Project Deliverable 6.4

Final Evaluation Report

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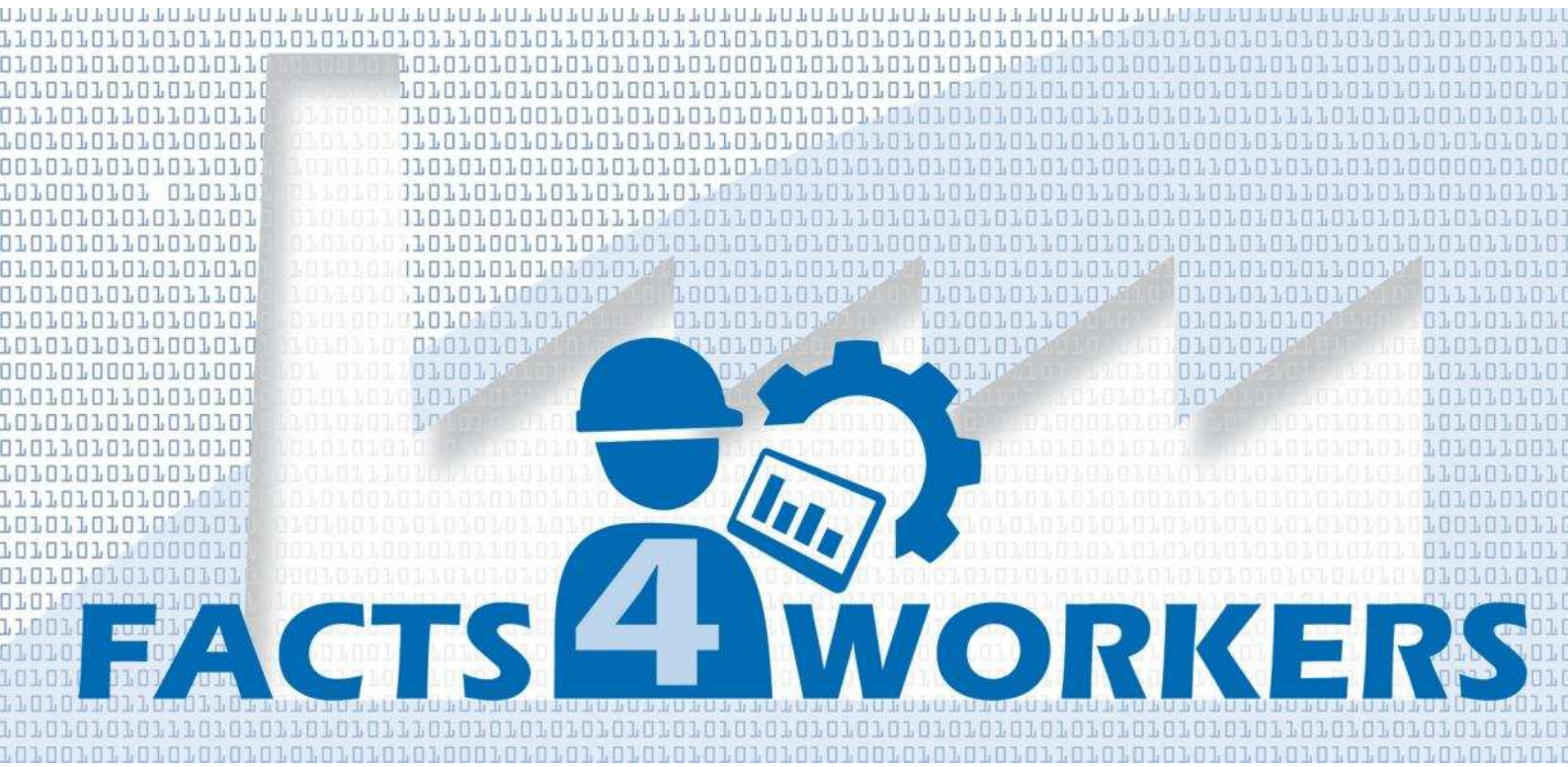

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About this document

Executive Summary

This deliverable is the last report of WP6. It presents the results of four years of work performed by the members of the FACTS4WORKERS consortium. More specifically, this document presents the results of the evaluations of eight prototypes implementing IT worker centred solutions for meeting workers information requirements as defined by the eight use cases identified in the six industrial partners of the consortium.

After briefly presenting the evaluation framework, the evaluations of the 8 prototypes implementing the worker centered solutions use case requirements are presented. From the industrial partner description, the use case definition and the evaluation selected methods the results and conclusions of each evaluation are presented.

Use case results are uses for extracting project level conclusions, both from the validation of the prototypes point of view and from the impact derived of their introduction. Validation results can be considered technological challenges, risk or actual limitations to be considered when an Industry 4.0 is started. They can explain the obtained project results, the degree of objectives achievement, which are determined based on the use case assessed impact.

Finally regarding for future framework improvements, this document also presented the learned lessons found during the different evaluation processes.

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Index of Abbreviations

AR ..... Augmented Reality

BB ..... Building Block

CA ..... Classical Approaches

EMO ..... EMO Orodjarna d.o.o.

HCI..... Human Computer Interaction

HID ..... Hidria Technology Centre d.o.o.

HMI ..... Human Machine Interaction

IA..... Impact Analysis

IC ..... Industrial Challenge

IP ..... Industrial Partner

KMS ..... Knowledge Management System

PQ..... Process of Quantification

SCA ..... Schaeffler AG

THO ..... Thermolympic S.L.

TKSE ..... thyssenkrupp Steel Europe AG

UC..... Use Case

1 Introduction

This deliverable is the last report of WP6. It presents the results of four years of work performed by the members of the FACTS4WORKERS consortium. More specifically this document presents the results of the evaluations of eight prototypes implementing IT worker centred solutions for meeting workers information requirements as defined by the eight use cases identified in the six industrial partners of the consortium.

The prototypes are evaluated using the FACTS4WORKERS evaluation framework which was defined in D6.1 (Lacueva et al. 2015). The framework, the strategy for evaluating a given prototype and the guidelines for evaluating the results are briefly introduced in chapter 2 of this document. Evaluations are performed assessing the impact that deployed artefacts have in workers but also trying to determine the quality of the prototypes (of their provided information, their interaction capabilities and of their system robustness and performance).

During the FACTS4WORKERS an evaluation was performed each time an artefact is presented to the workers or deployed to be used by workers. Chapter 3 of this report present the evaluations for each of the eight use cases. In order to make it possible reader can get the context of the evaluations, each industrial partner, its context and its use cases are briefly introduced. Then, the considered evaluation methods are presented together with the results both from validation and impact assessment. These results are used for extracting the conclusions at the use case level by trying to answer the questions: Does the prototype induce expected impact or not? Does the prototype meet workers Requirements?

From the conclusions at use case level we created the conclusions at project level. First the validation conclusions are presented by summarizing main issues found in each use case either if they are relevant enough or if they are common to several use cases. These issues can be considered challenges, risks or limitations to be considered when starting an Industry 4.0 project. Although the frontier between information, usability, devices and infrastructure we use these classes for presenting detected issues in an order way in chapter 4.1.

Chapter 4.2 present the impact assessment at project level. In other words, these paragraphs present the degree of achievement of project objectives. In this chapter we aggregate use cases' results for base our conclusions.

Chapter 4 finalizes with a review of the learned lessons and future improvements after using our framework.

Finally chapter 5 presents the conclusions about the whole evaluation process.

2 Evaluation Process

2.1 Evaluation Process Overview

The evaluation process derives from the evaluation framework defined in the deliverable 6.1 (Lacueva et al., 2016) and is defined in D6.2 (Gracia et. al., 2017). This framework divides the evaluation in two different concepts: Impact Analysis (IA) and Validation, following the work of Gable et al. (2008) as Figure 1 shows.

The IA is used for assessing the designed artefacts' impact on individual and organizational levels. According to the project's main goal, the individual impact comprises job satisfaction as well as innovation and problem-solving skills, whereas the impact on an organizational level includes measures of productivity. For measuring the impact, the following dimensions which represent our project goals, are used: 1) autonomy, 2) competence, 3) variety, 4) relatedness, 5) protection, 6) efficiency, and 7) quality. Finally, it anticipates the expected impact IS artefacts would have on the IPs context of use.

The Validation refers to the process of determination if the evaluated artefact provides the (system, information and interaction) quality the user expects. The results of the validation strongly depend on the maturity of the artefacts. If we consider a mock-up/demonstrator, a functional prototype/pilot or a deployed solution, we can expect to probe the functional feasibility of an idea (proof of concept), the value provided by a solution (proof of value) or the capability of a solution for addressing complex issues of operational feasibility (proof of use).

In the different stages of maturity of the prototypes, the Validation is a process to determine, monitor and get feedback of the solution proposed and if it suits the demands of workers in order to solve the requirements. This means that independently of the maturity of the prototype the TRL reached (not intended to achieve the highest TRLs since FACTS4WORKERS is a research project), the functionality of the prototypes should be ensured and new functionalities and improvements developed will be determined in the successive validations. In case we did not proceed this way, there would be the risk of having to reconsider the results as not appropriate as biased by missing quality of the prototypes.

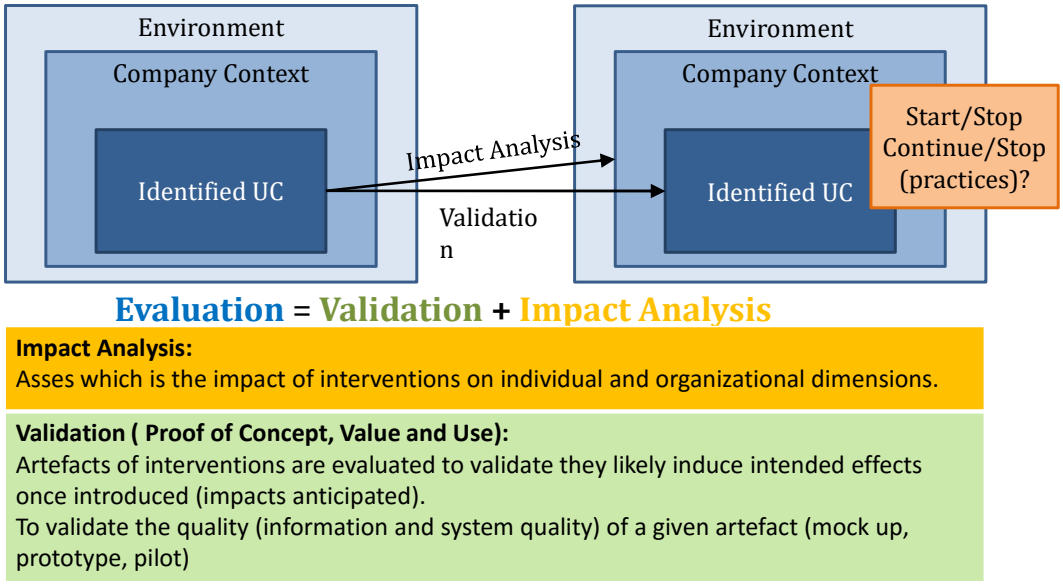


Figure 1. Overview of the evaluation

As mentioned above, for achieving these goals, the time dimension and the maturity of the prototypes are important. As the project progresses the focus of the evaluation moves from the validation (of the design of the artefact) to the assessment of the impact. Moreover, as the artefact of the intervention matures, application and log data would become available and they will support less intrusive measurements methods. Finally, time and maturity will determine when the selected tool/method could be applied (ex-ante, on-going, ex-post) and the kind of data to be obtained (quantitative, qualitative).

Figure 2 highlights the role of time and maturity by contrasting different classical and technological approaches.

Classical approaches (CA) are worker driven. Data are directly obtained from workers by interviewing or surveying them. Under this category, we consider the set of tools is the academic SotA of tools and methods for evaluating purposes. In addition to these academic approaches, as the project provides workers with prototypes for use in short/long term periods, also Technological Approaches (TA) could be taken in advantage and get some associated metrics.

The use of these solutions usually generates large amounts of data (logs, content/application data) that can be used to analyse how the worker is interacting with them as well as, to analyse workers' performance by using the solution. Under the category of TA different tools and methods are considered which take advantage of this data, wherever, observing the legal conditions, application data can be accessed and/or the logger Building Block (BB) can be deployed and configured.

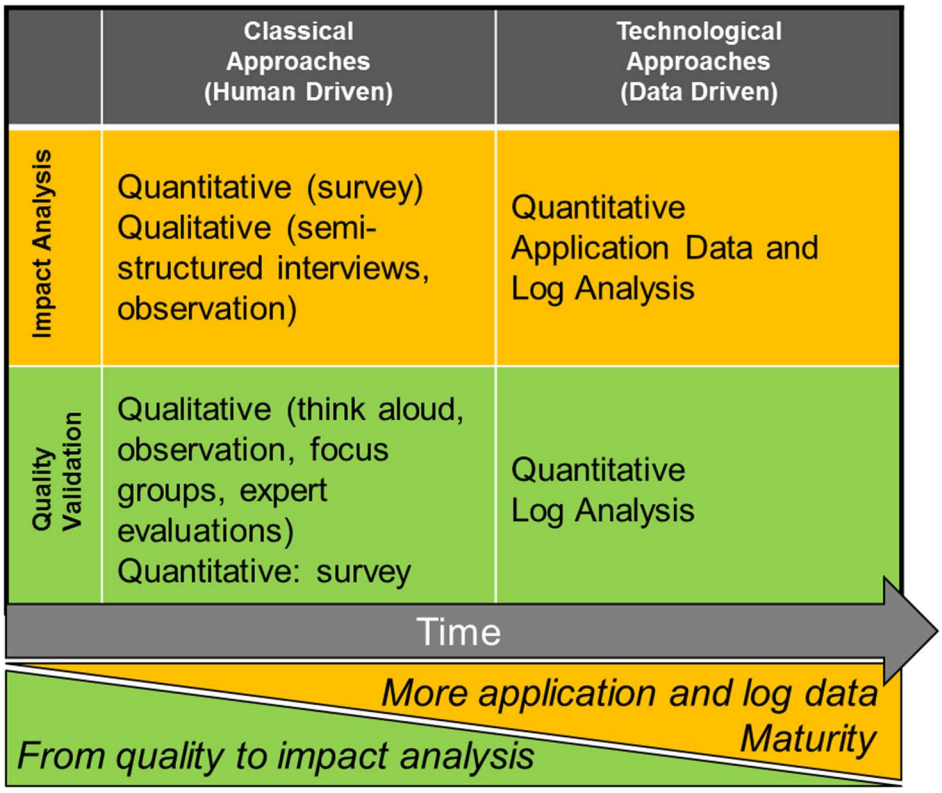


Figure 2. Tools and methods for the evaluation framework

For measuring the impact of the FACTS4WORKERS interventions, we assess job satisfaction, problem solving & innovation skills and productivity. They are measured using evaluations. The data and insights obtained are related to the dimensions which base on the project goals and which are defined in D1.1 (Heinrich et. al., 2015): autonomy, competence, variety, relatedness, protection, efficiency and quality. To assess the impact, different strategies will be defined using questionnaires, interviews, log or machine data, etc. Although the PQ is defined in Deliverable D6.2 and it is briefly described in chapter 0 of this document (D6.3), here we focus on the fulfillment of worker requirements and how this has been addressed within FACTS4WORKERS project

On the other hand, the validation activities are focused on assessing the quality of a presented artifact as it is a determinant of its acceptance, its use, its success and, in consequence, of the supported/induced changes in individuals and/or organizations(Delone, 2003)(Venkatesh, 2003). Different methods, for example: interviews, observation, and questionnaires, are proposed in order to get insights from the users about the artifact under evaluation. The important point for performing the validation is to determine, based on the maturity level of the artifact, the particular method to be used, the objective of the validation and its focus, the functionalities to be validated, the information used by them and the usability of the interaction interfaces (both software and hardware).

Because the ICT solutions are evolving at every stage of the project we have different maturity levels: paper based mock-ups, clickable one, first prototypes, and pilots. In each context of use, we will define a validation session to evaluate the different artefacts. The common idea with the validation is to focus on the system quality and information quality dimensions, assessing different key indicators, such as: perceived ease of use, perceived usefulness, information accuracy and data relevance to get data and valuable insights in order to forward the prototype developments with requirement redefinitions and new improvements following the perpetual beta development approach defined in FACTS4WORKERS.

2.1.1 Impact Assessment Quantification Process

The Process of Quantification (PQ) of the IA is described in the Deliverable D6.2. It has the objective of calculating indicator of impact of interventions on ID respecting, worker anonymity as far as possible. It requires the combination of data gathered using both CA and TA tools. That means dealing with multisource data, having different metrics. These raw data must converge in common metrics which can be used for determining the degree of project objectives achievement. The definition of the quantification and interpretation strategies are based on the Goal-Question-Measurement process defined by (Basili, 1994) and the processes followed in Big Data projects for transforming data in knowledge (Chen, 2014)

This problem formulation, how to move from raw data to a set of project KPIs, can be divided in more specific problems to be solved considering the different features of the handled data and of the surrounding evaluation environment. These sub-problems are described in next paragraphs.

Dealing with External Factors

As it is shown in Figure 3 temporary events affects emotions like happiness. In consequence, the effect of external factors in the results of evaluations must be determined. External factors biases can be determined using a CG of workers (workers not using FACTS4WORKERS solutions). However, as the temporary events can affect feelings evolve in time (Stones, 1999) and they affect both CG and FACTS4WORKERS. In consequence, although the effect of temporary events quickly blurred after it is finished, as Figure 3 shows, they can compromise the results of an evaluation.

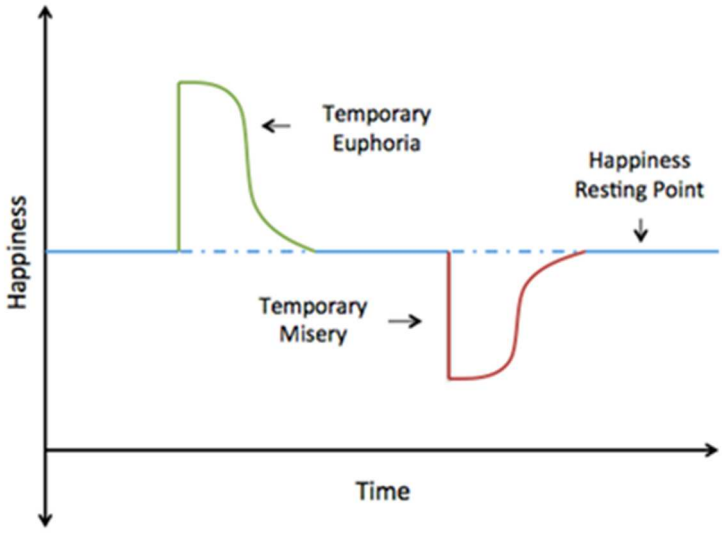


Figure 3.- Time Evolution of Temporary Events on Happiness (Kothari, 2015).

In particular the temporary events can affect the results when they happen just before or during the evaluation. The general rule is to note the event occurrence as a possible explanation of unexpected results. When the event happens before starting the evaluation, whenever it is possible, the best way is to delay the full evaluation or, if it is not possible, to perform the second part as close to the first as possible (2 or 3 weeks). In the case the event happens between both evaluations, if possible the second must be delayed as much as possible (3 or 6 weeks).

Quantifying Qualitative Data

Considering the nature of the handle data, first problem to consider is that data obtained from interviews are qualitative. In these cases, it is necessary to bring the data into context and interpret the workers answers to gain knowledge about the impact and the effects that FACTS4WORKERS solutions have on individuals and the organization. Relevant statements from the transcriptions of the interviews or from the interviewers' notes can be extracted and encoded to core-statements and them assigned to categories representing the possible impact dimensions (Mayring, 2000). Finally, the results are sorted and ranked by relevance (counting the references to each category- frequency-, the content of the category –relevance-, etc.). The coding and ranking are subjective processes to some extent. However, this can be addressed by making each step transparent and by including a team of researchers into the analysis (Walsham, G. 2006).

In doing so, the results that are gained from the qualitative data collection are comparable over different use cases. They furthermore can be normalized and hence, aggregated to data that have been obtained from other sources (such as surveys or log data).

Data Normalization

Once all the data are quantified next step is to make them comparable and operable: data from surveys and interviews are/are transformed to Likert scales data which are obtained in a given moment, data from logs and applications measure different units' which are obtained through the time. Normalization could be a way to avoid problem related with multisource values.

Our normalization process aassumes that: all the managed data is quantified; that for each of the measurement sources it is possible to define an order scale of values, the concrete range of valid values for the scope of the evaluation and, in consequence it is possible to define an optimal value for the projects objectives within this range.

Considering it, values are normalized relative distance from the current measurement to the optimal value. By applying this function to the measures, values are transformed to values within the range [0, 1] not having any unit of reference and it simplifies the interpretation of the results.

On the one side, after the normalization process handles relative distances to the optimal value of each metric, so the closer to the optimal value is , the better the measurement is. In other words, the lower the relative distance is the better is the result and 0 becomes the optimal value of the normalized scale. On the other side, the framework proposes to measure before and after interventions. In consequence, we can determine the positive or negative impact of the interventions calculating the relative variation in the measurements calculated as:

$$(d_t - d_{t+1})/d_t$$

In this formula d_t and d_{t+1} represent the distance values before and after the intervention and the positive of negative sing of the result would mean a positive or negative impact measurement.

Finally, we want to signal that this normalization process makes the raw data comparable and also operable. In consequence aggregations can be applied to a set of these.

One difference between CA and TA data is that CA data is event driven data while TA data is time driven data. Event driven data means that the data is obtained during an event which happens in a point of time. Time driven data are obtained through the time, their values could change with time and their metrics needs to include the time interval in the definition of the measurement units to make sense. It means that for making TA and CA normalized values comparable and operable the interval of time considering the TA data must correspond to the time interval (t_i, t_{i+1}) between the before and the after evaluation.

Transforming Raw Data into KPI

After normalizing the data, we have to deal with the issue of having a huge quantity of measurements (answer to questions, data from logs, etc.) which must be mapped to the project objectives in order to determine their achievement. Moreover, as we previously introduced, we consider FACTS4WORKERS objectives 1-3 are composed of the IDs. In consequence, we need to first map the measurements to ID and then ID to project objectives. Figure 4 summarizes the process of transforming raw data into objective indicators.

