) and the second was realised with the cobot developed within Sharework[3].

Below is an extract of the cognitive load results from the Cembre use case, showing a discrepancy between the perception of the collaborative task without the robot (Business as Usual) and with the robot (Human-Robot Collaboration) during the cognitive load assessment.

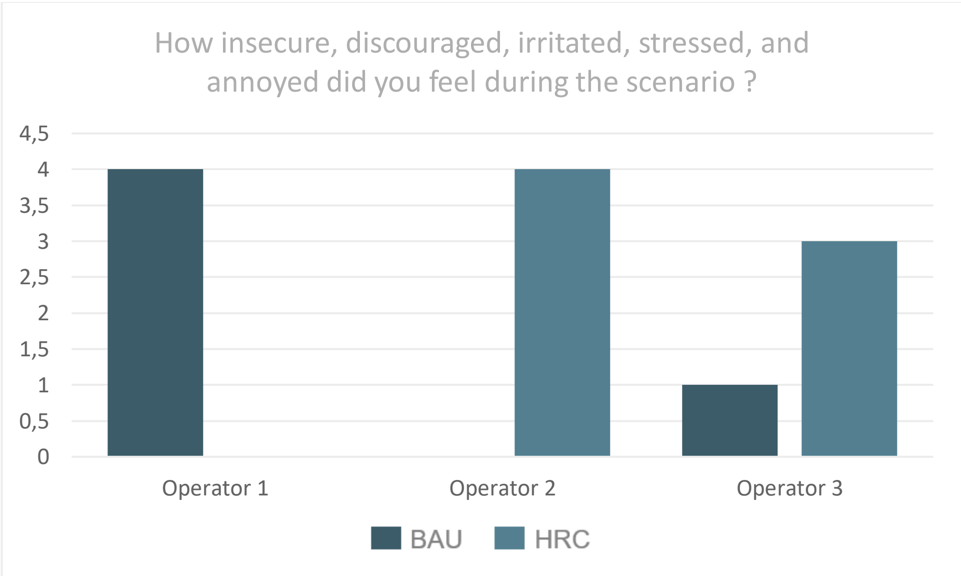

Figure 9 Extract of the cognitive load results from Cembre use case

This demonstrates the importance of carefully assessing the perception of all operators to tackle any emerging issue, such as a feeling of being more irritated with the robot rather than without.

[3] See Sharework deliverable D6.4

3. Best practices to ensure acceptability and acceptance of a robot in the workplace

Key learnings from the Sharework Project

1. **Choose a close-by integrator**
2. **Understand how the cobot is perceived by workers**
3. **Get the operators' expertise**
4. **Involve management**
5. **Train the operators and explain the safety rules of the cobot**
6. **Collect feedback and identify improvement points**

3.1 Choose a close-by integrator

The Sharework use cases were located in Spain and Italy, while the other technical partners were from Spain, Greece, Italy and Germany. Easy connections (by road, railway or air transport) between the industrial sites and their technical partners have proven critical. This turned out to be a key success factor for on-time integration, especially when considering that international travel was impacted by covid restrictions while the project was running.

Thus, choosing an integrator that is able to come on-site at least once a month, if not once a week, during the entire length of the project, would be highly recommended. To further facilitate knowledge transmission between the integrators and the operators, speaking the same language is also important, as one's mother tongue is the best language to express any concerns or comments.

3.2 Understand how the cobot is perceived by the workers

Trust is a key element of a successful HRC. Therefore, a proper assessment of how the robot is actually perceived is highly recommended. This will allow the early identification of any prejudice or issue at play together with suitable solutions.

For the Sharework project, we developed a questionnaire based on the European Working Conditions Surveys (EWCS, 2015; see Appendix) to understand the operators' perception of the robot before any interaction. The questionnaire included 7 dimensions: performance expectation, effort expectation, social influence, facilitating conditions, attitude towards the technology, anxiety and job contents.

Based on the results of this questionnaire, discussions were held with the operators. These discussions allowed us to identify a number of issues that we would focus on during the implementation phase.

3.3 Get the operators' expertise

Operators are the main people who will eventually get to handle the final product, sometimes for 8 hours a day, which makes it important for them to be involved from the very beginning. Because they are expert of the current process that will be replaced by a cobot, they can provide extremely valuable knowledge about it, including on the associated social context and job-specific difficulties. They can make suggestions that would involve a minor change in the system but substantial improvement on their work quality. As final users, they can be an important source of ergonomics improvement and should be consulted to make sure all safety features will be adapted to them (and not the other way around).

For example, some systems in Sharework needed to recognize human gestures. However, in the Goizper use case, a hardware incompatibility issue switched the initial 4-cameras tracking to a single camera. It caused the system not to properly recognize the operators' gestures used to command the rotation of the rotary table in the second Goizper scenario. It was therefore slightly more difficult to handle, as the operators had to make themselves "smaller" to be seen by the system.