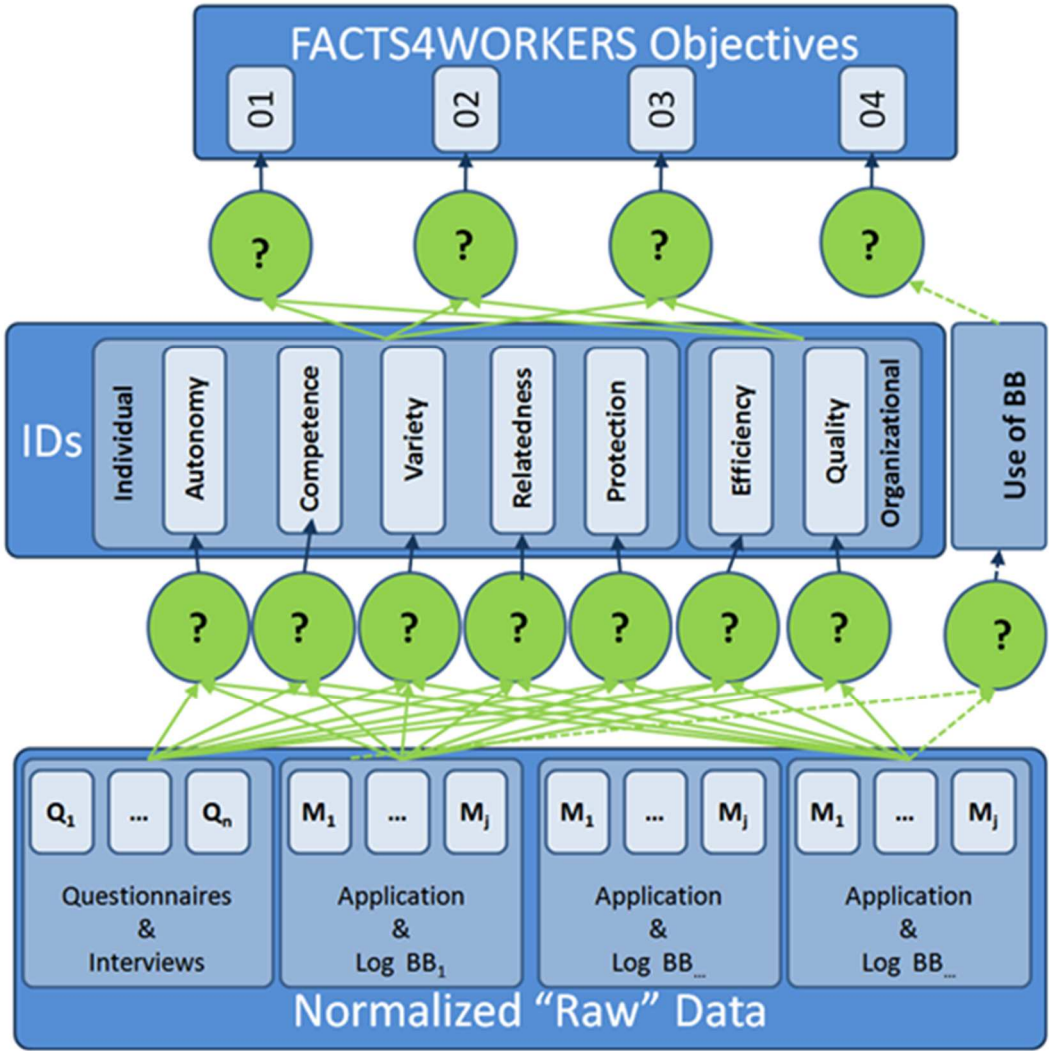


Figure 4.- Detailed Raw Data-Objectives Measurement Formulation.

Similarly, as the frameworks tools are thought to measure specific issues of the IDs, their measurements results are going to differently contribute to the measurements of the IDs. Additionally, a final fact to be considered is that the maturity of the artefacts under evaluation is going to determine if some tools can be used or not. In consequence, the transformation method also has to consider it.

In other words, we need to be able to transform normalized data into ID measurements and then into objective achievement measurements being able to consider different level of contributions from the raw data to the IDs measurements and from ID measurements to objective measurements.

Figure 4 summarizes what we expose in previous paragraph. For simplicity, it does not include all the connections between the ID and the objectives or between the measures and the ID. It can be observed that the method that we use for measuring the objectives achievements is going to create a kind of trees relationships, of hierarchical relations, between the objectives and the raw data measurements. In each of these trees, one per objective, the root is the objective, intermediate nodes are the ID and leaves are the individual measurements.

The link between all them be the function we apply for transforming the data from each level to the next one. According to what is exposed in previous paragraphs this function should have to be able to model the different influence in the result of the parameters have. Moreover, it would be desirable that the obtained value is in the range [0, 1]. This feature eases the interpretation of the results as we explained in previous chapter.

From our point of view the weighted arithmetic mean could be a good function for aggregating the values as it fulfils our requirements. It is calculated as:

$$m_p = \sum w_i \, m_i \, / \sum w_i$$

Where: m_i is one of the measurements which is influencing the measurements of an ID or and objective; w_i is a weight representing the level of influence of the given measurement in the obtained result; and m_p is the calculated value of the measurement.

Although weight can take values in any range, we recommend to restrict them to take values in the range [0, 1]. And additional restriction to consider is that weight values additions would be 1. We base this recommendation on two facts. Firstly, the weight is easier to understand. Secondly, the previous formula simplifies its calculations to:

$$m_p = \sum w_i \, m_i$$

Finally obtained results must be interpreted. For interpreting the results they must be considered both the IA results and the validations results as last provide the context of the interpretation. A brief introduction to results interpretation is done in chapter 2.2.3.

2.2 Evaluation Setting

These paragraphs provide an overview of the general setting up of an evaluation process. Figure 5 summarizes the process of setting up evaluations. It is composed of three main steps: preparation, planning & execution and analysis & conclusions.

2.2.1 Preparation

It considers the interventions, their expected change in practices and their expected impact on workers and organizations, and the artefacts to be deployed in order to determine what is need to be measured.

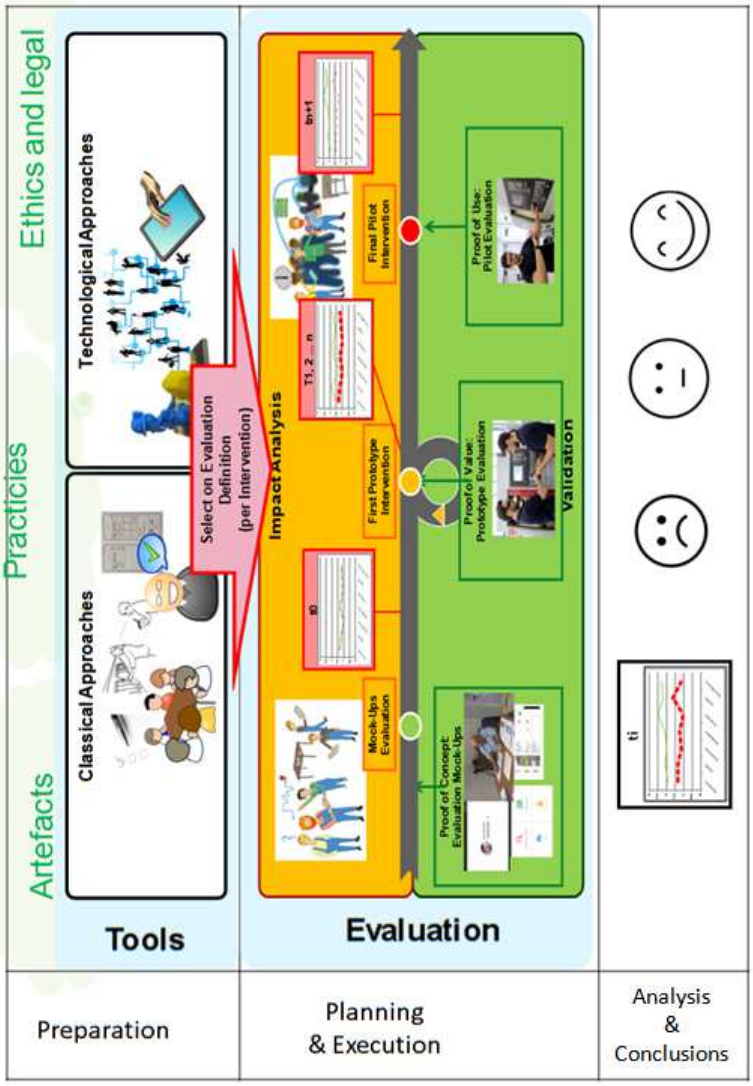


Figure 5. Evaluation setting up overview.

Regarding artefacts two facts must be considered. First, the maturity of the artefact to be deployed must be cleared established and then, before performing the evaluations, explained to the workers: while a pilot has a high TRL it is expected to have similar behavior to an out of the box solution (in words of usability, performance, information accuracy and quantity, etc.) while a prototype does not (many improvements can be detected because, in some sense, it is its mission). The second fact is related with the functionalities to be deployed: they must be tested by an expert (in usability and/or the field of application) before the evaluations: the prototypes and pilots must present to workers only functionalities working correctly (although in a prototype can be improved in accuracy, performance, usability, etc.) because of the undesired effects bugs and usability issues have in evaluation results.

Privacy and legal regulations are considered within FACTS4WORKERS project, so for each specific UC, the preparation will consider the most suitable set of tools to collect data or to get the insights, so in some case semi-structured interviews will be used instead of questionnaires to prevent collecting data from surveys but being a valid method for gathering workers' perceptions of the impact of interventions or for assessing the impact in productivity of a given intervention. Also other considerations are contemplated like the possibility of using a workers' control group for measuring external biases.

The need of local support for performing the evaluations is also determined. The person who is going to play the role of facilitator is selected and trained. He/she will be in charge of the evaluations logistics (choosing participants, translating documents, supporting evaluations, etc.).

2.2.2 Planning & Execution

This step's timeline is guided by the development and deploying phases of the artefacts: the evaluations must be executed each time a release of an artifact is presented to the workers.

Time window between the before and the after evaluation of the each intervention is also scheduled. It depends on the maturity of the deployed artefact. When the evaluation focuses in validation (no production artefacts like mockups or not, functional prototypes) it must be performed once. In the case of prototypes and pilots it must be performed before and after the deployment. In these cases, a time window between 4 and 6 weeks between both evaluations is desired. However, in the case of prototypes providing prove of concept not running for shortest time (less than 4 weeks) the second evaluation must be performed just after stopping.

Impact Analysis:

- Select involved workers (FACTS4WORKERS and control group).

- Determine expected impact due to the given intervention (considering also the maturity of the artefact).
- In the case of using interviews select the relevant questionnaire questions, prepare the guide for the interview as well as, the way for quantify the workers answers.
- In the case of using Technological Approach of assessment determine the measurement and the way they are going to be interpreted.

Validation: the maturity of the artefacts (and the safety of the participants in the evaluation) determines the environment for performing the validation as well as, the tools to be used:

- Mockups and functional prototypes testing can be performed on labs; two-rounds: think-aloud, post-experience (UMUX-LITE, validation questionnaire).
- Prototypes: on labs/real scenarios; observation, think-aloud, post-experience (UMUX-LITE, validation questionnaire).
- Pilots: real scenarios; observation, think-aloud, post- experience (UMUX-LITE, validation questionnaire).

The help of the facilitator must be considered for presenting the project and the evaluation works to the selected workers who are going to participate as well as, for supporting the selection of the involved workers and the evaluation processes (in particular where language issues should be considered).

For each evaluation, following actions are needed:

- The workers consent form;
  - If any part of the evaluation is going to be recorded (audio or video), request explicit worker permission for it.
- The project and evaluation objective presentation: a presentation of the project and the evaluation process and objectives is prepared. The general presentation must be extended with a clear explanation of the intervention to FACTS4WORKERS: the scope of the intervention (processes supported, artefact maturity;
- The IA guide must be prepared: interview guide and rules for quantifying the impact or the questionnaire –on line of offline version;
- Validation guide –what must be tested, assigned task for validating the solution, and the rules for quantifying;
- Tools for preparing the data for analysis.

Expected results:

- Interviews transcriptions/notes, fulfilled questionnaires, aggregated data from the logs, systems.

Observation and/or think aloud notes, fulfilled questionnaires, log detected errors.

2.2.3 Analysis & Conclusions

Interpreting the results of evaluations has the purpose of objectively supporting what to do next.

The relative importance of IA and validation in the evaluation process depends on the maturity of the deployed artefact, on the moment when the evaluation is performed in the project life cycle and on whether it is done before or after the deployment of the artefact. If we consider the maturity of the artefact, we can identify two classes of them: mockups and prototypes.

Mockup-evaluation

Mockups focus on understanding the interaction capabilities workers, they help to determine if there are special interaction requirements and to understand the processes to be supported/caused. In the sense, they ease the communication between users (workers) and development teams on early stage of development. Their features are:

- They are non-functional interaction interfaces supporting the validation of the development teams understanding of the problem to be solved (non-functional means that only CA can be used).
- Changing their design/implementation is cheaper and easier to be performed than for prototypes.
- As they are not deployable, they are not going to support/to cause any real change in workers' practices and if we perform an assessment of their impact, no significant changes are detected.

Mockups support the design of the HMI which should support workers' tasks, in consequence, their tests refine the requirements of the virtual process to be implemented as well as, of the features required to the information to be exchanged between the systems and the worker. Their validation provides valuable insights about the information and user interaction requirements and improvements to be considered by the system usability, special requirements for the interaction device, kind of charts to be used, etc. Validation of mockups generates a list of requirements that, once priorized and valued, can be used to determine how far from a solution the project is.

Mockups are not deployable, they do not support/to cause any real change in workers' practices and if we perform an assessment of their impact no significant changes are observed (other than workers expectations and perceived utility).

However, expected impact values and the list of prioritized and valued requirements can be used for support decisions. Firstly, if the results do not correspond with the expected impact that was defined when the project started; it would be advisable to reconsider its viability (in particular if the costs are high). Secondly, if several projects are being valued, their evaluation supports a more objective prioritization of the projects. Thirdly, when a project is selected to be executed, the prioritized list of assessed requirements can be used to determine the number of prototypes and the scope (functionalities) of each of them. From this list also, an estimation of the progress in the degree of compliance with the objectives may be derived. In other words, from the list of requirements it is possible to derive the number of interventions and their expected relative impact.

Evaluation of Prototypes

Once a project is selected to be executed, the number of interventions and their scope (functionalities to be implemented by each artefact release, and expected impact) are established and planned. This information is used during the planning phase of the whole evaluation project to specifically determine which is going to be evaluated within each intervention. Since prototypes implement functionalities, it is expected they contribute to change worker practices. However, the degree of the changes is influenced by the maturity of the developed artefact. This maturity is determined by the implemented functionalities and the quality of the implementation. How to measure, but also what to measure, is determined during the preparation and execution phase of the evaluations. However, the initial decisions should be reconsidered before any intervention in order to make the evaluation correctly fit to the scope of the intervention.

When evaluating prototypes, IA is more relevant because its measurements determine the success or failure of the interventions and of the project. However, the results of the evaluation become important after the deployed artefact is used for a while, that is at t_{i+1} (after intervention), when the variance in the measurements can be obtained. In any case, the IA at t_i (before intervention), before the artefact will be deployed, will provide a reference measurement for determining the improvements.

At t_i, validation will provide more valuable insights than IA assessment. After the validation process ends at t_i, a list of improvement opportunities (changes on requirements and new requirements) and non-conformities of user requirements are obtained. Because non-conformities influence the quality of the artefacts, they must be carefully valued in order to determine if the intervention, the deployment of the artefact, can continue or must be postponed until they are solved.

When artefact is finally deployed, after a period of time (between 2 and 6 weeks of use) a second evaluation process will be performed, at t_{i+1}. In this case, both CA and TA data may be considered for validation and IA purposes. Validation data is providing information about new improvements and/or functionalities to be implemented

in order to better support workers. These requirements could be valued and prioritized and included in the list for future interventions.

The IA assessment at t_{i+1}, the variation of the objective indicators by comparing at t_i and at t_{i+1}, shows if the intervention causes the expected effect or not. Where it is possible to use a control group CG, the obtained values from it can be used to determine the influence of possible external effects to the project objectives achievement. It becomes particularly important when the development time is long and the evolution of the environment modify the AS-IS scenario as well as, the to-be situation, in other words, requirements can change but these changes can be detected during the validation.

When the expected effect is achieved and the quality of the artefact is not good enough because many non-conformities are detected (errors are reported, performance is lower than expected, etc.), first priority should be to solve them and redeploy the artefact as soon as possible. In this case, and in general whenever errors and performance problems are reported, log data could provide valuable insights to determine the source of the problems, the causing BBs. After non-conformities are solved, and the new artefact release is used for a while a new evaluation is required.

When the result is not the expected for one or more objectives both, IA measurements and validation measurements, can help to determine their causes. If the validation is not good for a given BB, it is necessary to solve the non-conformities and to redeploy the artefact in order to evaluate the impact again.

However, sometimes validation results do not show non conformities. In these cases, a more detailed analysis of the impact dimensions IDs determines the possible causes of the result. For each of the unexpected objective results, we compare each ID measurement with their expected impact which is established at the beginning of the intervention.

IDs results depend on the evaluation results of the BB used for implementing the solution of a given UC. Each of the BBs contributes differently to each of the ID. In consequence, the analysis of the evaluation results of the BBs contributing to the ID achievements has to be performed. If the IA to the BBs are not the expected one, the available validation data could be used for trying to determine the causes of the problem.

Firstly, the cause can be that the BBs do not implement the required functionalities. It can be determined by reviewing the requirements list. In this case, as for previous ones, new interventions should be considered. Secondly, the causes can be quality issues such as poor performance, bugs, etc. In this second case, once the causes are determined, it is necessary to provide a solution as soon as possible and to perform a new evaluation to determine if the corrections lead to the expected results.

When the expected effect is achieved and the quality of the artefact is good enough (just requirements changes and new functionalities are reported), the cumulative objective achievements and the prioritized list of valued requirement should be considered. If it is possible to improve the objective achievements at reasonable costs, the possibility of a new intervention should be considered. If a new release is not acceptable, because there is just little room for improvements or the costs of the improvements are too high in comparison with the expected benefits, the possibility of convert the prototype in a pilot should be taken into account.

Pilots Evaluation

There is a very subtle difference between a prototype and a pilot. Functionally, they could be completely equivalent, but as pilot deployments are used by more workers and to support real activities in real time, pilot infrastructure requirements are higher, they must support higher performance rates; information content must be complete for supporting all involved worker tasks; and the usability of the artefact must be close to perfect. As explained in chapter 2.2.2, the intervention (scope, involved processes and roles, etc), what is being evaluated (a prototype or a pilot), its functional, information and performance features (including it lacks) must be clearly explained to FACTS4WORKERS workers in order to avoid creating erroneous expectations.

From the evaluation point of view, the evaluation of a pilot takes the results of the prototype evaluations. IA results of prototypes provide proof of value of the deployed artefact based on their impact measurements. These measurements can be used to more objectively determine the expected impact of the pilot deployment. On the other side, validation of the pilot changes its main focus from interaction and functionalities refinement to the performance and error issues.

As for the rest of the artefacts, for pilots we recommend to perform two evaluation processes: one before the intervention, at $t_{i,}$ and after the intervention, at t_{i+1}. At t_i, the IA has to be conducted for establishing the baseline of the pilot measurements. Validation at this time must focus on the correct functioning of the artefact in all workplaces where it is going to be deployed. More than in the correctness of the interaction and functionalities the validation tries to determine if there are infrastructure problems to be solved, i.e. network access. As with prototypes, depending on the resulting problems a decision about continuing with the intervention or delay until if it is solved, should be taken.

At t_{i+1} IA gains in importance: the pilot success is measured as the project objective degree of achievement. On the other side, although the validation is less important it should be monitored because of the influence the quality of the artefact has on its acceptance. At this time, in the same way that at t_i it is not expected the reporting of new requirements of problems.

Objective 4 of FACTS4WORKERS deals with demonstrating the achievement of a TRL level between 5 and 7 by the deployed solutions. Levels 5 and 6 require that the artefacts will be validated and demonstrated in relevant environments. In our case, that means to be validated and used in controlled workplaces during a given short period of time. This can be probed by the validation of the prototypes previously introduced. However, TRL level 7 requires the demonstration in an operational environment, that is the deployment of a pilot during a time on the shopfloor.

2.3 Use Cases Evaluation Process

Framework evaluation enables to analyse specific UC requirements. In order to analyse how the prototypes implementing UCs contribute to achieve UCs, the evaluation results are presented to easily visualize the UC fulfilment structured in the following items:

- The UCs are briefly presented based on their description of deliverables D1.1(Heinrich et al., 2015) and D1.2 (Denner et al. ,2015) together with the expected impact of their implementation.
- The performed evaluations (timing objectives and selected tools) are introduced for each UC.
- The results of the evaluations are shown: new requirements from validation and the measured impact for each of the dimensions.
- The conclusions for the given UCs are presented.
- The perceived impact in the IPs as reported by the management is described.

3 UC Evaluations

3.1 EMO UCS

EMO Orodjarna d.o.o. (EMO) produces (progressive and transfer) tools for metal stamping. The company's main customers are the automotive and aviation industries and their suppliers to which EMO delivers tools for large presses. Most of the tools' components are manufactured in-house. These components are later assembled into the final product (progressive and transfer tools) that is delivered to the customer. The company aims for maximum production quality and works in close cooperation with its customers from the stage of the simulation and design activities to the actual manufacturing process and, finally, to the quality control and shipping phases.

Table 1 summarizes the use case defined in D1.1 and D1.2 by showing their AS-IS situation (the situation at the beginning of the project) and the TO-BE situation (the desired situation after FACTS4SOWERS interventions are performed).

The comparison of both situations, that's the interventions performed at EMO, can be described as:

- FACTS4WORKERS solution helps assembly workers to know the state of the part they need for working, where these parts are, when they are going to be available. Using this information, in addition with worker´s scheduled tasks, the system will determine when the worker cannot continue working and it will use the tool to inform production manager.
- Because of these tracking capabilities of the FACTS4WORKERS solution it is possible to know who worked in each tool and in each of its parts. It makes easier the process of finding help whenever a fault is found in order to solve it.
- By supporting the Schedule of jobs, FACTS4WORKERS solution helps workers and team leader to have an overview of current machine maintenance tasks, including status and scheduled time maintenance. The FACTS4WORKERS solution provides access to a knowledge repository of machine errors which could be extended by workers either by adding solutions to new errors of by modifying existing solutions.

The first two interventions were implemented by EMO-1 use case, while the last one was implemented by EMO-2. Figure 6 shows the expected impact of the interventions on the different dimensions. In this figure, 0 represent none impact, 1 low-impact, 2 medium impact and 3 high impact.

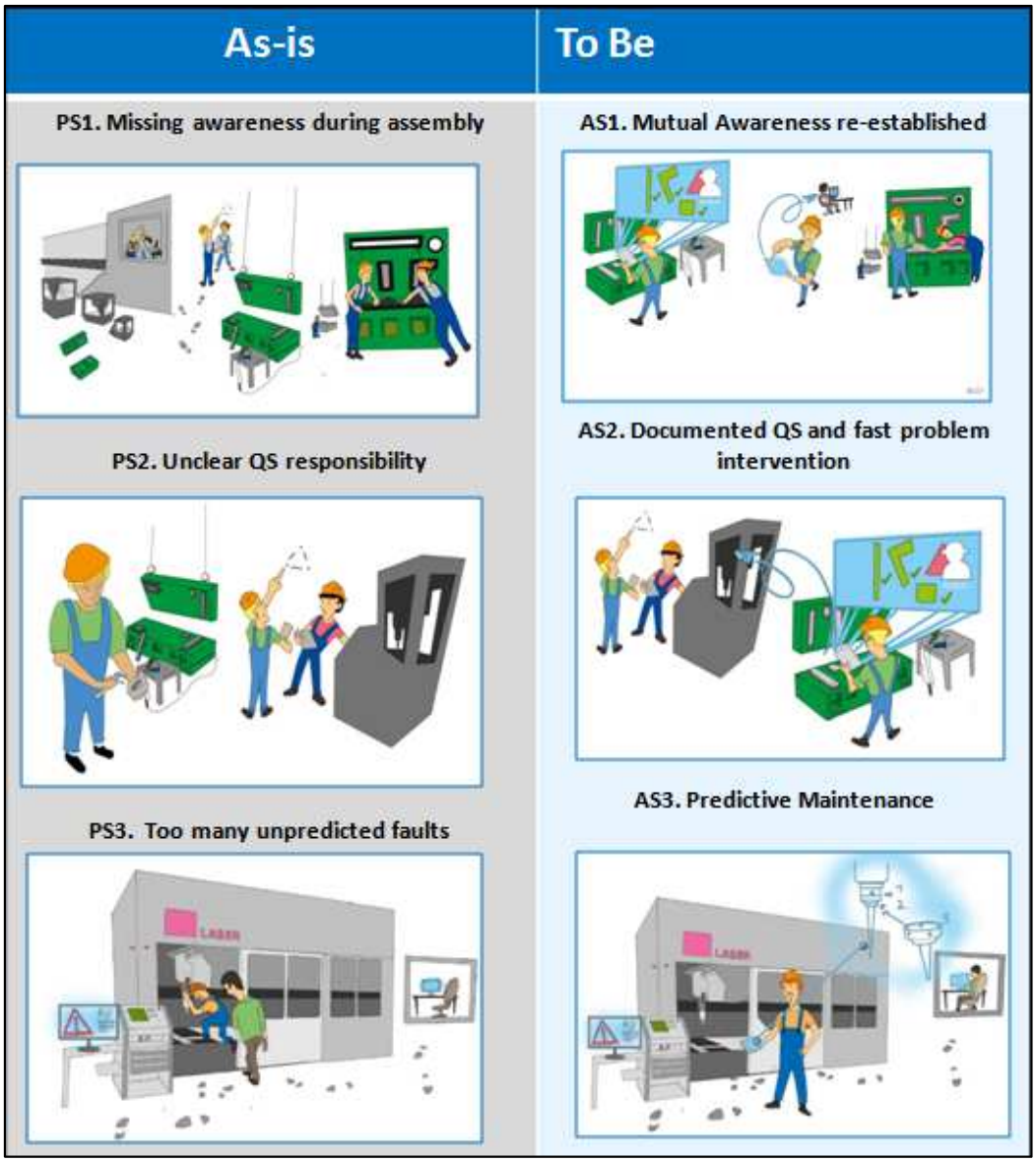


Table 1. Summary of Interventions at EMO.

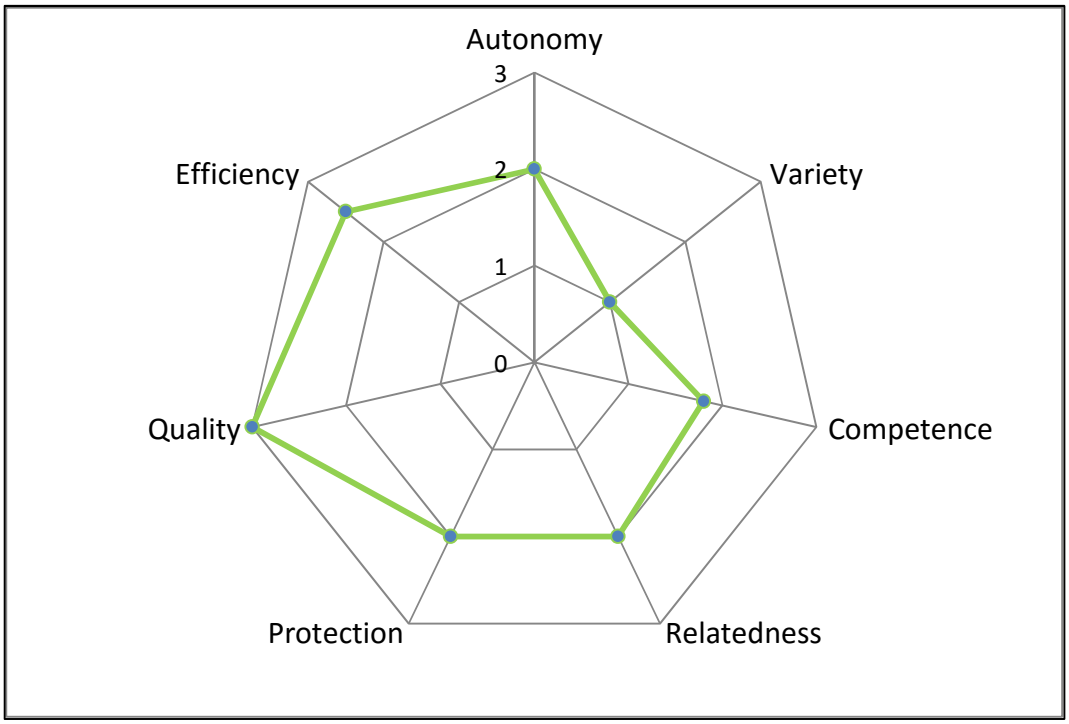


Figure 6. EMO expected impact.

3.1.1 Description of EMO Evaluations.

EMO evaluations were performed linked to deployments in June of 2017 and June of 2018. As Table 2 shows, evaluations were performed considering both: FACTS4WORKERS workers group and Control Group in order to be able to determine external biases in the results. In order to obtain significant insight and results we tried to have a representation of all the roles involved in the definition of the Problem and Activity Scenarios: CNC operators, assembler workers and project managers.

Because of the language issue Impact Assessments were performed using questionnaires and, for validation, using some open questions looking for clear explanations of what is working or not based on the worker´s opinion.

Impact Analysis questionnaire, which is translated to Slovenian, German and Spanish, is accessible following next link:

https://ec.europa.eu/eusurvey/runner/F4W_IA_QUESTIONNAIRE_V2

The EMO version includes a set of specific questions for measuring productivity.

The validations of the prototype were performed by assigning tasks to be performed by workers using the prototype in two rounds. The evaluated prototype considered the project management application (t1 and t2) and Evocall BB (t2).

UC	Date	N. of Participants		Object	Method
		(future) F4W users	CG		
EMO-1	07/2017	9	6	IA	Questionnaire
EMO-1	07/2017	7		Validation	Questionnaire for measuring productivity
EMO-1& EMO-2	06/2018	8	10	IA&Validation	Questionnaires + Interviews

Table 2. Evaluations at EMO.

In round A, workers were requested to provide their feelings, impressions, etc; by using the thinking aloud method and evaluator (facilitator) noted it as objectively as possible.

In round ,B workers were requested to perform other tasks after receiving a brief training on the use of the provided solution and their impressions were obtained using UMUX-LITE questionnaire and an open questionnaire related to quality (satisfaction with system, information and system quality) issues and their intention to use the system.

3.1.2 EMO Evaluation Results.

Validation Results.

As we mentioned when introducing the framework, the goal of validation is determining if the prototypes induce intended effects once they are introduced (impacts anticipated). To support the validation, the UMUX-Lite questionnaires, which are based on the Usability Metric for User Experience, are used. These questionnaires include two-item questions regarding the easiness of use and if the prototypes meet workers requirements.

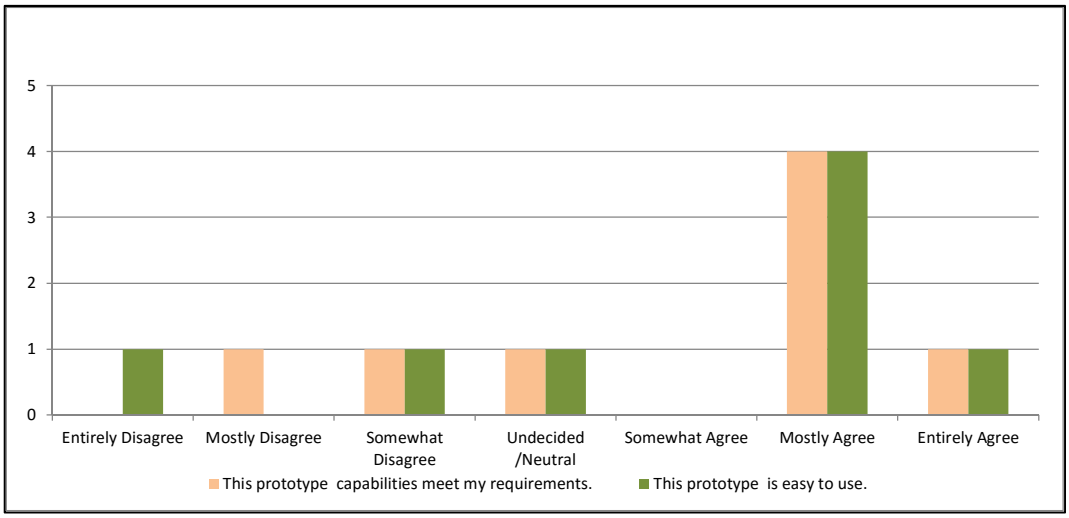


Figure 7 - UMUX-Lite Results in EMO in July of 2017.

Figure 1Figure 14 and 8 show the UMUX-Lite evaluation results in July of 2017 and in June of 2018. During the test of the first prototype scalability is perceived as a disturbing factor by workers. On the second evaluation, solution is perceived as completely integrated with the work (tasks) to be performed. However, some workers thought that an extra training on the solution and on the processes is required. In general, information and functionalities are perceived as correct.

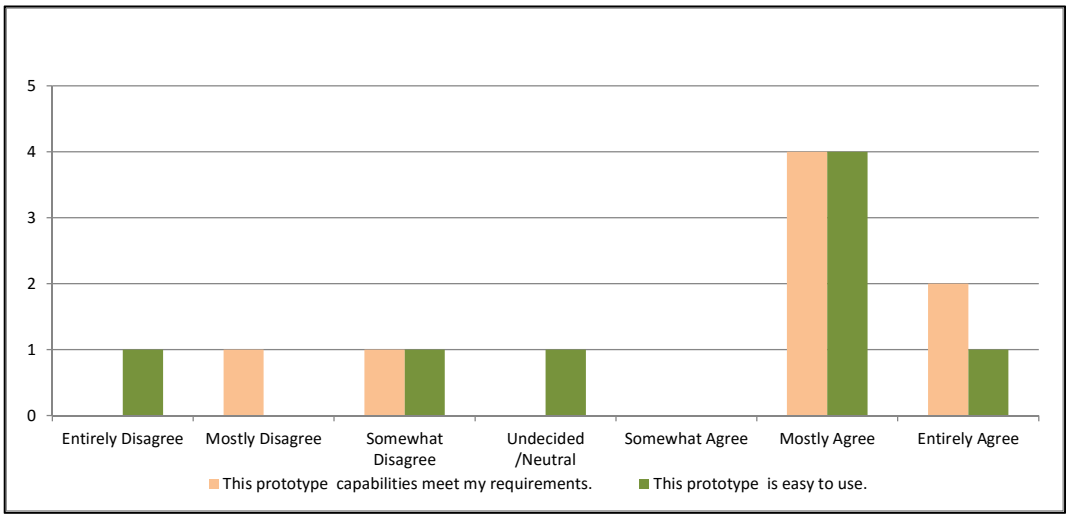


Figure 8 - UMUX-Lite Results in EMO in June of 2018.

Both figures show the fact that workers like the prototypes. Workers say the prototypes are easy to use and to learn and are perceived to be almost entirely integrated with the work (tasks) to be performed. Prototypes meet requirements such as: to get info of processed position, error notifications, status of the work orders, better overview of the work and the errors that occur in production, etc. When they com-

pare the first and the second release, the second one is perceived to be more mature and they highlighted the importance of the translation to Slovenian.

Regarding functionalities supporting workers' tasks, their appreciation and acceptation level seems to be related with worker's role (assembly, CNC operator, project manager). Workers appreciate the possibility of having a summary view of the projects, the assigned responsibilities and the possibility to connect to different colleagues. The possibility of moving the orders and instructions with the workers is also appreciated. Workers also show the importance of error notifications because it allows to act quickly and, in consequence, to improve productivity.

Considering the provided information, workers say it is clear, good, correct, specific and useful to them. In particular, the Multimedia capabilities (taking pictures, recording video, Evocall) are seen quite interesting for supporting workers. However, although taking pictures is really appreciated for reporting errors, cameras having a biggest resolution are requested in order to provide the required accuracy for error reporting.

Some workers requested more use time under real conditions for having a more informed opinion, about the provided information and also to determine if they improve their performance using the solution. In any case, in general, most workers like the solution which fits their needs and they find the system useful.

However, some concerns are expressed in relation with its use by all the workers. The feeling of being controlled, the need of training and additional knowledge of EMO productive processes are recurring concerns expressed by the workers Regarding the general use of the application, some workers reported a overload of administrative work in the phase of creating the content to be used by the system.

In any case, main concerns of workers are related with the used devices. Many workers rejected using smart-glasses (tested on a lab environment due to the fact that they are not still certified for being used on the shop floor) and they think tablets are too fragile to be used on the shop floor (although they appreciate their capability of taking photographs). Some workers directly suggest that it will be better to use desktops placed close to their workplace due to their capabilities for reporting errors (typing and drawing are needed) as well as for reviewing plans.

Finally, it must be remarked the concern about the scalability of the solution ("congestion problems during peak working hours", "limited number of screens at the beginning", etc.) expressed by some workers

While the second prototype is perceived as more mature than the first one, some requirements are requested. Most improvement requests are related with changing the devices (even for workers requesting time for using the system), since the preferred device option are desktop computers.

"Edit" and "Start" buttons of the maintenance application are not well understood. The edit button provides the opportunity to edit maintenance tasks and type in comments to provide a description of an error from a specific machine. The workers perceive this button as confusing and not intuitive.

Impact Analysis Results

By measuring the impact, we are interested to know if the **F4W applications** increase the problem solving and innovation skills and, the cognitive job satisfaction and productivity of their users which was presented to them as:

- Problem Solving Skills: ability to solve unexpected situations based on your experience, the information and knowledge which is available on your site or receiving the support of a colleague, who is not present on your workplace.
- Innovation Skills: ability to detect improvement opportunities of the task and processes workers are responsible for or of the products they are working with.
- Cognitive job satisfaction: you are provided with the correct information or the support from a more expert colleague for executing your tasks, increasing/improving your competences or, to have a clear view of the task you are performing.
- Productivity: reducing the resources required for executing a task and increasing the quality and performance of the result (product or service).

At EMO, these were obtained from questionnaires in an anonymized way during first and second evaluations. They include questions for assessing the efficiency and the quality improvements due to interventions.

Figure 9 and Figure 10 show the measured impact at first evaluation and second evaluations. In this figures (and in the rest of the document) green column represent CG values while blue column represent F4W values.

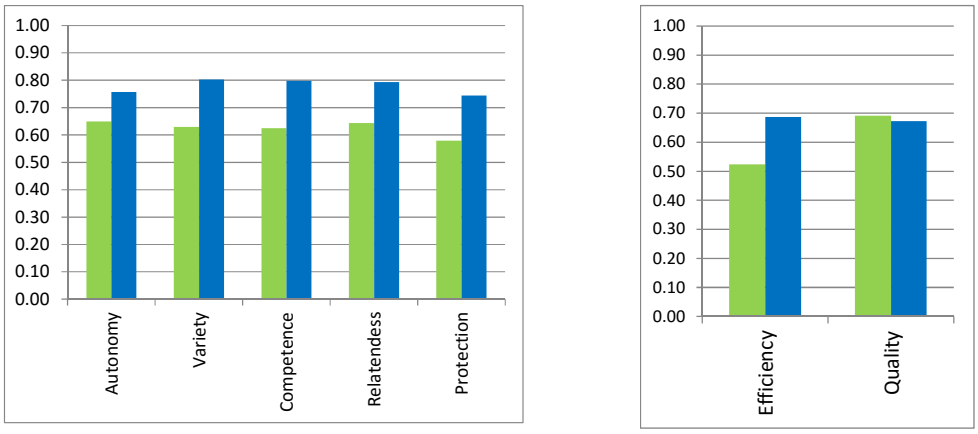


Figure 9. Individual and Organizational ID in EMO at first evaluation.

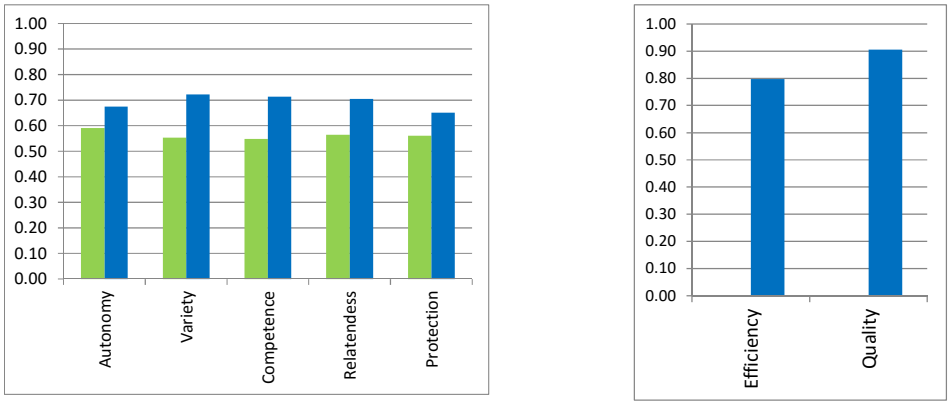


Figure 10. Individual and Organizational ID in EMO at first evaluation.

By comparing CG and F4W values it can be follow that provided solutions improve most of the dimensions. The only exception is quality in the first evaluation. However, it increases significantly.

Together with the results of the questionnaires, interviews allow us to gain knowledge about the impact. The purpose of the interviews is to get workers´ relevant assessments of the effects of the FACTS4WORKERS solutions in the work floor and use them as valuable indicators of the dimensions. Table 3 presents some examples of these quotes and how these quotations are mapped to the dimensions.

All together we could expect that introducing solutions like the ones provided by FACTS4WORKERS will contribute to increase variety, competences, relatedness and protection and, especially, quality dimensions. Figure 11 compares the obtained impact against expected one for each of the dimension.

In this figure, 0 represent none impact, 1 low-impact, 2 medium impact and 3 high impact. Expected impact is shown in Green and Measured impact is show in Blue.

Quotations	Impact Dimension	Relevance
"It is much easier and faster to measure and view the positions" "It allows quick scan of the positions that have been already processed" "We will waste less time looking for information and parts" "The system provides better traceability and overview of the work" "This systems helps to plan activities better"	Efficiency	High
"I like the way the information is presented" "We have all the information we need" "We will waste less time looking for information and parts" "it suits to my needs" "I liked the possibility of no need to walk around the shop floor to find help and also the videos for maintenance work are very helpful" "I like the idea, that with the system, you don't have to walk around the shop floor to get working instruction and maintenance instructions also and that you could see exactly what you have to do"	Competence	Medium-High
"The prototype integrates with most of my tasks" "It would be integrated into our shop floor easily" "The system provides better traceability and overview of the work" "I think it would be easy to involve it into our working process"	Relatedness	Medium-High
"It will be easier to solve some tasks due to the support of the solution"	Autonomy	Low

Table 3. Evaluations at EMO.

3.1.3 EMO UCS Conclusions

Prototypes tested at EMO contribute to increase workers satisfaction, their problem solving and innovation skills and their productivity when comparing measurements of both groups. Figure 12 shows it.

For comparing the results of both evaluations it must be highlighted that the first evaluation considers the connection of several data BBs while the second evaluation also considers maintenance support BB. This could be one of the reasons for explaining that the value of the Innovations skills and problem solving decrease. Another reason could be the better understanding of the concepts by workers after the introduction of clear definitions in the presentation of the evaluations and in the questionnaire it-self since through the project this need to clarify concepts was seen as necessary.

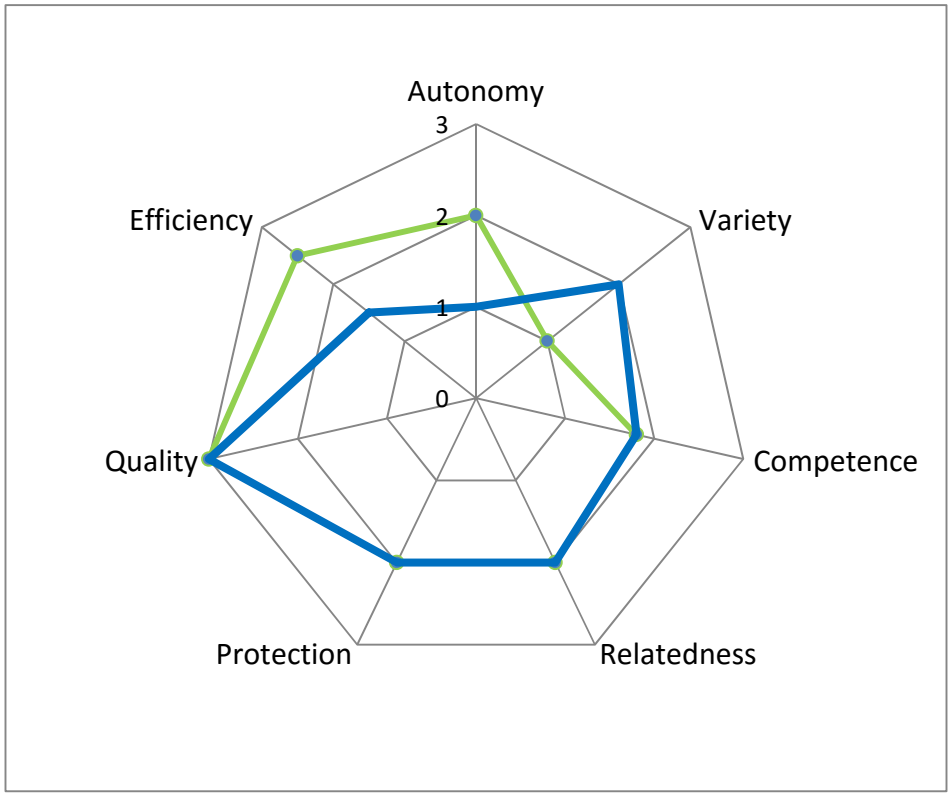


Figure 11: Obtained Impact vs Expected Impact at EMO.