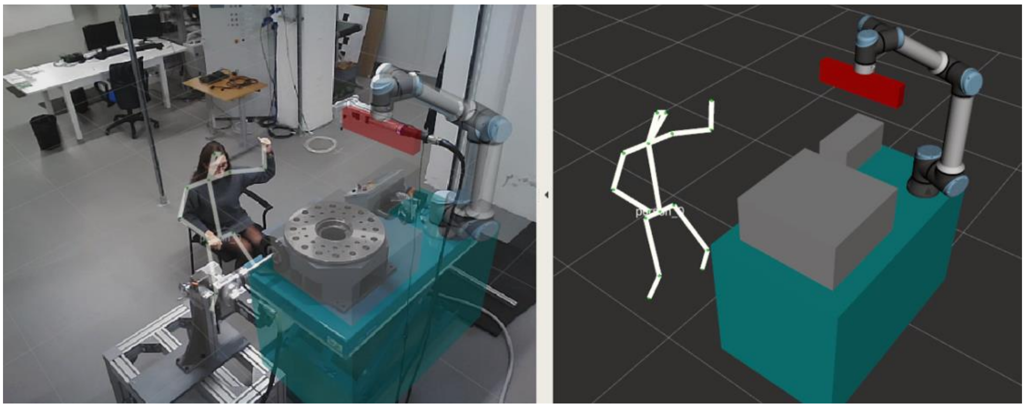

Figure 10 : STAM demonstrator for Goizper second scenario human gestures recognition (source: STAM).

Involving operators early in the process has also a training benefit: they learn how the system works over the course of a few months rather than in a dense half day training session.

3.4 Involve management

Prior to the robot integration, an assessment of innovation management and work culture should be performed. This includes for instance the company culture, the way innovation is usually introduced, and any current events relevant to the company's project to integrate robots or cobots in the production lines. The objective of such assessment is to make sure that innovation will be optimally introduced. For example, if the company has faced a previous failure in innovation integration, it should be taken into account when introducing the robot in the workplace.

Keeping an open discussion with management during implementation is important. Even if all objectives are shared at the beginning, unexpected events may happen (in the case of Sharework, it was the Covid-19 pandemic) that can shift priorities and technical possibilities. Thus, it is important to manage expectations so that the management is not disappointed by the delivery and understands that extra time may be needed between the delivery of a cobot and its full launch into industrial conditions.

3.5 Train the operators and explain the safety rules of the cobot

Along with the robot, training of operators is an investment in time and may be perceived as a punctual loss of productivity, when it is in fact an essential step in robot integration. All operators whose tasks are impacted by the robot should be trained, and it is of critical importance that the training contains all necessary information about the safety measures and rules.

Recommended training sequence

Day 1

- Introduction of the system and its functions, with a video of the process, possibly with a 3D animation
- Explanation of the controls, description of the tasks, demonstration by the integrator

Day 2

- Demonstration of safety measures (slowing down of the robot, stop, collision force) with voluntary workers able to physically test the effectiveness of the safety rules
- Hand-on practice of the system with full support from the integrator, answering questions and detailing instructions

Day 3 and following days

- New iterations of hand-on practice of the system, with support from the integrator gradually decreasing over time

An example of good practice during the demonstration of safety measures is to test with the operators the case of a human-robot collision. The integrator can provide a first demonstration and then ask voluntary workers to experience the collision. As the collision should be unharmful, it may reassure workers on any consequence of an accidental collision with the robot during the task.

In the Cembre use case, because operators had not previously experienced the safety measures, stress remained noticeable (via heartbeat monitoring) during the experimentations.

Figure 11 A Cembre operator with high cardiac frequency when collaborating with the robot

Training should be delivered in the workers' usual language to ensure that they can express all their questions and uncertainties and receive adequate answers. An alternative option that was used in the SEAT use case was to dedicate a translator to the training phase. We also recommend that the integrator provides a user's manual with all step-by-step information, including as many pictures as possible to avoid long texts.

The organization of a collective training gathering all the operators can be a good option, because it allows operators to both answer one another and follow their own individual learning curve.

For the SEAT use case, the demonstrator involved Augmented Reality (AR).

AR training can prove especially useful if operators are only used to caged robots. Training can happen outside of the production line, thus avoiding the associated risks of industrial environment and maximizing its acceptance.

The SEAT demonstrator offered two different modes: 1) a **training mode** where the robot didn't move. In this mode, each step was displayed on the glasses, including a hologram of the moving. It showed where to position oneself and what each individual task consisted of; 2) and an **assistive mode**, where the robot was effectively doing the tasks and moving according to the movements shown in the training mode.

The case of AR training

Augmented Reality is a great way to increase the learning speed, as it can help with cognitive load and have operators see directly through the glasses the actions to execute rather than following a hands-off training or searching through the documentation of the system.

AR can allow the operator to visualize the trajectory of a cobot, hence increasing trust and situational awareness.

It is however necessary to be careful, as too much information on the glasses may overwhelm the operator and go against the objective to lighten cognitive load.

Figure 12 : Training session at SEAT

Because there was only one set of glasses and watch, operators successively watched what one of them was doing. A screen displayed what was seen in the glasses. They could thus become gradually familiar with the task sequence, the commands and the actions and movements of the cobot.