It can be concluded that prototypes contribute to advance in gathering the expected impact in the different dimensions and, in consequence, it could be interesting to follow with the development of the solutions.

3.1.4 Impact within EMO

After the prototype was tested and evaluated by workers, the worker-centred philosophy of the project demonstrated to the management staff that keeping workers in the loop helps both to understand their requirements and to accept the solution as it can be more naturally introduced.

The use of the solution helps workers to feel more connected to their work and allow and support each other in problem solving skills as well as, sharing their knowledge.

The prototype test shows that the solution is very helpful, especially for assembly workers, and in consequence it is quite interesting to convert it into a productive solution which will focus on monitoring the product and the material flow on the shop-floor and for planning the production capacitates.

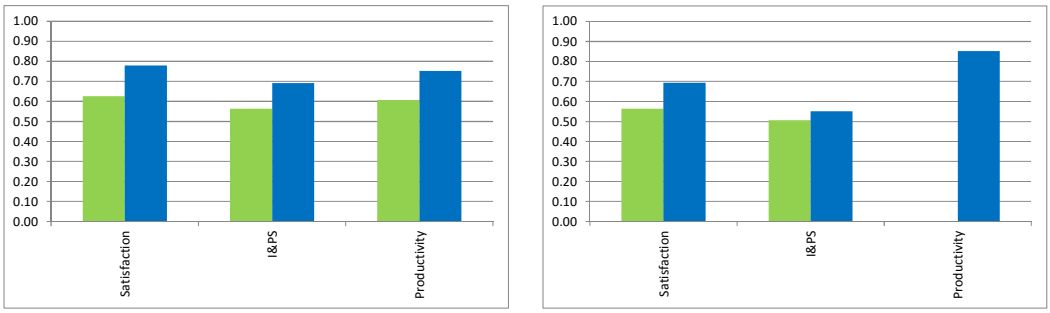


Figure 12. FACTS4WORKERS Objective Assessment at first (left) and second evaluation.

FACTS4WORKERS enables EMO to acquire knowledge about the necessary information flow and IT infrastructure which is required to support the achievement of Industry 4.0 goals.

3.2 HID UC

The Hidria Technology Centre d.o.o. (HID) designs and manufactures a wide spectrum of partially or fully automated assembly lines, ranging from simple conveyer belt designs that support manual assembly to fully automated lines equipped with state-of-the-art instruments that ensure the products will meet their specifications. These sophisticated machines are tailor-made: They are designed from scratch for specific customer needs (engineer to order).

Since the machines are equipped with programmable devices to control the process, the development is a co-design effort by mechanical, electrical and software engineers. However, once installed at the customer's site, these assembly lines show a typical efficiency of only 65% (overall equipment efficiency, OEE). The loss in efficiency is due to either time-consuming setup and maintenance activities or lacking supplies. In such cases, the line comes to a halt or produces parts that have not been specified. The reduction of setup and maintenance time is the focus of this context-of-use.

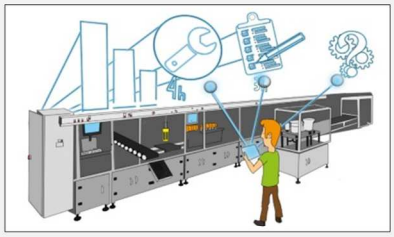
As-is	To Be
HID1. Tricky machine setup and complex fault condition 	**HID1. Automated fault detection and guided checking procedures** 
HID2. Scattered information and event-driven maintenance 	**HID2. Planning of maintenance activities and task assignment** 

Table 4. HID UC definition.

As Table 4 shows HID "Problem-solving support for production workers" was defined by the implementation of two scenarios:

- Automated fault prediction and guided checking procedures: FACTS4WORKERS solution provides support to production teams for sharing the knowledge related to the machine created events that need to be treated and establishing their importance and urgency.. It allows performing some checking and solving problems operations by workers through a updates set of instructions which are constantly improved by operators, team leaders and by big data algorithms. Provided information can also be used for reducing setup time, and shared knowledge can be used for training worker without experience.
- Shared documents and integrated human-machine information: FACTS4WORKERS solution helps to overview existing problems and to receive notifications of new ones. The solution incorporates data introduced by operators and maintenance team, from the machines and from the developed intelligence systems which can be searched and used for solving new problems if they reappear in the future. The analysis of the existing data allows the creation of new checklists of preventive maintenance operations.

New problems can be assigned (together with associated documentation) from the provided solution.

The expected impact of the line maintenance solutions as defined in D1.1 is shown in Figure 13.

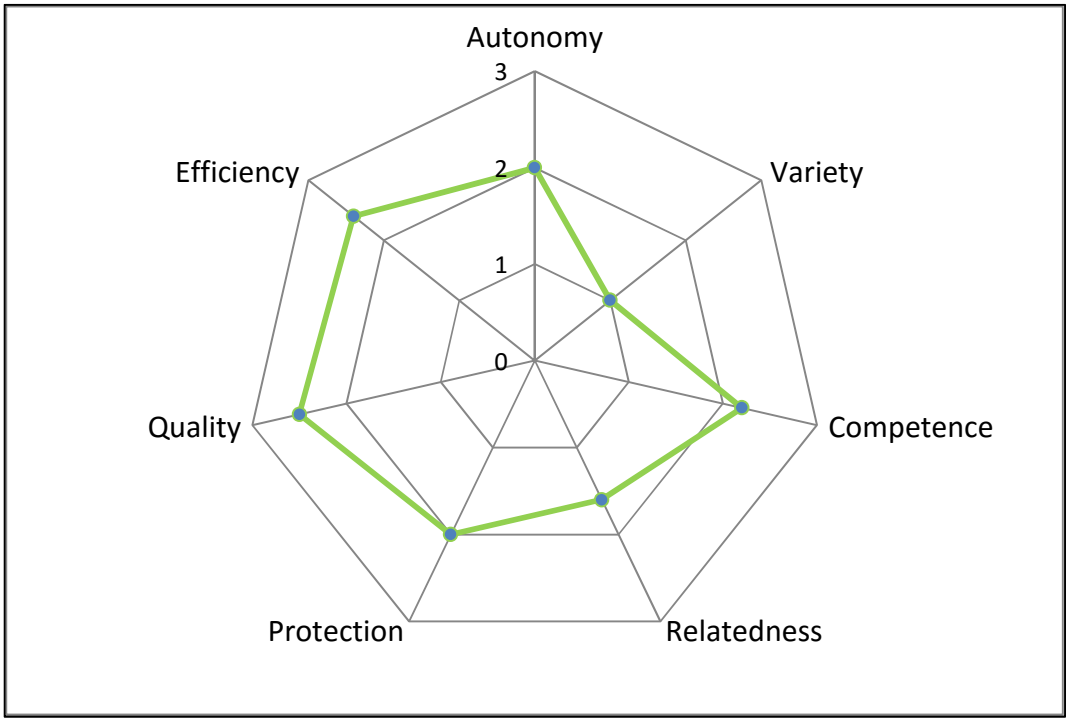


Figure 13: Expected Impact of HID UC.

3.2.1 Description of HID Evaluations.

The evaluation of first HID prototype was performed during April of 2017 before and after testing it. The prototype supports the work of maintenance workers providing information about the Defect & Solutions, as well as access to the documentation of the production lines machines.

As Table 5 shows, a group of 6 workers participated in the evaluation: 1 *technologician* (a kind of shift leader and 5 production workers of the Glow Play assembly line). Moreover a group of 3 workers not using the solution participated in the assessment of the impact as control group.

Because of the language issues the evaluation was performed by the UC leader and a facilitator. In this case, the facilitator role became crucial because of the language issues: the facilitator presented the project, the evaluation process and its objectives to the workers as well as, he/she translated the answers of the workers for being analysed by the development team.

UC	Date	N. of Participants		Object	Method
		(future) F4W users	CG		
HID	04/2017	6	3	IA&Validation	Questionnaires + Interviews + Think Aloud +Observation
HID	07/2018	8	14	IA	Questionnaires

Table 5: HID Evalutions Description.

During July of 2018 after the deployment of the solution at HID, an assessment of the impact was performed. In this case, 22 workers participated on the evaluation. 8 of them using the solutions in two production lines. And 14 not using it in other two lines.

In both cases, IA was performed using paper questionnaires because of the language issues. The validation performed during first evaluations was performed after a previous presentation of the solution to the workers using a PC and then workers were requested to perform some tasks using a tablet. Then observation and think-aloud methods were used for retrieving the feedback from the workers.

3.2.2 HID Evaluation Results

Validation Results.

The presentation of the tool has been appreciated and took only few minutes. After that, workers started to work autonomously on the tablet: a convertible (add-on keyboard) that has been appreciated by the operators. The process has been really smooth and they immediately understood the functionalities provided by the tools.

Although some data was preloaded before starting the evaluation, it was requested to add more information (already tested solutions and machine documentation) in order to better support workers.

In general, operators had no problem to remember how to access the history of defects and appreciated the way (icons, colours, fonts, etc.) used. They easily created new solutions for a new problem. However, they said that while tablets work correctly for creating a single solution, it would be better to use a PC for a massive inclusion of solutions.

Operators easily access to see new events. They easily assigned the ones they think are not able to solve to the maintenance leader ("just clicking on a button").

However some improvements were requested by workers:

- It was requested to replicate the solution for other production lines.
- To include support documentation and existing reports on defect and solutions.
- To include the timestamp to the used solution.
- Automatically assign some events to the maintenance leader (*technologician*).

Impact Analysis Results

While validation only was performed with the first prototype, IA assessment was performed for the two executed evaluations. Figure 14 shows this fact: the first one on the left side, the second one on the right.

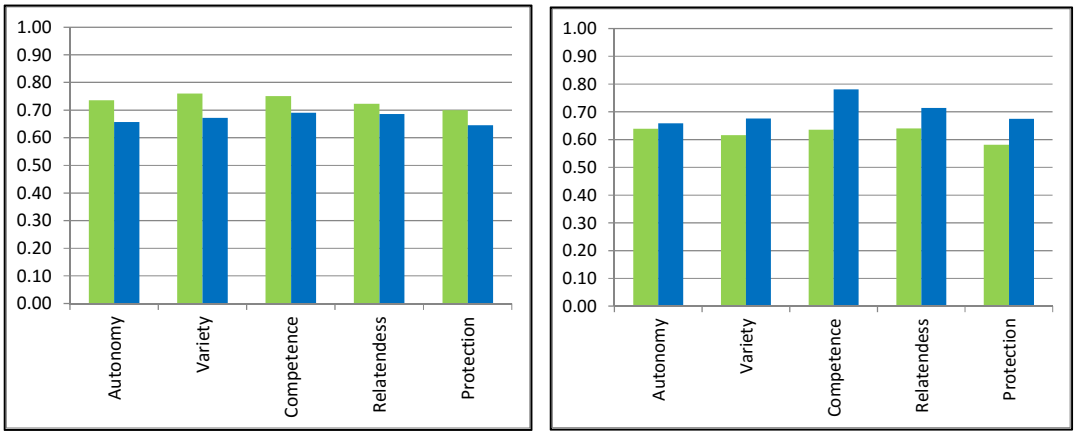


Figure 14.- Impact Dimensions Measured in HID.

First evaluation results were obtained in a testing session while the second evaluation was obtained after releasing the prototype in two production lines: results from the second evaluation clearly improve the obtained from the first one. F4Ws results do not only improve when compared, they also improve when they are compared with CG: the values decrease while the values for F4Ws increase in all the measured dimensions.

It can be explained by considering that the solutions being used in two production lines but also by the preload of more content, as it was requested by the workers and, in consequence, workers had a higher perception of utility of the prototype.

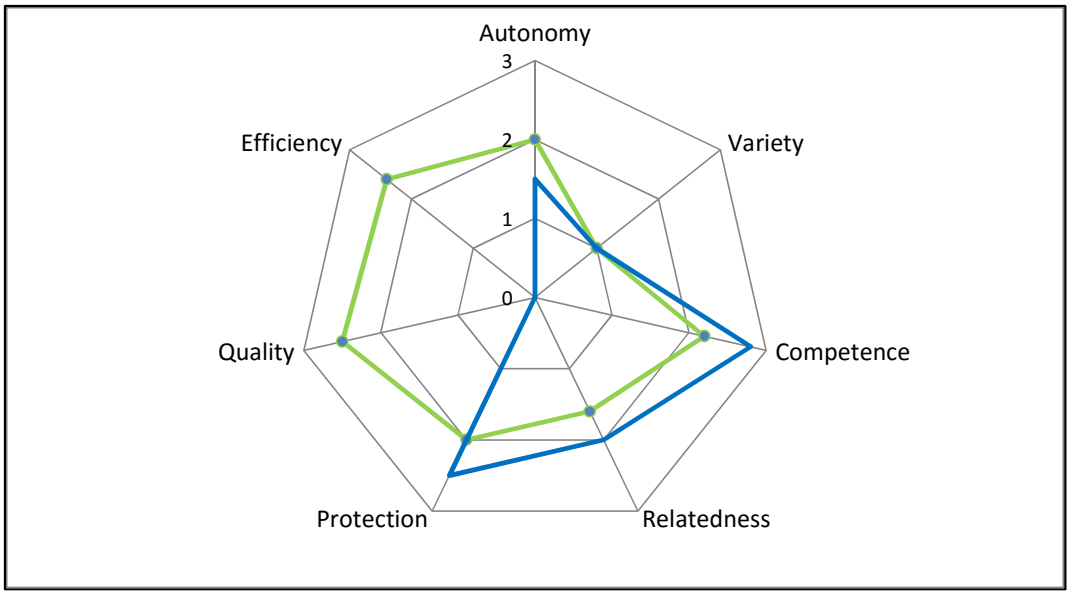


Figure 15: Comparison of Expected and Measured Impact in HID.

3.2.3 HID UCS Conclusions

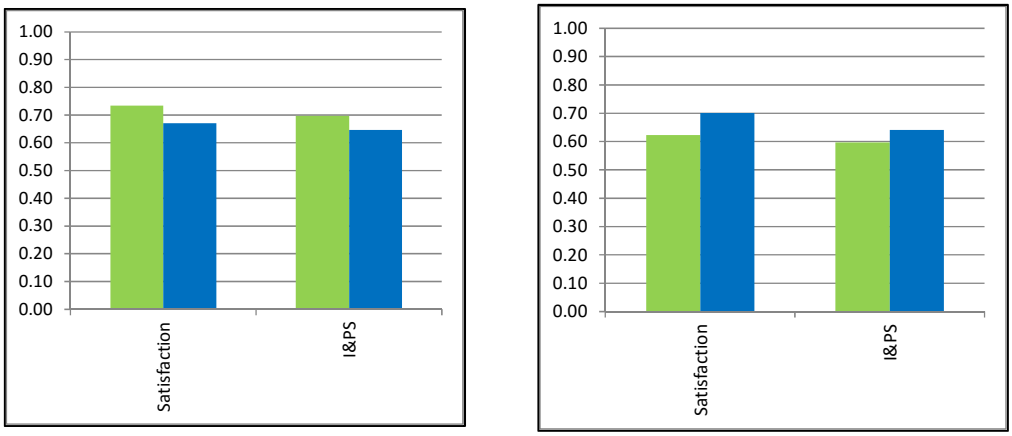


Figure 16: Job Satisfaction and Problem Solving & Innovation Skills at HID.

After deploying the solution in two production lines and introducing data on the systems it seems the solution is improving all the considered dimensions and in consequence, it has positive impact on the satisfaction, the problem solving and innovation skills of workers.

From the very beginning, workers appreciate the prototypes as they demand to extend its use to other production lines. They are found easy to use and to learn as well as, they find the provided information (content and way it is shown) really valuable. Workers really like the possibility of rating solutions and the way the system make them accessible (recommendations, ordering, searching, etc.).

As more information (solutions and machine documentation) will be added, it is expected to have better impact on workers. They appreciate the solution, the information it provides and the capability of accessing it anywhere, anytime. It will make more easy operator´ works and save time when they think they are not able to solve a problem which can easily communicate to the maintenance leader.

According with Figure 16 and considering the assessed dimensions, prototype seems to impact as desired.

3.2.4 Impact within HID

Best way to show the impact the prototype has in HID is that it is being used by two production lines and it is expected to be extended to other two. The provided solutions help to plan the generic operations (e.g. maintenance) and to assign them to a specific operator and timeframe.

As workers receive a to-do list, they can organize their tasks and increase their autonomy which is also supported by the provision of relevant information.

Moreover consciousness of the planned activities contributes to reduce the stress level due to a better planning and the reduction of last minute tasks. Moreover they can be rescheduled if an expected event occurs and requires stopping the machine close in time to the planned maintenance activities.

Finally based on the analysis of reported events, new periodic maintenance operations can be created and team leaders can create repetitive events that will pop-up in the to-do list of a worker in due time. Depending on the complexity of the tasks and on the required competences, some of these tasks can also be assigned to operators reducing the workload of maintenance workers.

3.3 HIR UC

Hidria Rotomatika d.o.o. (HIR) produces electrical steel laminations and die-cast rotors for automotive and other industrial applications. The company produces parts in the desired quantity according to its customers' designs and specifications. One stream of products is die-cast rotors with shafts that are used in electric motors. These die-cast rotors are compound components consisting of electrical steel laminates and aluminium that form the basis of these squirrel-cage rotors of electric motors. In a later processing step, a precision-machined steel shaft is inserted into the rotor to complete the assembly. The process from raw material to completed product is spread out over the plant, as it involves numerous processing steps at the factory's different workplaces, including steel stamping, laminating, die-casting of aluminium and the final assembly.

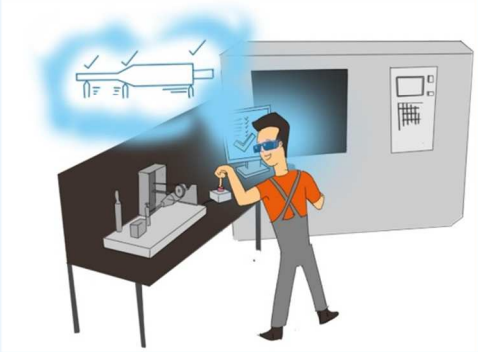
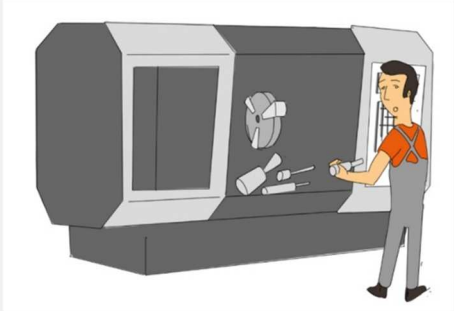
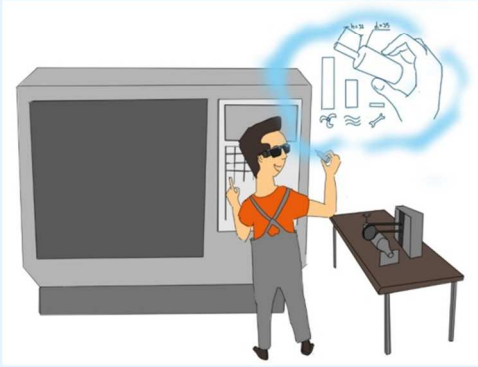
As-is	To Be
HIR. Tedious manual quality control and machine setup	HIR. Automated quality control and guided machine setup
	
	

Table 6. HIR UC definition.

HIR use case, "Augmented decision making for production workers", was defined in D1.1 and D1.2 and considers the scenario: Automated quality control and guided machine setup. Table 6 shows it.

The scenario takes advantage of big data capacities used for integrating machine data, MES systems, CAD systems and automatic measurement in order to help workers to monitor production. The information (alarms, recommendations, etc.) are presented to workers using either smart-glasses or tablets.

Figure 17 shows the expected impact for this UC.

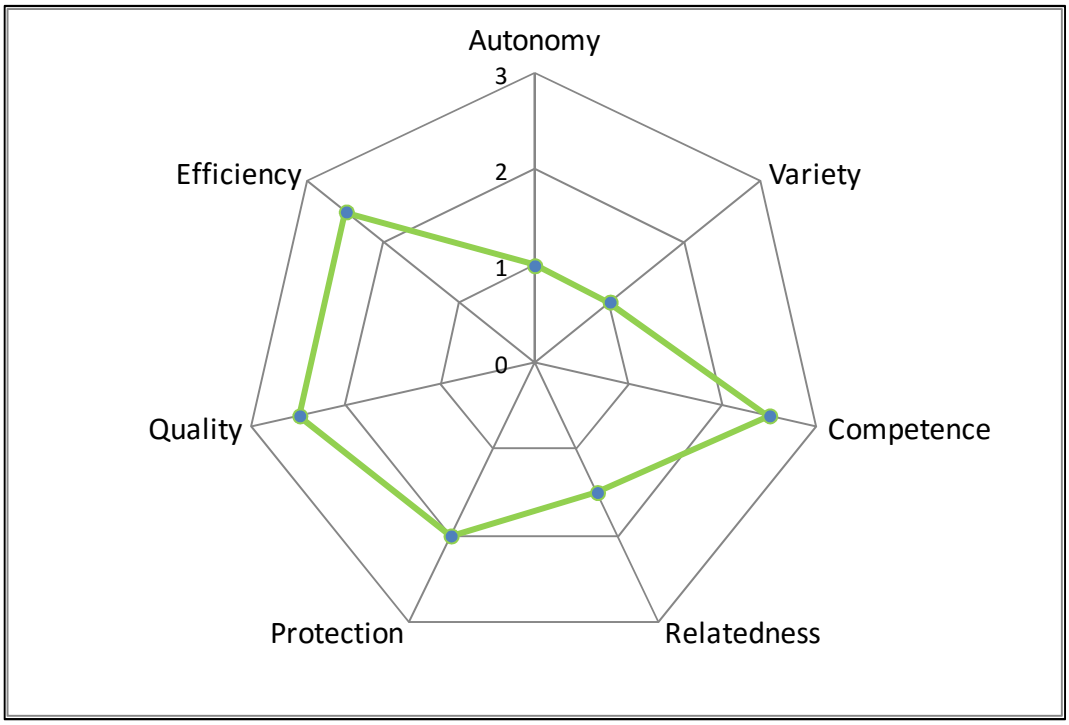


Figure 17: Expect Impact of HIR UC.

3.3.1 Description of HIR Evaluations.

As table shows only one evaluation was performed in Hidria in May of 2017. It has the purpose or gathering data for validating and assessing the impact and it considered both CG and F4W workers.

UC	Date	N. of Participants		Object	Method
		(future) F4W users	CG		
HIR	05/2017	3	3	IA&Validation	Questionnaires

Table 7: HIR Evalutions Description.

3.3.2 HIR Evaluation Results

Validation Results.

Workers like using the prototype in a tablet because it eases the offset process calculation. Nevertheless they asked for a (physical) support that facilitated the use of the tablet keeping free their hands. In addition, it was requested that the infor-

mation could be entered directly into the machine without the need to type it twice as it happens also with the data gathered from the gauge. It is due to the not full implementation of the automate gauge at the time the prototype was tested. Finally the automate gauge project was abandoned due to technical problems for the implementation making it unviable to continue with this prototype.

Impact Analysis Results

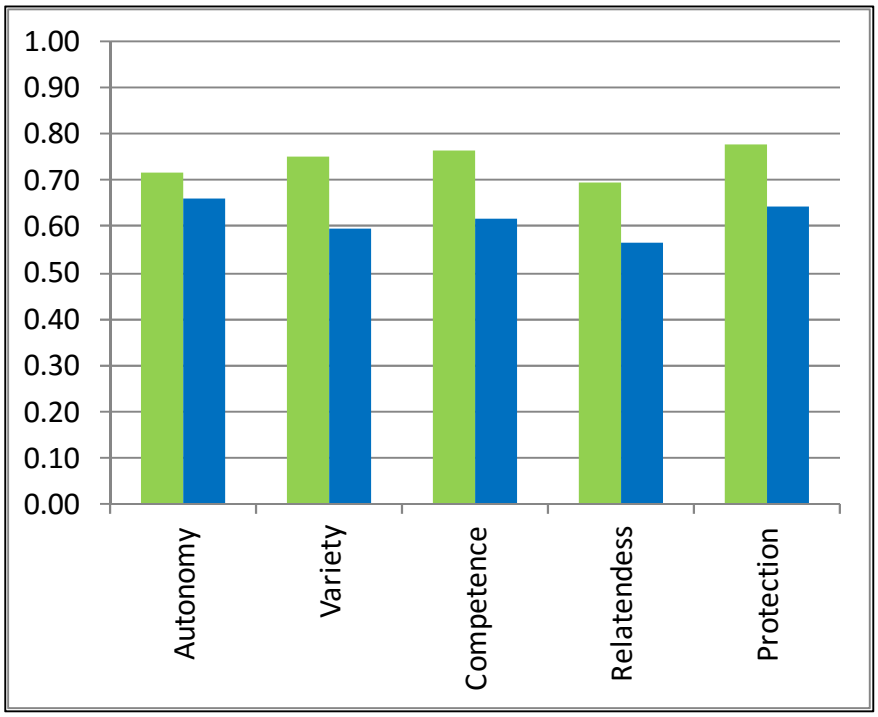


Figure 18. Impact Dimensions Measured in HIR.

Figure 18 show the assess impact in each of the dimensions. This negative impact can be due to the issues introduced in previous paragraph. As workers are required to introduce twice the same information instead of gathering automatically the data or sending it automatically to the machine, the expectations created during Use Case definition are not met.

However as it can be seen in Table 8 a positive opinion and impact can be extracted from their testimonies.

3.3.3 HIR UCS Conclusions

Figure 19 compares the expected vs the real impact. In this UC the expected impact is not achieved due to the impossibility to meet expectations created during its definition.

Quotations	Impact Dimension	Relevance
"I like to use a tablet instead than a sheet of paper and a calculator: it is error proof, save time and provide me a lot of additional data, like blueprint, that simplify my activities"	Efficiency Protection	Medium Medium-high
"I like this innovation: it eliminates the risk of doing error in the offset setting"	Protection	Medium-High

Table 8. HIR Workers' quotation evaluation.

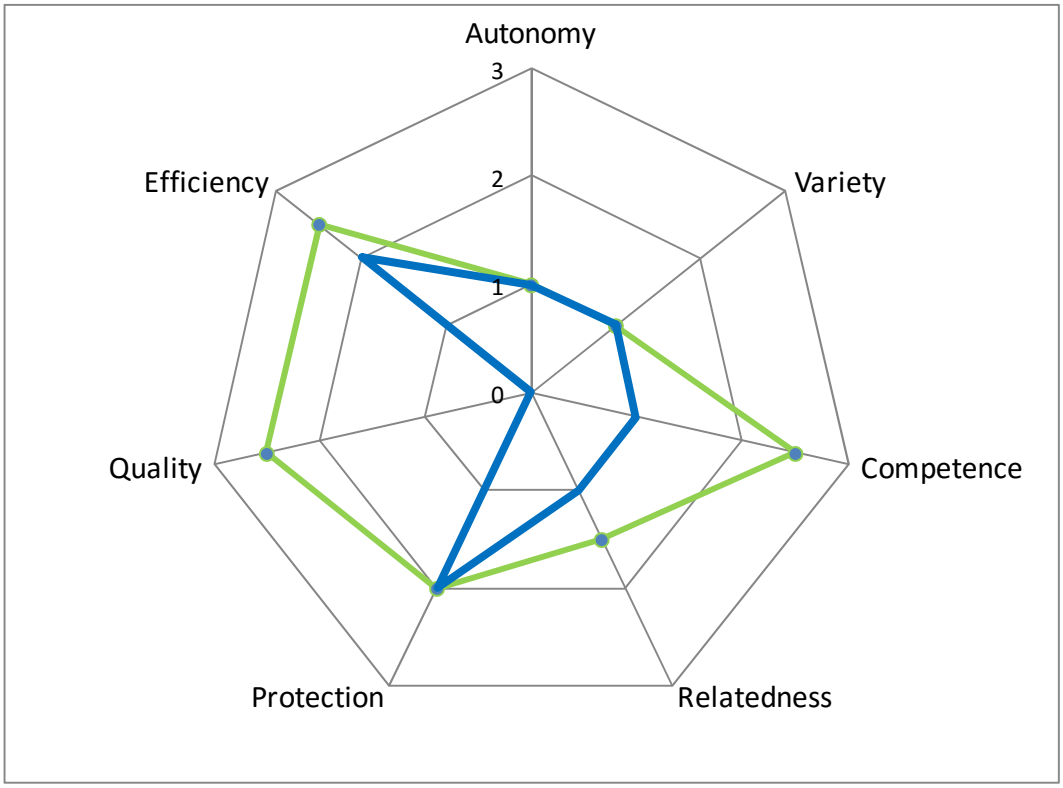


Figure 19. Expected vs Assessed Impact at HIR.

3.3.4 Impact within HIR

FATCS4WORKERS has been the head start to introduce "Industry 4.0" solutions in the production area. It showed to the workers the potential of digital solution. They showed high interest to use new digital solutions and devices and, which is more important, to be more involved their development.

F4W has been the first step into a digital transformation of the company. HIR is implementing a completely new lines based on the output of the project, that include a new measuring machine connected to the ICT based on F4W proposed scheme. All the new lines will use the same approach but considering the trying to avoid the lack of connectivity between the applications, the gauges and the machines in order to gather expected impact.

3.4 SCA UCs

Schaeffler has more than 90,000 employees and is one of the world's largest technology companies in family ownership. Operating in approximately 170 locations in 50 countries, it has a worldwide network of manufacturing locations, research and development facilities and sales companies. As a global development partner and supplier, Schaeffler maintains stable long-term relationships with its customers and suppliers.

3.4.1 SCA-1 UC

First SCA UC was defined in D1.1 and D1.2 as "Quality control expertise for workers" it includes the following scenarios:

- Preventive measurement tasks
- Digitized inspection documents
- Enable the production employees to solve problems
- Regular preventive support on the shop floor

Because of the technological progress, and with the agreement of the industrial partners, it was decided to use Mixed-reality devices under controlled conditions in order to provide learning support for test rig operators.

The decision is based on the absence of certified devices to be used on the shop-floor, which determined moving the use case from the production of engine components to the testing of bearings, and on the fact that implementing this solution supports advancing on the industrial challenge of in-situ mobile learning on the shop floor.

In this sense, as it is shown in Table 9, it is equivalent to the UC defined in D1.2 by comparing the As-is situation (" Complicated tasks, no uniform praxis-oriented training quality") to the To-Be situation ("Augmented learning support at workplace"). In both situations, workers could receive contextualized training (parts, task, language, etc.) using see-though capabilities of Mixed-Reality devices.

As-is	To Be
PS1. Complicated tasks, no uniform praxis-oriented training quality 	AS1. Augmented learning support at workplace 

Table 9. SCA-1 As-Is and To-Be situation.

Figure 20 shows the expected impact of implementing SCA-1 UC.

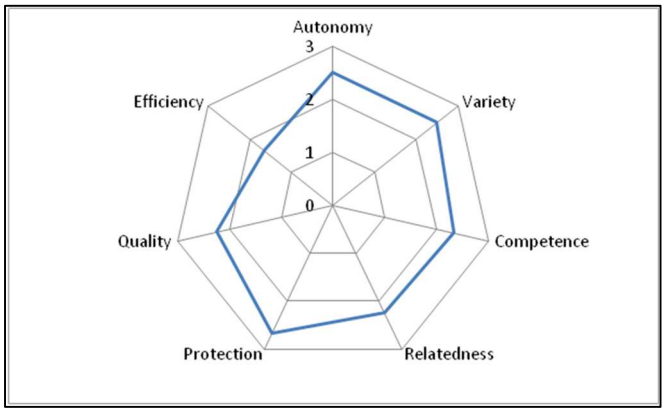


Figure 20: SCA-1 Expected Impact.

3.4.2 Description of SCA-1 Evaluation

Evaluations of SCA-1 were performed on August and September of 2018 involving only users of the solution as Table 10 shows. The first evaluation was performed for validating the first release of the prototype and involved trainers, while the second evaluation focused on determining the impact of the intervention and also involved machine operators.

3.4.3 SCA-1 Evaluation Results

Validation Results.

As introduced in previous paragraph, the validation of first prototype was performed using questionnaires (UMUX-LITE) and interviews. It provides really interesting insights from workers perceptions about the prototype.

UC	Date	N. of Participants		Object	Method
		(future) F4W users	CG		
SCA-1	08/2018	4		IA & Validation	Questionnaire+ Interviews
SCA-1	09/2018	12		IA	Questionnaire for measuring productivity

Table 10: SCA-1 Evaluations Description.

Workers say first prototype fits workers requirements although they appreciate it is in an early stage of development. The prototype is appreciated because it can be used for transferring detailed knowledge to workers, in particular to beginners. Its capabilities of interaction and the fusion of different media, audio and holograms (video see through) makes easier to understand the content because workers perceive images to be closer to real world images than the provided by other applications although video rendering does not perform always well.

However, some interaction issues must be solved or added (selecting cutting planes, zooming, better see through holograms, text label placing, selecting the speed of animation, etc). In relation with this, workers report problems linking the web and the Hololens applications and it is not understood the need of two applications. In any case, workers demand more animations.

The prototype seems easy to use to workers although they reported some problem with smart glasses when wearing prescription glasses. It fits well with defined training processes and it can be easily use in existing facilities. It is particularly appreciated the capability of transferring knowledge anyplace around the world reducing language barriers as well as, for reducing the number of supporting workers' problems instead of requesting help from experienced colleagues.

While the provided information is well presented and valuable it must be improved in two complementary ways: adding more content and providing more details for beginners.

Main concerns of workers for using the solution are related with the need of create new facilities for support this kind of training solutions and also the necessity of creating content cheaply and associated with it the need of trained people for making it.

From the previous paragraphs it can be follow provided prototype meets workers requirements and they perceive it as easy to use and learn although the supporting technology is still on an early stage of development. It is aligned with the results of UMUX-LITE questionnaire show in Figure 21.

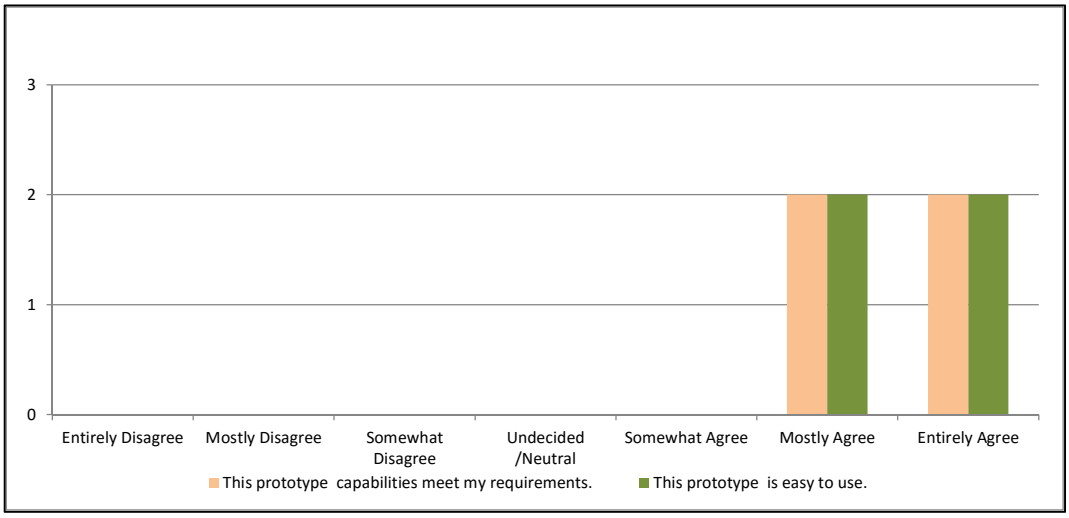


Figure 21.- SCA-1 UMUX-LITE.

Impact Analysis Results

The evaluation of the IA was performed using questionnaires. Figure 9 shows the results for the first, and the left, and the second assessment, on the right.

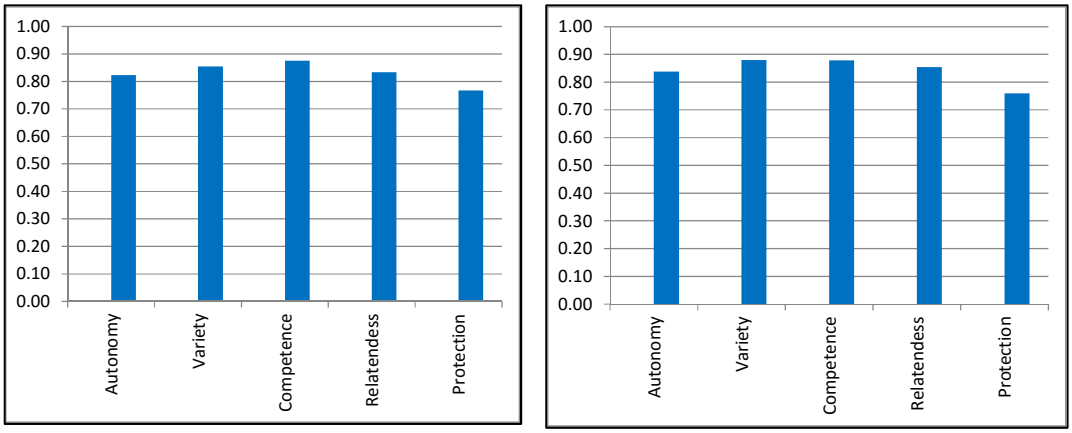


Figure 22. Individual ID measured for SCA-1.

Due to the early stage of development of the solution, the short time between the evaluations and the fact of not using CG; it is not easy to extract conclusions from this data. However, this data can be complemented with the insights obtained from the validation interviews which are shown in Table 11.

Quotations	Impact Dimension	Relevance
"Yes, it could help with problems that occur."	Autonomy	Medium-High
"Yes, you can transport more information." "We work with the whole world and animations would help us to make things easier to understand, beyond language barriers." "It could help at training, so you do not need the help of experienced colleagues as often." "Yes, it will be good for training purpose." "The information is good."	Competence	High
"We work with the whole world and animations would help us to make things easier to understand, beyond language barriers. "	Relatedness	Medium-High
"It can save us many trips to other locations."	Efficiency	High

Table 11: Workers Quotations at SCA-1.

Table 11 shows some workers' quotations. Based on these answers during the interviews it can be follow that the solutions have a positive impact in autonomy, competence, relatedness and efficiency.

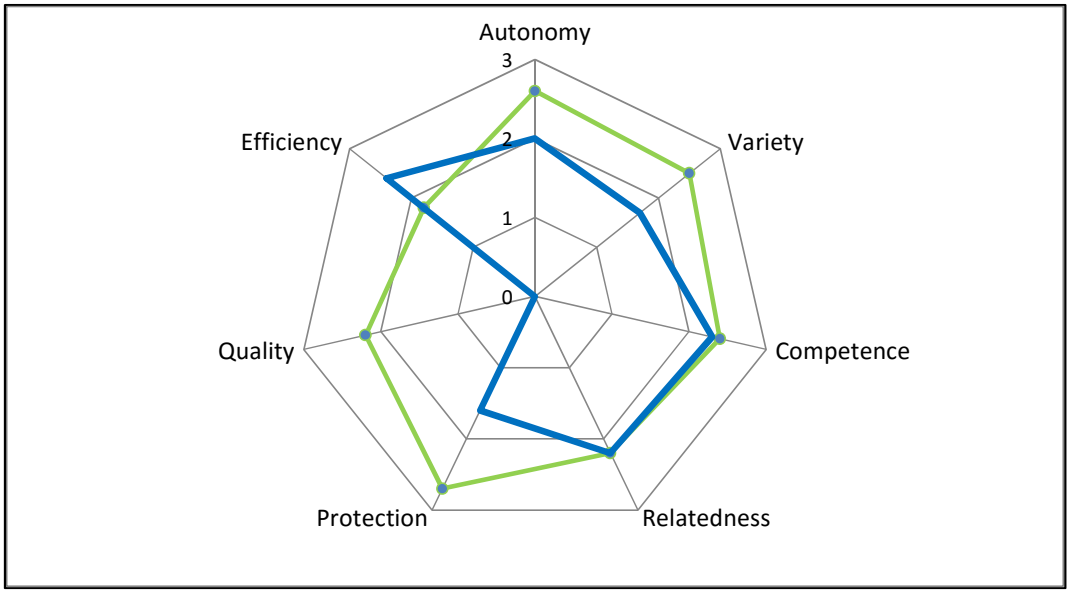


Figure 23: Measured Impact vs Expected Impact for SCA-1.

Figure 23 shows the comparison between the measured and expected impact. To conclude, it must be considered that the implemented UC partially implement the

initial defined UC. In consequence, it can be considered that impact in competence and relatedness advanced as expected.

3.4.4 SCA-1 UC Conclusions.

Although the supporting technology is not ready to be used on the shop-floor (not mature enough), it has a very promising future impact on workers. However, workers express that content generation (and associated knowledge requirements) and facilities can be limitations to be considered when using this technology.

3.4.5 SCA-1 Impact within SCA

Based on the FACTS4WORKERS prototypes developed for SCA, the MR technology is being promoted within the company. It will be expressed as new in situ learning projects covering more UCs as they can contribute to time and money savings in training because MR contributes to reduce language barriers and to avoid many travels all around the world.

3.4.6 SCA-2 UC

First SCA UC was defined in D1.1 and D1.2 as "Paperless information management for assembly workers" it includes the following scenarios:

- Integrated workflow control for maintenance work
- Integrated digital shift logging
- Easy information access for retooling a machine
- Digital workforce management

During the planning phase of the developments it was decided to implement the second of this scenarios, as Table 12 shows.

As result of the implementation, a digital shift logbook was created supporting workers reporting of important occurrences during their work time, the shift-handover sheet or automatically generated information from machines and systems. It enables the look up of team leaders and other workers in the future for recovering knowledge and/or increasing it.

Figure 24 shows the expected impact of the full UC implementation as introduced in D1.1.

As-is	To Be
PS2. Issues Documenting the Shift in a Handwritten Log 	AS2. Integrated Digital Shift Logging 

Table 12: SCA-2 As-Is and To-Be situation.

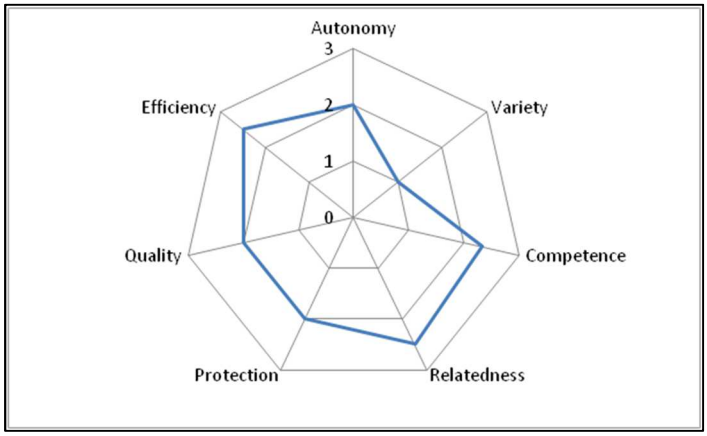


Figure 24: SCA-1 Expected Impact.

3.4.7 Description of SCA-2 Evaluation

First evaluations of SCA-2prototype were performed on November and December of 2016 involving only users of the solution as Table 13 shows. They focused on the impact of the prototype and only future users of the solution were involved. Regarding the legality of the process (it was not possible to meet with the workers council before the evaluation), the assessment of the impact was based on the answer of the workers to a guided interview based on selected questions of the IA questionnaire related with the prototype expected impact.

The second evaluation was performed on August of 2018. In this case it included both Digital Shift Logbook users and control group users, it consider both the validation of the presented prototype and the assessment of the impact. Later questionnaires were also used.

UC	Date	N. of Participants		Object	Method
		(future) F4W users	CG		
SCA-2	11/2016	10		IA	Interviews
SCA-2	12/2016	4		IA	Questionnaire+ Interviews
SCA-2	07/2018	5	7	IA&Validation	Questionnaire for measuring productivity

Table 13: SCA-1 Evaluations Description.