3.6 Collect feedback and identify improvement points

During and after the integration of a cobot, all feedbacks from operators, management and technical partners should be collected to identify improvement points. To this end, we recommend the organization of at least one focus group at the end of the implementation with all the stakeholders, including integrators, managers, and operators, along with any other partners involved. Feedbacks should especially come from the operators themselves, as they are the ones who will both get to handle the system and feel in control and at ease while using it.

For example, one particular piece of feedback came up in several use cases: the need to have a signal (be it a light or a coloured message for example) to indicate that the task of the robot was over, and that the worker could keep going.

Management can learn and record all those improvement points so that the next robot integration becomes even smoother.

4. Conclusion

Integrating a robot is a complex technical and technological investment, and as such, it must involve a close monitoring of human factors aspects during the entire process.

Final users must be included as much as possible during the design phase and their feedback must be carefully listened to by the integrators. As experts of their task and of their working context, operators are in the front line to understand their own ergonomic needs. They also need to be reassured about their own safety, to have a clear understanding of how the robot works and how it will make their task easier. At the end of the integration journey, how the operators feel, use, and understand the robot will be a major factor of its success or failure.

5. Appendix

European Working Conditions Surveys (EWCS, 2015) adapted for the purpose of Sharework.

This questionnaire was used to understand how the operators perceived the integration of a robot in their workplace, before they saw the robot.

Dimension	Question selected
Performance expectancy	Using the collaborative robot will : 1. increase my effectiveness 2. increase my productivity 3. improve the quality of output of my job 4. makes my job easier 5. reduce the time I spend on routine tasks
Effort expectancy	6. Learning to operate the collaborative robot would be easy for me 7. I believe that it is easy to get the collaborative robot to do what I want it to do 8. I think that the interaction with the collaborative robot will be clear and understandable 9. It would be easy for me to become skillful at using the collaborative robot
Social influence	10. The proportion of coworkers will influence my use of the collaborative robot 11. My supervisor is very supportive of the use of the collaborative robot for my job 12. In general, the organization supports the use of the collaborative robot
Facilitating conditions	13. Using the collaborative robot is compatible with the main aspects of my work 14. I think that using the collaborative robot fits well with the way I like to work 15. I am confident that I will be given the necessary knowledge to use the collaborative robot
Attitude toward using technology	16. Using a collaborative robot is a good idea 17. Using a collaborative robot is a foolish idea 18. I like the idea of using a collaborative robot 19. Using a collaborative robot is unpleasant
Anxiety	20. I feel apprehensive about using the collaborative robot 21. It scares me to think that I could make mistakes I could not correct using the collaborative robot 22. I am confident in my ability to control the collaborative robot 23. I believe that I can use a collaborative robot securely
Job content	Working with a collaborative robot will : 24. make my job more interesting 25. get me more responsabilities in my work 26. enable me to gain new skills 27. reduce my autonomy 28. make me proud

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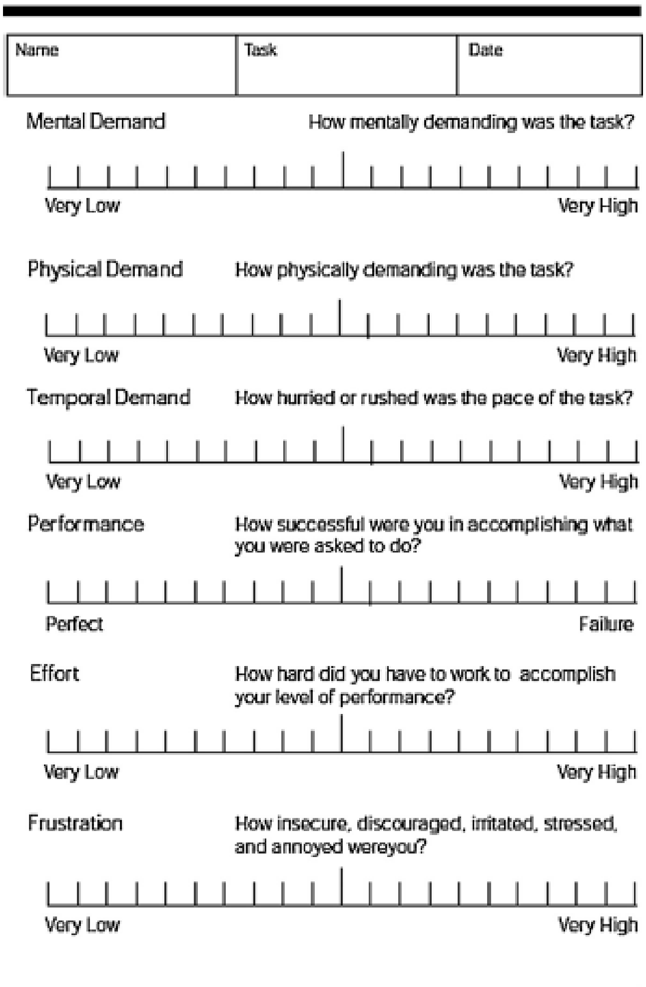
7. Annex

NASA – TLX Scale



Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Figure 13 - NASA – TLX Scale (source: Colligan et al., 2015)