3.4.8 SCA-2 Evaluation Results

Validation Results.

As in other cases for validating the solution SCA-2 evaluation used UMUX-LITE and a questionnaire which can be used for interviewing the workers once they tested or used the solution under evaluation. UMUX-LITE questionnaire results of the second evaluation are shown in Figure 25.

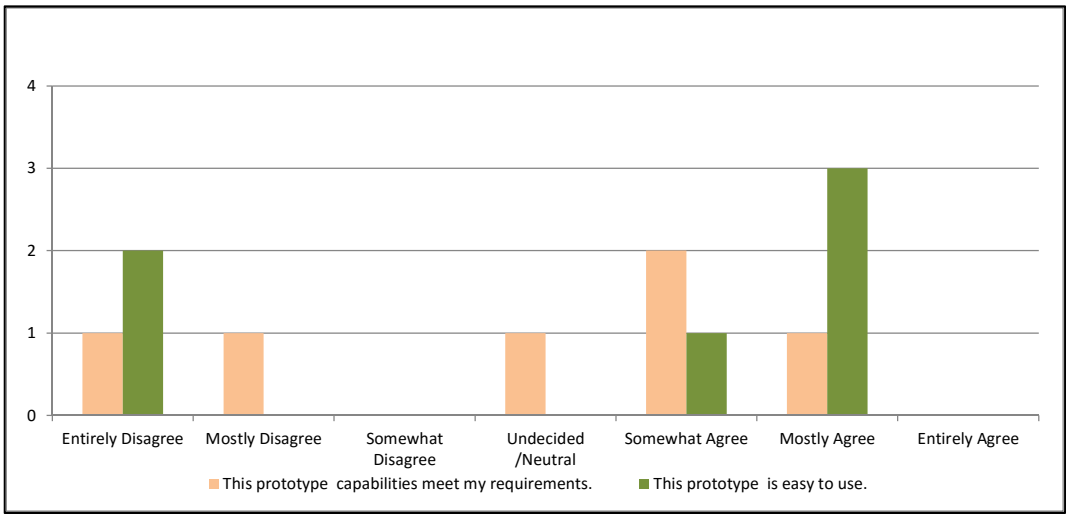


Figure 25.- SCA-2 UMUX-LITE.

When these results are compared with other UCs' results, it can be appreciated a higher level of disagreement. First evaluations do not validate the prototype, in consequence, bugs and new requirements were not reported and, as some worker reported, they were not solved or implemented.

However, workers say second prototype works better than the first one. They find it helpful for supporting their tasks, providing correct information, making it possible to know the state of existing tasks, easing the possibility of reviewing what happened before (with an installation, an error solution, etc.), as well as, communications (explicitly or not) with their colleagues.

To end, reducing the use of paper is also remarked as an important fact to be considered. Some workers say the prototype will reduce the shift-handover time if more machines were added in the system and they could take the tablet from machine to machine. The availability of the devices for using the solutions must be guaranteed. Although tablets are appreciated (because they support mobility), some concerns are shown related with their fragility and also with their interaction.

They suggested linking the prototype to externals data sources and access them directly by implementing powerful search functionalities for easing workers access to information.

In the case of maintenance workers, knowing in advance assigned tasks (their states, devices location, existing reports, etc.) reduces waste time and in consequence, increases productivity.

To assure the access to the information ubiquity is necessary. While in most shop-floor scenarios connectivity is assured, in some others (because dead spots, metallic structures, electromagnetic noise, etc.) it is not. For these scenarios an off–line application must be provided which supports the download required supporting data and information, the local storage of data input by workers and the possibility of uploading these data as soon as connectivity is recovered.

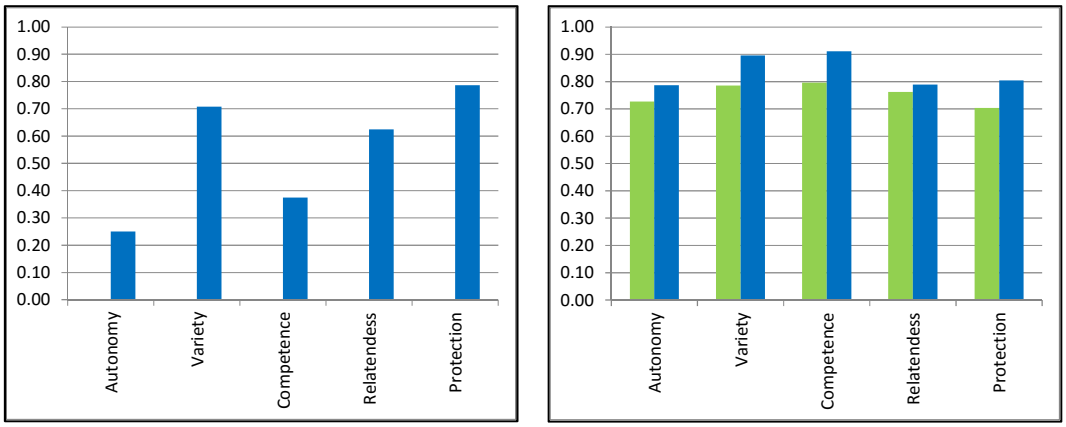


Figure 26: SCA-2 First evaluation results.

Although the hiding of text by keyboard is reduced from previous version it is the most annoying usability reported issue. In any case, the improvement of the user interaction, the increase of searching capabilities and the implementation of some

requested improvements (not implemented yet) are perceived as limiting factors for their regular use of the provided solution.

Workers requested to use the application in more work places and with more information included in the system.

Impact Analysis Results

The SCA-2 evaluations performed by the end of 2016 were the first evaluations performed using FACTS4WORKERS framework. As it is explained previously they were performed using guided interviews based on a selected group of question from the questionnaire. It supported not only gathering valuable insights for assessing the impact of interventions but also for finding issues to be solved within the framework tools it-self.

Quotations	Impact Dimension	Relevance
"We work with the whole world and animations would help us to make things easier to understand, beyond language barriers. "	Protection	Medium-High
"It helps to save paper and you can trace back documentation." "You do not have to write by hand and it is clearer." "Yes, it would make shift handover easier and faster" "Yes, it would make shift handover faster" "In the current status it slows down work." "For short-term use and handover the old system is better, for searching for old entries the new one is better." "The system could save time and money, and with the tablet we can have better access to the documents from anywhere." "It can make our work faster. We won't need so much time for documentation. " "It can be helpful and make our work faster." "The process will change, I don't have to move around so much on the workplace"	Efficiency	Medium-High

Table 14: Workers Quotations at SCA-2.

From the feedback provided by the workers regarding the framework, it was appreciated that workers did not correctly understand the concepts under evaluation and some of the question formulations. Although it was solved in the remaining evaluations, these facts must be considered when interpreting the results to be presented in next paragraphs. Left side of Figure 26 shows the impact assessments for the first evaluation while the right side shows the results for the second evaluation.

The second evaluation of SCA-2 was performed in July of 2018 using questionnaires and CG for assessing the impact of the second release of the prototype. While comparing the results of first evaluation with the second ones, Figure shows an increase in the perception of autonomy, competence and relatedness of the workers while the variety keeps equals and protection decreased. However when comparing the results from FACTS4WORKERS solution users with Control Group all the values are higher for the FACTS4WORKERS group.

Quotations of Table 14 complement the results of the second evaluation and are considered for creating Figure 27 which compares expected and measured impact of the SCA-2 UC.

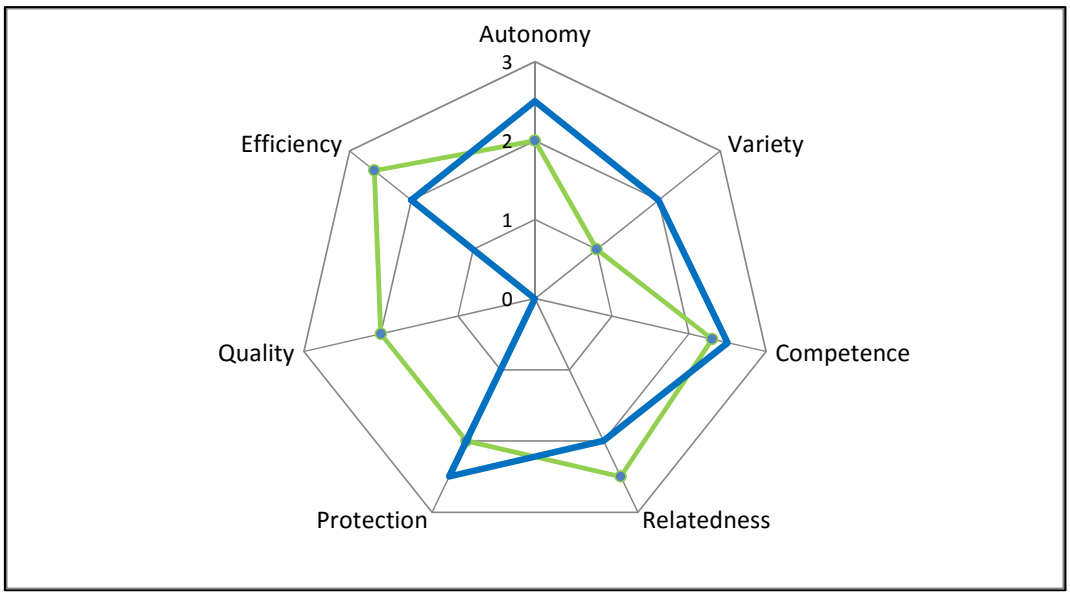


Figure 27: Measured Impact vs Expected Impact for SCA-2.

3.4.9 SCA-2 UC Conclusions.

Although the digital shift logbook is not a core activity of the production process, the obtained results of the intervention at SCA show that it can be a good way for starting the development of the digitalization strategy of the company. Figure 28 compares the Job Satisfaction and Problem Solving and innovations skills measured for both F4W and CG. It shows improvements in both goals.

When these increases are considered by dimension, the expected impact is partially obtained because only digital shift logbook is implemented and it seems we advanced in the right way. Although this fact is important, the learned lessons about

limitations that must be consider within the process are even more important for the job satisfaction.

As in other use cases, issues with usability, inclusion of more information, availability of devices and connectivity are highlighted by workers but, more important for the success of the interventions is the solution of detected problems and the implementation of compromised features in a short time which are essential factors for the success.

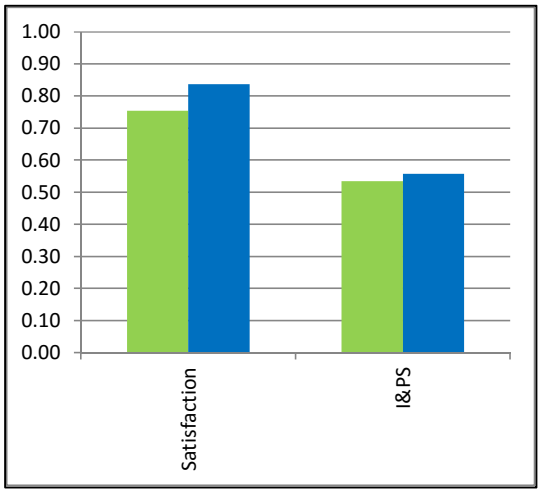


Figure 28: SCA-2 Goals Achievement.

3.4.10 SCA-2 Impact within SCA

Promising results previously presented and the acquired know-how encourage SCA to include prototype and supporting technologies (docker) as basis for the continuation of Schaeffler's digital shop floor management project. As a first step, the prototype shall be transferred to a production.

However, the most important impact of this UC is the decision of including workers as active members of the implementation process of the different solution. Management have realizedthat providing worker-centric solutions and involving workers in the development process results in providing valuable insights about the real productions process and reduces the risks of the projects.

3.5 THO UC Evaluations

Thermolympic (THO) is a family-owned business that has been in operation since 1971. It has 91 employees and is based in Zaragoza, Spain. THO is a specialist in the field of thermoplastic injection moulding. It also designs and constructs the moulds used in this process. THO produces complete pieces or processes prefabricated

work pieces as well as piece components. The components are assembled into intermediate or final products before they are shipped to the customer. THO's customer base ranges from original equipment manufacturers in the automotive industry to suppliers of end-consumer products for supermarkets. THO aims for maximum production quality and works in close cooperation with its customers from the simulation and design activities to the actual manufacturing process and, finally, to the quality control and shipping. The biggest challenge is that much of the information is not yet digital, and therefore most of the information quickly becomes outdated.

Therefore, THO mostly wants to improve real-time data collection and analysis.

3.5.1 THO UC

THO UC "Paperless information management for production workers" was defined in D2.1 and D2.2. It is composed of the following scenarios shown in Table 15:

- Automatic measurement reduces job pressure: based on machine production parameters, automatic measurement of produced parts and according with quality specifications a system determine if the part fits specifications or not and notify to machine operator who just must review parts not passing automatic control. Operator introduces its decision about reviewed parts on the system together with the measurement he/she takes. This information is recorded together with automatic acquired data in other to support improvements in the automatic decision system.
- Database simplifies decision making: the provided module supports workers by identifying machine errors based on the deviation of machine parameter values. It is able to notify workers the error and, if it is already solved, to show the possible solutions and also the person who solve it (operator or supervisor).
- Self-paced training on the job: an e-learning module is defined to support worker's training on workplace.
- Evaluating real-time data: application of big-data technologies that collect the data produced from different systems (machine, ERP, CRM, etc.) and support decision-making process.
- Detailed guidelines increase reassembly speed: instructions for setting up new production (moulds) managed by a system supporting multimedia content and communication tools.
- Together with these scenarios it was defined the expected impact of their implementations. This is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

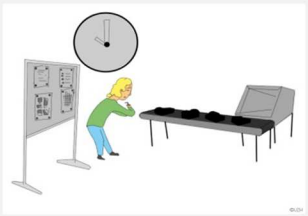
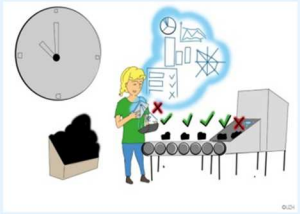
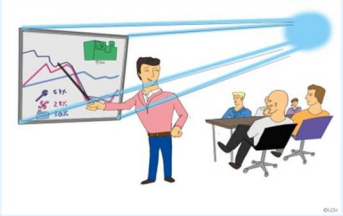
As-is	To Be
THO1: Issues with manual measurements 	THO1: Automatic acquisition and analysis of data from process reduces job pressure 
THO2: Fixing the production of faulty parts 	THO2: Database simplifies decision making 
THO3: High barriers for 'in-between' learning 	THO3 Self-paced training on the job 
THO4: Missing trustworthy data/documents 	THO4:Evaluating real-time data /documents 

Table 15: Scenarios of THO UC.

3.5.2 Description of THO Evaluations

The evaluations of the use case were done assessing the impact via questionnaires as it is shown in Table 16. The first prototype of the Training, Control Chart and Defect and Solutions applications was deployed in June of 2017. The evaluation was

performed by WP6 members supported by the UC leader. The second evaluation focused on the Smart Documents module deployed in THO in August of 2018.

The validation of the deployed solutions was performed using UMUX-LITE questionnaire and interviews based on the questionnaire used in other UCs. Next paragraphs show relevant results and insights.

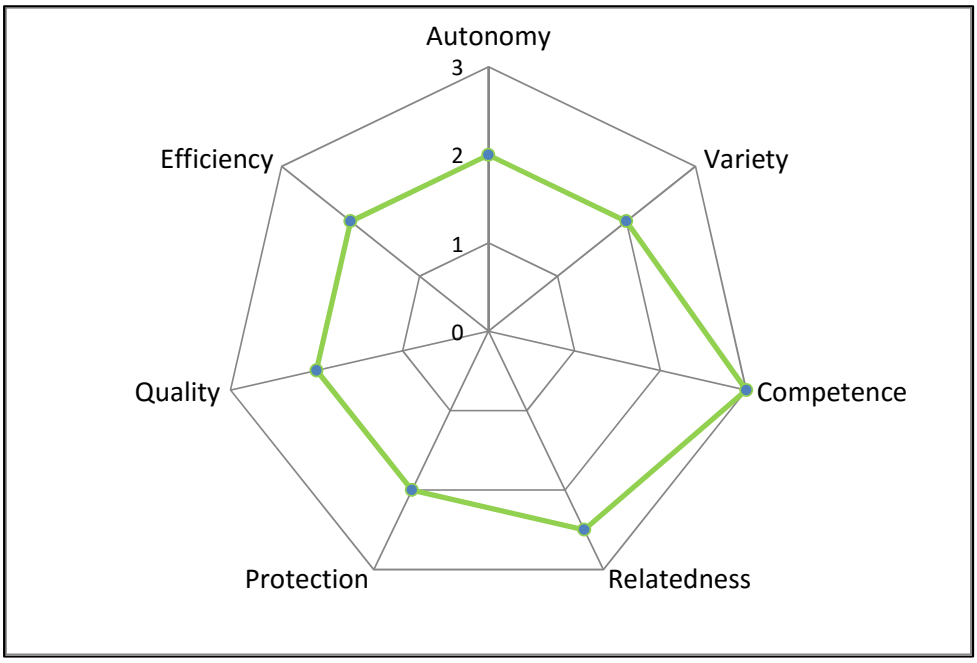


Figure 29: Expected Impact in THO.

UC	Date	N. of Participants		Object	Method
		(future) F4W users	CG		
Training Control chart Defect and Solutions	06/2018	7	6	IA & Validation	Questionnaire+ Interviews
Smart Documents	09/2018	7	5	IA & Validation	Questionnaire+ Interviews

Table 16: Description of THO Evaluations.

3.5.3 THO Evaluation Results

Validation Results.

Next paragraphs show the results of the validations performed in THO. First, they are presented the ones form the validation of the Training, Control chart, Defect and Solutions applications and then the Paperless results.

Figure 30 shows the UMUX-LITE first validation results focused in Training, Control chart, Defect and Solutions applications. It shows that presented prototypes meet workers requirements who find them easy to learn and use.

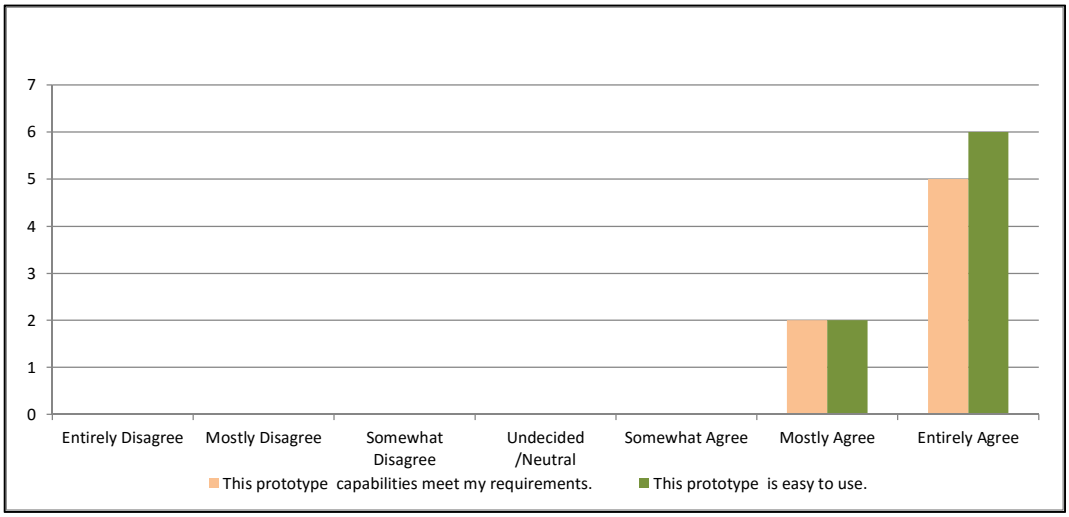


Figure 30: First validation UMUX-LITE Results in THO.

Applications were tested using a tablet. Due to their skills with mobile devices, workers do not perceived it as a barrier and they consider the application easy to use and useful. Workers like the navigation and the interaction with the prototype.

Regarding to the training materials and content, workers appreciate all the visual information associated to the learning materials and questions (diagrams, images, etc.) and, they say they are adequate because "These are the documents we use in our daily work" which helps them to find the required information to be learn.

ILUO tests are appropriate when considering the dimensions: required time for gathering information and difficulty for answering the questions. ILUO is an incremental workers knowledge/competence assessment method based on the provision of training to workers by a mentor. The achieved knowledge is evaluated by both the worker and the mentor. It is incremented from I to O as worker gets more competence on a part, machine of process. Workers expect between 15-20 questions to

certify the ILUO level and no more than 10 minutes for fulfilling them. What they do not want is an extra effort on their daily basis.

There are three kinds of requirements from workers:

- Increase the font size and highlighting relevant information (such as links to documentation);
- Facilitate login access;
- Link the training process to the manufacturing process: once they have to start to manufacture a piece they would like to be able to receive the training and have access to this specific information.

The second evaluation was performed in August of 2018 and it was focused on Paperless application.

The UMUX-Lite results, Figure 31, show that prototypes meet workers requirements and they find it easy to use. The prototype was tested using tablets. Workers like the clear and intuitive navigation but it was requested to have bigger screens in order to easily review some documents (such as mould mounting instructions).

UMUX-results are aligned with the opinion expressed by workers in the interviews. They find the new way of working very powerful because it allows real time access to information and documentation both, on shop-floor and in office. It eases and reduces the time to communicate between production and quality staff and, in consequence, it increases quality because workers can stay on their workplaces supervising production.

New application does not only contribute to improve exchange of information between colleagues efficiently, as required documentation can be accessed from workplaces workers. It also reduces the time for starting a new job making easy to read/review documentation as a way for avoiding problems (or to know in advance possible solutions). Finally, application capability of tracking access to documents contributes to ensure changes in documentation are communicated as they happen.

Required improvements on the prototype can be grouped in: document and templates creation, workers interaction with information and devices interaction. First, there are the related with the generation of the documents. Regarding the creation of the templates and of the documents, it is requested to be able to access to external editors (video, audio, etc. as they are seen as a good way to explain things) directly from the application for easing the inclusion of multimedia data (which in some cases could be generated by workers). It is also required to simplify the creation of the documents by enabling the reuse total or partial of existing documents, by including dynamically or not data from external sources (databases, files, webs, etc.), enabling the inclusion of several files (images, video) at once, being able to highlight important content or to include temporary requirements (i.e. an specific quality con-

trol during a week). Another kind of requirement regarding the creation of the documents is the capability of tracking the version of the documents and its templates for assuring that they are recoverable in the future.

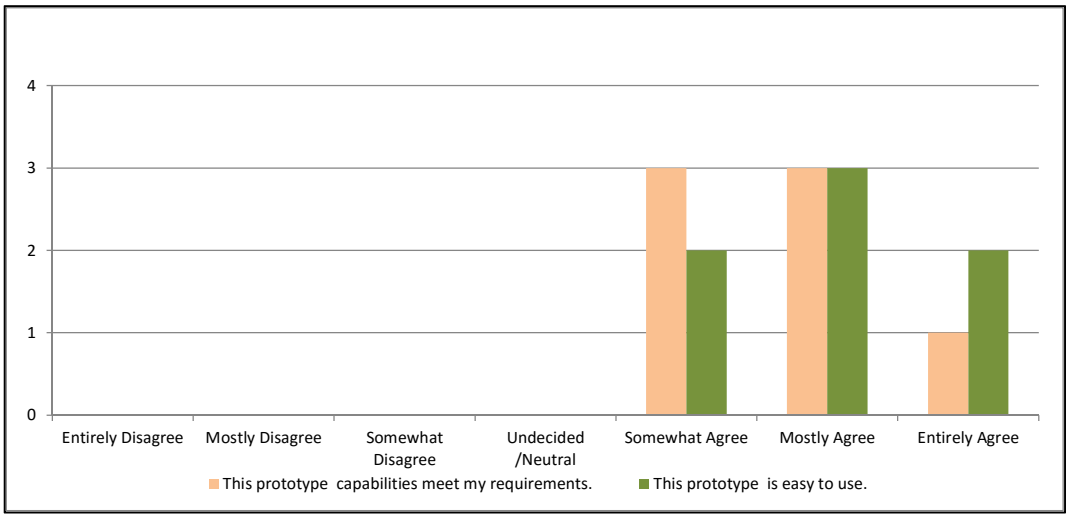


Figure 31: Smart Documents UMUX-LITE results in THO.

Associated with the last editing requirement, there is a need to clearly notify to all relevant workers any change in the documentation (by including a visual signal) and to track the access. These requirements can be considered within the interaction requirements of workers with provided/required information. Here the main request is to simplify the information presented to the workers: it must be contextualized to the role they play and the tasks he/she is involved in: document templates must not be showed to shop-floor workers, for a given part operators must be able to access Standard Operations Sheet (HOS- control guide), packing sheet, defects to operator of a given machine or rework instructions (videos are suggested as a good way to explain them). Finally to summarize, present the information in graphic form to the workers is the most useful and understandable way for them. In order to simplify the interaction it was requested to remove the login requirement or to provide it without active workers participation (i.e. using a kind of RFID card). As we already say, bigger screens are requested because of the requirements of some tasks (i.e. for accessing mounting mould instructions). It will be interesting that the interface adapts itself to the visualization capabilities and to be able to zoom images or editing them.

Impact Analysis Results

In THO impact assessment was performed using questionnaires and CG. Figure 32 shows the results for both evaluations: the Training, Control Chart and Defect and Solutions applications on the left side and the Smart Documents application on the right.

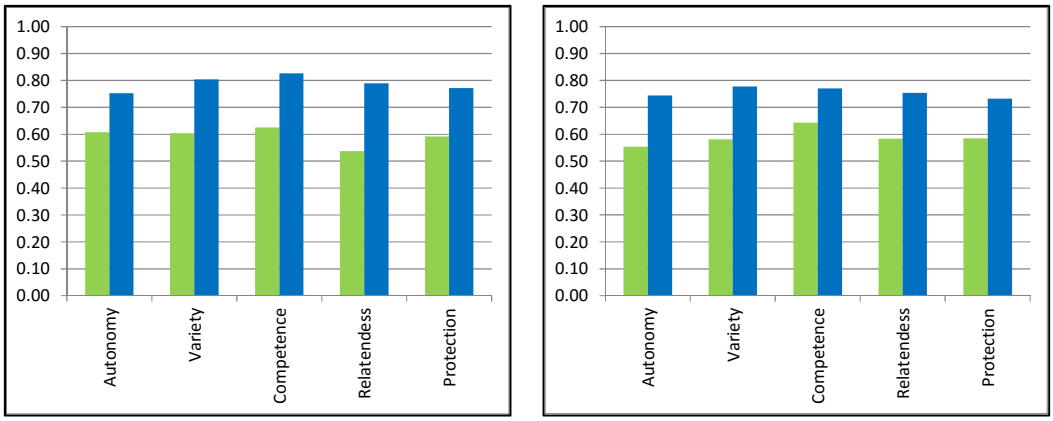


Figure 32: IA Results of THO Evaluation.

Regarding the first evaluation results, the one obtained from Training, Control Chart and Defect and Solutions applications FACTS4WORKERS prototypes contributes to increase, in comparison with the values of CG, all the measured impact dimensions.

This data can be complemented with the information obtained from the interviews during the validation. Table 17: Workers' Quotations in THO at First Evaluation. Table 17 shows relevant workers quotations. They show worker's perception about the positive influence in their competence, relatedness but also in the efficiency and quality of the task they are involved in.

Quotations	Impact Dimension	Relevance
"The prototype could help us to learn more and to gain knowledge, so we will work better"	Efficiency, Quality	Low-Medium
"Once I receive the production order, I would like to have this information as a support tool". "This tool could support our training process anywhere, anytime, not only on the shop-floor but also outside of the factory". "I would like to use it. I would like to have it in my mobile so I could take some courses at home" "Yes, I would like to use it. I think training is very important"	Competence	Medium-High
"I would like to have, once I receive the production order, all this information and training materials linked to the piece".	Relatedness	Low

Table 17: Workers' Quotations in THO at First Evaluation.

Coming back to Figure 32: IA Results of THO Evaluation.Figure 32, its right side shows the impact as measured using the FACTS4WORKERS questionnaire. In this

case it is measured the impact of the Smart Documents application. As in the previous evaluation it has positive impact in all the dimensions.

Quotations	Impact Dimension	Relevance
"It greatly improves the way of working because the information / documentation is easily accessible. The visualization is very good (now docs in black and white)"	Protections, Relatedness, Efficiency, Quality	Medium-High
"The information is in real time since you send it (now you have to find the document, print it, take it to the position)" "What to include defects is very good…If you could do so would be the host because if you have a defect now run to find the quality or the manager and many times you are in the machine and cannot move" "The best thing I see is that of the defects since you find out about those that have appeared and if you give one, you communicate it directly and you know who to consult. 'You are released from responsibility'" "I would spend time reading the documentation because if not the problem is mine and then I can waste a lot of time" "[Now] I do not look at the folders with the documentation info, it is great"	Efficiency, Quality, Relatedness, Protection	Medium-High
"Now it's not clear how we work …it can change it."	Quality	High
"It is great to show [part] on the screen" "I'm going to have time for this … [now] I cannot; I'm 15 minutes early to prepare the workplace, etc." "It would have to be that we arrived and had the piece on the screen. We do not want to have to look for the piece (when it is taught, it is not complicated to look for it)"	Efficiency, Protection, Quality	
"It makes me nervous a lot of information, I just want to see what I need"	Protection	High

Table 18: Workers' Quotations in THO at Second Evaluation.

Table 18 shows the quotations gathered from the validation interviews. They reinforce the results obtained with the questionnaires for the individual dimensions and also provide some valuable insights about the impact of the solution in the organizational dimensions based on the workers` perceptions.

3.5.4 THO UC Conclusions

Evaluations in THO were performed on different applications. It can be difficult to obtain conclusions but the use of CG allows doing it by comparing these results with the users of the applications.

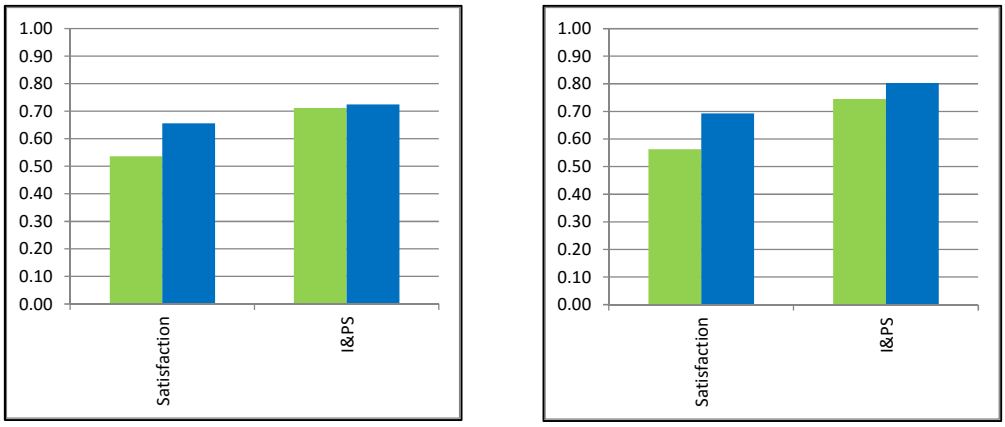


Figure 33: THO UC applications goals achievement.

Figure 33 shows the obtained results after evaluating both applications. In both cases, they contribute to increase the satisfactions of workers. Although Problems solving and innovations skills increases, it does not seems to be significant enough probably because of the kind of tasks performed by workers in THO.

Taking a look into the insights obtained from workers quotations it can be appreciated that the applications contribute to increase the (perceived) efficiency and quality of the tasks.

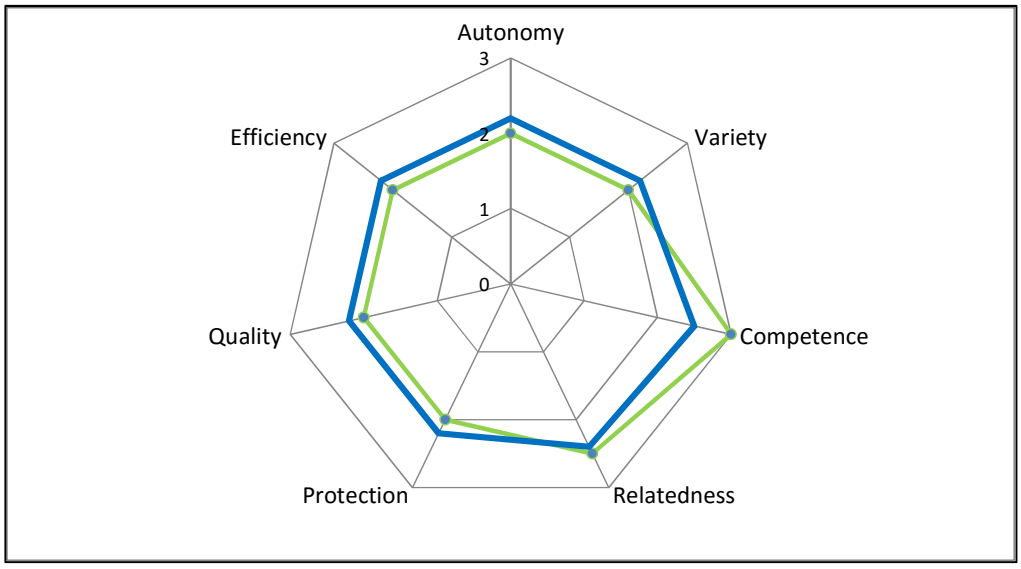


Figure 34: Expected vs Measured Impact in THO.

Figure 34 compares expected and measured impact after deploying applications in THO. It shows they contribute in the expected ways. However, some issues must be solved in the applications. They can be summarized in:

- Increasing the available information, customize it to the worker and the tasks he is involved it.
- Simplify the navigation and make it more graphic.
- Use devices which best fits each work/task.

3.5.5 Impact within THO

F4W has been a head start to test Industry 4.0 solution and to promote the culture of digitalization within the company both from the side of the machines (now most of the production lines are connected to the ICT infrastructure of THO thought BMS) and from the documentation side.

Results of FACTS4WORKES project are going to be used by THO in the future. First, it is planned to extend more mature applications (i.e. training) to more workplaces (including more content).

Less mature FACTS4WORKERS application will be further developed and new applications for introducing new features will be implemented after the project end. The Open source license of the building blocks is going to be used for extending available building blocks.

Smart Documents will be enhanced by integrating it on THO's ICT infrastructure. Big Data building blocks will be used for implementing predictive detection of part failures.

THO workers, due to the lean organization of the company, will be kept in the loop and they will see immediately the newly developed features.

3.6 TKSE UCs

Thyssenkrupp Steel Europe AG (TKSE) is a leading supplier of carbon flat steel products. Approximately 19,500 employees manufacture high-quality steel products for innovative. Customised steel material solutions and services complement the business activities. TKSE values the knowledge of skilled workers as a crucial factor in meeting increasing demands for quality and efficiency. Simultaneously, these demands also increase work complexity. A decreasing number of employees and shorter familiarisation phases of young employees require continuous operational and extra-occupational development of employee knowledge and competencies.

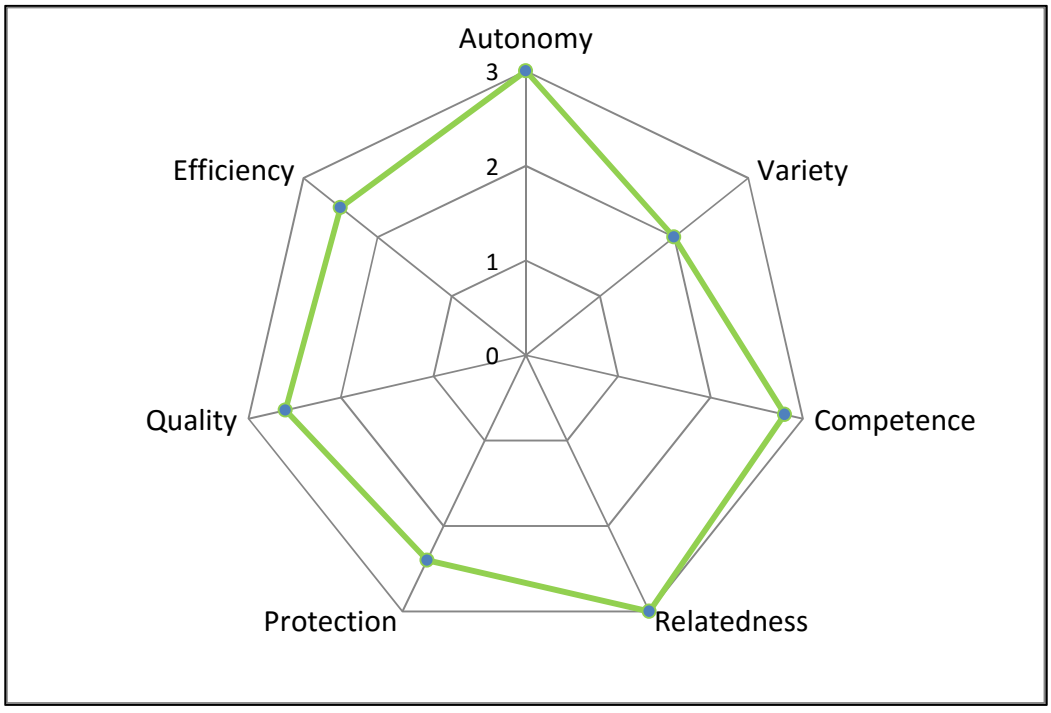


Figure 35: TKSE Expected Impact.

Table 19 summarizes the use cases defined in D1.1 and D1.2 by showing their AS-IS situation (the situation at the beginning of the project) and the TO-BE situation (the desired situation after FACTS4SWORKERS interventions are performed).

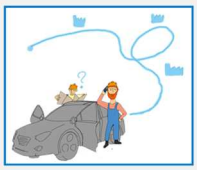
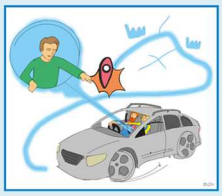
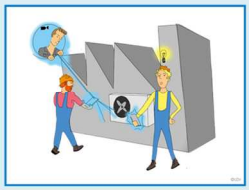
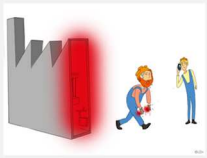
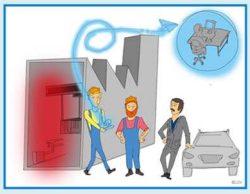
As-is	To Be
PS1. Start shift – Missing Contextual Information 	AS1. Beginning of a shift – an informed start 
PS2. Issues Documenting the Shift in a Handwritten Log 	AS2. Guided Route 
PS3. Repair – Missing Support 	AS3. Repair – Virtual Support 
PS4. 60° Working Temperature in the Crane and Missing Information 	AS4. On site – Progressive Planning and Quick Fix 

Table 19: Scenarios of TKSE UC.

The comparison of both situations, that's the interventions performed at EMO, can be described as:

- FACTS4WORKERS solution provides information about the scheduled maintenances and the break-down devices to maintenance workers. Team leader can assign this task to workers who can review them before the brief meeting where doubts can be solved. As the required spare parts are known in advance they can be put on the van.
- The information managed by the designed solution incorporate data about the devices location, the device itself, previous repairs, the involved colleagues which can be used for quickly solving unexpected issues.

- The managed colleague's information and the video conference capabilities of the solution support the repair of devices with the remote support of colleagues.
- Scheduling and communication capabilities of FACTS4WORKERS solutions support the communication, coordination and collaboration between workers having different profiles.

Figure 35 shows the expected impact of the implementation of solutions meeting this use case requeriments.

3.6.1 Description of TKSE Evaluation

The evaluation of the use case has been done assessing the impact via interviews and doing the validation of the prototypes (the prototype was tested starting in August of 2017 during 6 weeks). In this UC, because of the reduced size of the Electrical Maintenance team, all the workers (4 maintenance workers and 2 technicians) participated in the evaluation.

In Table 20 we summarize the framework tools used for evaluating the deployment solution:

Impact Analysis	Because of the functionalities presented by the prototype, the complete questionnaire was not used: only problem solving and job satisfaction related questions were used and some of them modified when translated to German for having a better worker understanding.
Validation	Validation before the deployment was performed using observation and Think Aloud Methods while workers perform their tasks. The validation was performed using a rugged tablet which was used for data entry and for the order generation. The tablet was used at the workshop (before deployment), at the installations and in the basement.

Table 20: Evaluation Tools Used in TKSE.

3.6.2 TKSE Evaluation Results

Validation Results.

Figure 36 shows the answers of the workers to the UMUX-Questionnaire: most workers think the prototype meets their requirements and it is easy to use and to learn.

These results were also obtained during the evaluation: it was observed that every worker stated clearly that the app with its functions covers the existing requirements. The main difficulty reported during the evaluation was the missing data of the app. Nevertheless every worker looked forward to use this application whenever a full dataset would be provided.

The test of the application uses tablets for data entry and the order generation. At the beginning the tablet was frequently used, subsequently more sporadic (probably because of extra workload due to data entry which must be done twice).

Some workers, who find the solution helpful, showed their concerns about the use of a tablet, because of its fragility, and also because of the effort it requires entering data using it.

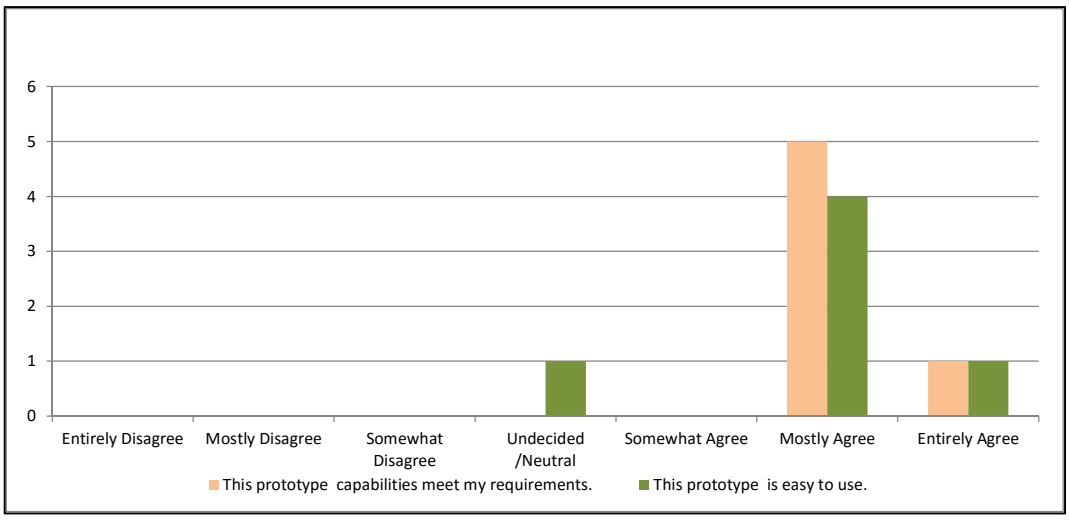


Figure 36.- UMUX-LITE Results in TKSE.

Workers state the need of integrating more information of all installation data (using the installation reference in SAP), components (it was requested to be able to add device specifications of a given device as part of other or as a part of an installation), route descriptions (also as sketches) as well as, to be able to complete TKSE internal data with the data available through of apps of air conditioning fabricants (e.g. Hovatherm, Mitsubishi, Danfoss, Trane, etc.).

Workers requested to be able to see their assignment as a pool showing their priority and status (which must be track through all the order screens). Also alarms of the most important errors in the mobile would be appreciated.

Apart from the included information an important limitation for using the application is the existence of areas without the possibility to connect to data networks (dead spots).

Quotations	Impact Dimension	Relevance
"The prototype could reduce the shift handover time with the provided information" "The solution will help us to lead an easier shift handover" "Workers save time when locating the air condi-tioning unit to be maintained and to prepare the needed materials/tools in advance" "It is good. Now we know which spare parts are needed when we are still at the base"	Efficiency	High
"I like the option of having tips from colleagues. It is a great advantage" "Maps and descriptions prepared by other col-leagues are very helpful"	Competence	Medium-High
"The application is really useful and it will be more when all the devices will become included. For me, a particular valu-ated app functionality is the possibility of taking a look to colleagues' tips, its support for shift handover, and the pos-sibility of getting guided by the maps and descriptions pro-vided by other colleagues. "	Relatedness	Medium-High
"I will be able to make better decisions for deter-mining my task orders" "The technology will have a big influence in our daily basis if all the data will be available (functions cover the existing requirements although not all the data from all the devices is not included)" "I like it because we get the information we need. And now although the paper versions of the documents exist most of the time they are vague or in-complete" "We are able to prioritize and arrange the order of the tasks by ourselves. Serious malfunctions come first. Additionally they can distribute our working time as we like (except shifts)."	Autonomy	High
"It helps to reduce stress, specially stressful periods during summer time"	Protection	Medium-high

Table 21: Workers Quotations at TKSE.

Usability of the prototype is good, although some minor changes are recommended Scrolling would be helpful as sometimes the keyboard hides some points; Highlight the active entry field of screen where entering data; Drop down menus are better readable than check-boxes; Heading for the different search topics would help for making clear which is current search.

Finally a new functionality is requested: the possibility of creating and accessing guidelines for supporting accessing the devices and the maintenance tasks.

Impact Analysis Results

The evaluation of the Impact Analysis has been done using interviews. We have gathered insights form workers´ working routines and how they cope with problem solving and aspects regarding job satisfaction.

Table 21 collects a summary of important quotations and their major impact on the dimensions addressed on this use case.

3.6.3 TKSE UC Conclusions.

Based on the answers of the workers during the interviews it can be concluded that the solutions have a positive impact in all the dimensions with the exception of quality. It can be due to the fact that perceiving the quality of a maintenance job is not easy to express. It is shown in Figure 37.

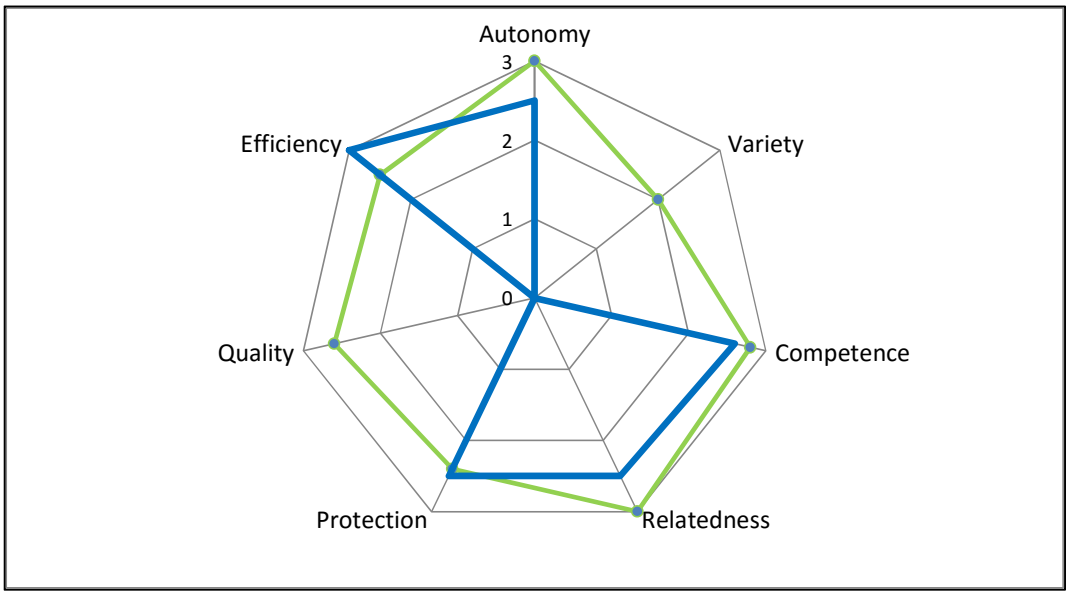


Figure 37: Measured Impact vs Expected Impact.

Main limitations for extending the solution are the available devices information and the need to work without data connectivity. The first can be solved by providing alternative ways for accessing existing information (instead of creating from scratch) and by creating a client application with a local database for downloading required data and local saving introduced data where connections are not available.

3.6.4 Impact within TKSE

From the point of view of the enterprise the insights and understandings of FACTS4WORKERS contribute to the definition of corporate strategies, in particular, in the transversal area of IT and digitalization projects.

These contributions are reflected in internal white paper reports, such as the „HR guidelines for digitalization projects“, used by disseminators and communities to extend the Industry 4.0 initiatives to all the employees.

Moreover the worker-centred cooperative philosophy followed by FACTS4WORKERS will be followed by daproh, a large-scale project for harmonizing data and processes throughout thyssenkrupp, and StahlAssist, an R&D project: assistance systems for safe and secure handling of complex situations.

4 Project Level Conclusions

Chapter 3 of this report presents the evaluations performed during the FACTS4WOKERS project at the UC level. Next paragraphs try to summaries them from a more general point of view. First, we present the validation conclusions; then we present the FACTS4WORKERS goals achievements.

4.1 Validation Conclusions

From the reading of the evaluations of the UCs it can be follow that most of the workers involved find the provided solutions easy to use and learn and that they meet their requirements and fix with their tasks.

Figure 38 shows the aggregated results of the UMUX-Lite questionnaires fulfilled by workers during the validations. They are in line with previous paragraph but there is significant number of workers showing not positive opinion about the applications:

- 15% of the workers say applications do not meet their requirements, and 6% say they cannot decided
- 16% say it is not easy to use or are not able to decide.

Next paragraphs try to find the answer to these significant values by reviewing UC validations in order to determine the causes, the opportunities of improvement of the deployed prototypes as issues to be considered for projects started from FACTS4WORKERS results or, in general, Industry 4.0 started from scratch.

First it must be remarked that many worker requested more time of using the applications for forming an opinion about the applications and some training in using them. This fact can explain the neutral opinions.

We organize this analysis in four categories: Provided Information, Usability, Devices and IT infrastructure. While it can be seen as a clear division, the borders are not so clear and many links will be established between them. Three first categories of opportunities for improvement are clearly related with the worker-centred approach of FACTS4WORKERS. Last relationship is not so clear but it must be considered: if it works perfectly nobody care about it, but a minor problem may make quite difficult the use of the solutions by workers.

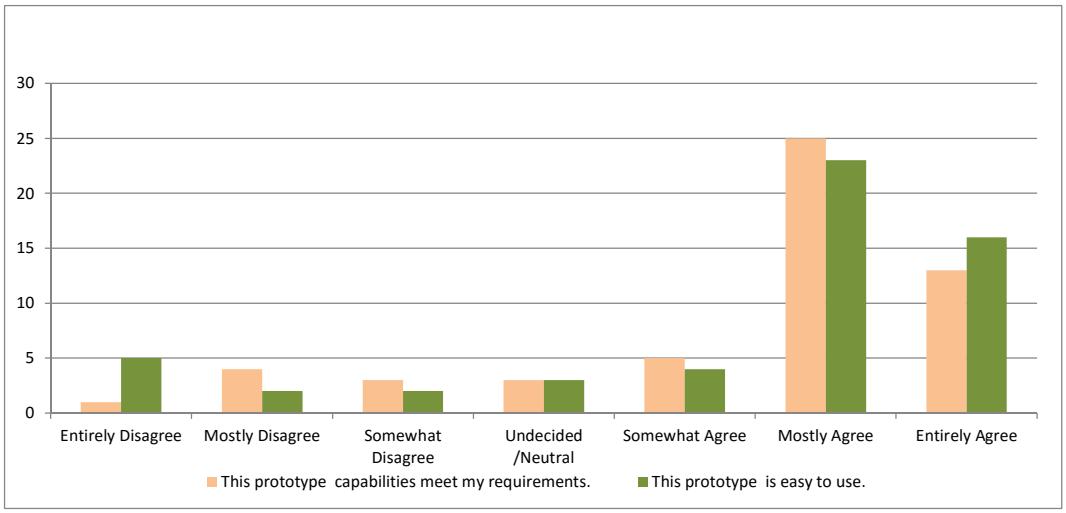


Figure 38: Overall UMUX-Lite results.

4.1.1 Information Improvement Opportunities.

In general, information and functionalities are perceived as correct by workers however, they suggest improvements on the management and on the information itself. More common request is the inclusion of more information before deploying a system: more parts, machine devices, etc. must be preloaded in order to get all the potential from the deployed solutions. Together with the inclusion of more information they suggested to extend it by linking, in a smooth way, to provided information from other external sources (from other company systems, from the web, from providers, etc.). Additionally, some workers requested the provision of information not only directly related with the task they perform but also about the production processes.

Assuming that the systems provide enough quantity of data, next common request is to present it as simple as possible. A first step toward it, is the provision of powerful search functionalities as it allows to review what happened previously. The results of searches and, in general, of information must be as graphical as possible and it must highlight important issues: the use of text must be reduced as much as possible. Moreover, searching results and, in general, all the information presentation must be contextualized to workers: filtered by the worker role and the task he/she must do in the near future.

Being able to have a quick overview of the used information obtained in real time (assigned task, search results, important events, parts/project state, etc.) is really important for workers as knowing in real time any circumstance affecting their work helps them to avoid errors and inefficiencies.

With the accessed information workers requested to be able to interact easily and quickly. They want to be able to create comments, to communicate with other workers, to assign/reassign/reject tasks, etc. in a very practical way (dropping, …) etc.

One important issue for workers is the inclusion of multimedia content to provide certain kind of information (maintenance processes, reworks, etc.). Video is suggested as a powerful tool for training workers in particular new colleagues. Where it was tested MR capabilities, see-thought interaction is also well valuated for training although workers requested better interaction with the holograms (not just watching them, being able to determine what must be presented).

MR validators highlighted that together with the need of more content, the cost of creating it and the skills required are also important. More generally, the cost of creating the content is one possible limitation that workers perceive. On the one side, it is important that content can be generated by workers themselves (as they have the knowledge). On the other side, tools for creating and/or importing existing information are requested.

4.1.2 Usability Improvement Opportunities

Although some prototypes were tested using smart-glasses, more common used devices were tablets. As most of the workers are familiar with them, it helps them to learn to use the applications but also to make suggestions about possible improvements.

Let's start with a brief comment about the smart-glasses. Workers really appreciate them for being used for training people as their capabilities helps to understand the presented activities and concepts. They say they will attract young people and help to safe cultural and languages issues. However, they think tested devices are a bit heavy and they cannot be easily used with prescription glasses. Moreover, higher interaction capabilities are requested (probably associated with demo videos available through the web).

In any case, workers like the multimedia information provided with the smart-glasses and, in general the multimedia capabilities provided by tablets and smartphones. Workers highlighted the need of being able to interact with the provided content in the same way they do: zooming, stopping, moving, etc. This is sometimes essential for being able to use the content.

The possibility of taking pictures/videos (with enough resolution) is also important for reporting new errors and to communicate with other colleagues. Workers requested the provision of functionalities for making basic edition on taking pictures.

While mobile devices are appreciated because of cameras and for receiving notifications, workers say their capabilities for typing are not good enough in some cases, and requested computer for introducing certain reports.

The capacity of visualizing information is also reduced when keyboard is shown. This, and in some cases the absence of scroll bars, make it difficult to introduce information in some cases.

The size of the screen also make difficult to visualize certain kind of documents (such as plans). In consequence, workers requested bigger screens available on the shop-floor.

4.1.3 Device Improvement Opportunities

From previous paragraphs the conclusion can be that there is not "the device" to be used on the shop-floor. Smart-glasses, smart-phones, tablets, computers present advantages and disadvantages.

From our perspective the applications must be designed to be used in different devices allowing taking the best of them. In some cases, the capabilities of taking pictures and typing quickly are required by workers to reduce the time it takes to create a report.

Workers say it is important to have enough devices to be used by all the workers and replacing them in case of breakdown. In this way, used tablets were perceived as fragile to be used on the shop-floor and in consequence rugged ones must be consider when production applications will be released.

4.1.4 Infrastructure Improvement Opportunities

Regarding infrastructure workers requested deployed solutions to have a good performance. They show their concerns about the response of the system when the prototype is extended to be used by all the workers of the factory.

This concern is related with the computing needs but also with the bandwidth availability. In some cases, workers reported loss of connectivity in some factory areas. Here the solutions can be either try to improve existing networks, use mobile connection if possible or design the applications to be used off-line when/where it is required.

4.1.5 Other Improvement Opportunities

In this section we include some issues to be considered during Industry 4.0 project developments regarding their success.

As workers are the centre of the solutions, they must be informed about the plans of deploying the solutions. In some cases they condition their answers to the extension of the use of the solution to all the plants. As important as this, it is the training of the workers in the use of the solution.

Once they are involved in the developments, solving reported bugs and making them know about the new considered improvements will determine their opinion about new releases of prototypes.

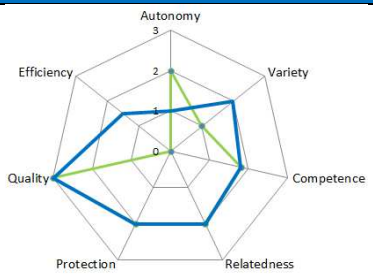
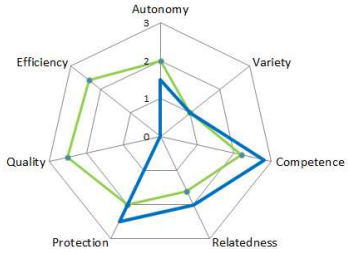
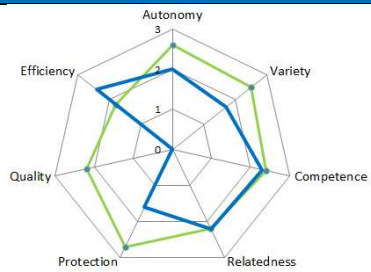
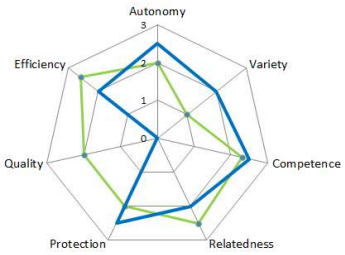
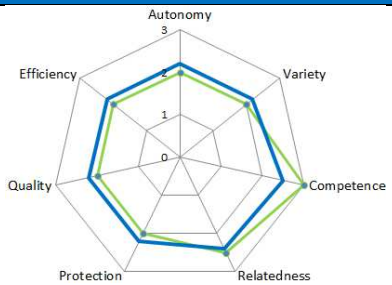
4.2 Project Goals Achievements

Abstracting the results of projects goals achievements at the project level that is the increase in Job Satisfaction, Problem Solving and Innovations Skills and productivity is not easy as it is for abstracting the validation results. It is due to the fact that interventions were performed on different industrial partners, on prototypes implementing different functionalities and achieving different maturity levels, more over they are different cultures and legal issues which can influence the obtained results and, in consequence their abstraction.

Table 22 shows the comparison between expected and measurement impacts introduced in previous chapters. As it was described for each of the use cases, for the measurement dimensions most of the prototypes seems to contribute to improve in all the dimensions and in consequence, they contribute to advance in achieving their goals.

Figure 39 shows the comparison of the average expected impact for each of the dimensions. It shows that considering the impact at project level, the evaluated prototypes produce results in the expected directions. As these dimensions are related to the Job Satisfaction, Problem Solving & Innovation Skills and Productivity of the workers, it can be follow that the prototypes contribute to obtain project goals.

However, opportunities of improvement reported on chapter 4.1 must be considered before taking the prototypes into production applications as they, in many cases, will limit the success of the projects.

EMO	HID
	
HIR	**SCA-1**
	
SCA-2	**THO**
	
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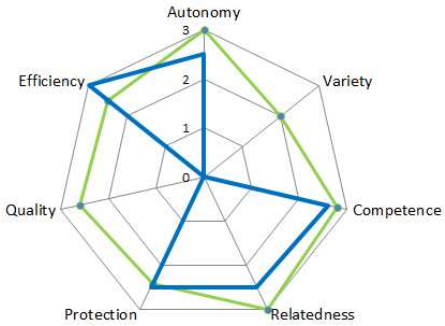	

Table 22: Comparison of Impacts in All the UCs.

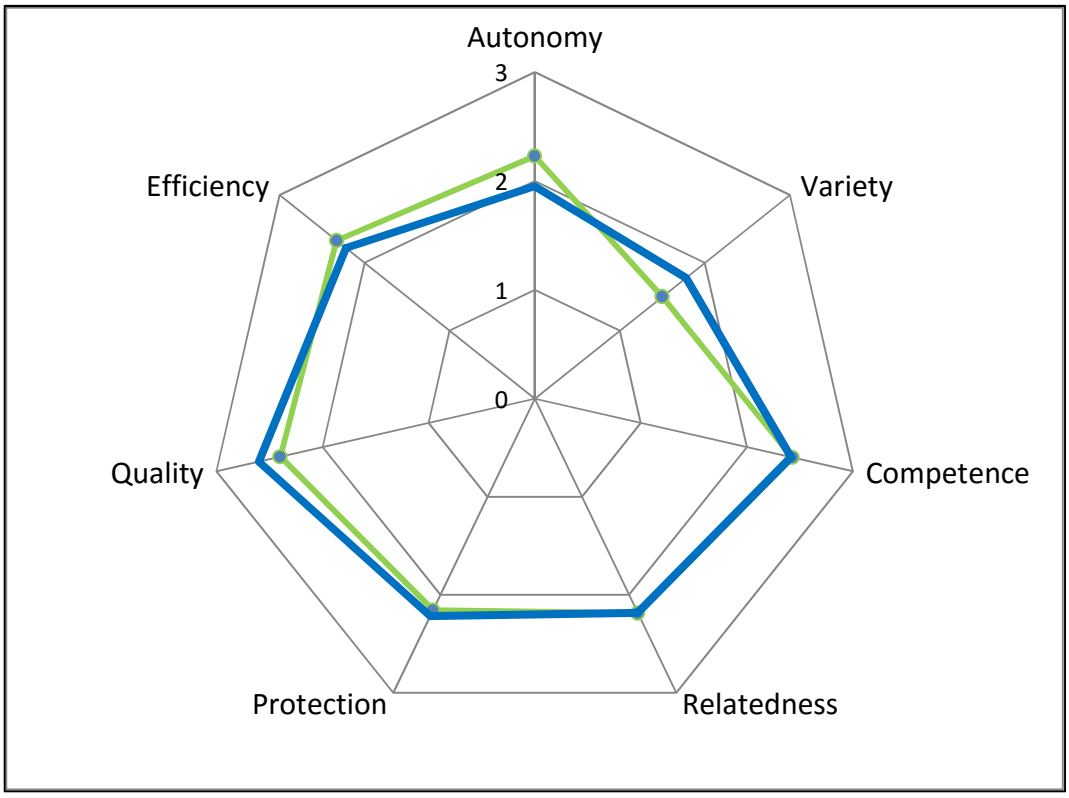

Figure 39: Comparison of Expected and Measured Impact at Project Level.

4.3 Framework Lessons Learned

FACTS4WORKERS framework is conceived for being used for evaluating the impact of Industry 4.0 worker-centred interventions. This requires the framework to be flexible enough for being used in different industrial scenarios, for evaluating different maturity levels (mock-ups, porotypes, pilots), having different purposes and under different legal frameworks. Moreover the framework must be useful for both scientific and practitioners and, over all, assure worker' anonymity.

Aiming to achieve these objectives a set of tools, guides for using it and for determine the strategy of each of the evaluations were identified, defined and described in deliverables D6.1, D6.2 and D6.3 of FACTS4WORKERS. They were used for performing the evaluations which results are presented in this report. We summarize here the lessons learned not included in previous documents to be considered when the framework is going to be used.

Probably the most influencing factor for performing correct evaluations is the creation of a good evaluation team. It must be composed of members of the developing team, evaluators and the facilitator. Members of the developing team provide in-

formation about the scheduled releases and the releases functionalities. Evaluators prepare the evaluations and perform them with the support of the facilitator. Together all the members agree on the evaluation scope, objectives and tools to be used.

The facilitators is a member of the industrial company in charge of providing logistic support for the evaluations and, in some cases, helps to perform it when language is a barrier. In these cases, it is important to know the prototype, the changed/new practices and the evaluation process as he/she must explain everything to the workers: explaining clearly the objectives of the evaluation, the evaluated concepts is essential to obtain a honest answer from workers and, in consequence, for the success of the evaluation.

From our experience considering the use of a Control Group is quite important. As it was introduced in chapter 2, CG allows detecting external factors influencing the measured results.

5 Conclusions

Trying to determine how the introduction of new digital tools and the evaluation of their impacts on the shop floor workers, their skills and work practices is a challenging task. Research and practice may diverge about the right evaluation approach, methods and measures to apply under the context of specific Industrial Partners in order to contribute to this challenge, FACTS4WORKERS purpose is to provide solutions that could empower workers on the shop floor by changing work and organization practices reflected as improvements on their satisfaction and problem solving and innovation skills.

The evaluation framework presents an overview of classical and technological approaches and a set of tools which will be used to perform quality validations or to determine the impact assessment of the interventions at seven case companies in Germany, Slovenia and Spain. Because of this diversity of cultural, legal and shop-floor, the framework was conceived to be flexible enough for being used in a practical way as well as to respond to our research challenges.

This flexibility is shown in the evaluations presented in this document. The evaluation section tries to show how far FACTS4WORKERS solutions assess the results of the interventions and to determine if their objectives are achieved by implementing the IC requirements based on the evaluations performed each time a prototype was presented to workers or deployed in the factory premises.

As general conclusions obtained from the validations of the interfaces of the solutions, we can say that the FACTS4WORKERS prototypes are reported as easy to use and learn and workers value the interaction, visualization and multimedia functionalities.

Of course, some restrictions and boundary conditions have been faced within the FACTS4WORKERS project. These boundary conditions, among which it can be mentioned that the systems are not in production environments (not all the data is available in all the UC, no close integration with the systems already present in the factories, etc.) are common in this type of projects. Taking these conditions into consideration, was one of the reasons to adopt a flexible framework developed within FACTS4WORKERS (instead of proposing a framework based on scientific high volume of data analysis) to be able to develop useful procedures that will apply well, both for group of workers, either in SME and large companies, to be able to cope with real scenarios present in factories like: non-extensive use of the prototypes, no prototype lines, not parallel systems used, etc.

Due to the abovementioned reasons, too many factors may influence in the results so therefore there is not an absolute measure for Job Satisfaction increments within the project. The purpose of the evaluation has been to try to exclude these biases and under control conditions determine how the FACTS4WORKERS prototypes presented to the shop-floor workers have influenced on the individual dimensions: autonomy, variety, competence, relatedness and protection and on the organizational ones: efficiency and productivity and how these impacts have a direct relation on the increase of innovation skills and job satisfaction of the workers.

At this point, we can assume from the results of the UC, that providing solutions that support the expected drivers of innovation skills and which provide feedback for the development with required improvements on the deployed capabilities or new needs identified through the interventions will reflect increases in the dimensions and under these conditions it will have a direct impact on worker' job satisfaction and, problem solving and innovation skills. Additionally, this process described is very useful in order to early identify possible risks that can have significantly impact on workers' job satisfaction. One of these major risks in ICT solutions deployments is the fact of the acceptance of the solutions by the workers. The worker centric development approach and the validations carried out within FACTS4WORKERS try to ensure that the proposed prototypes will be the desired solutions envisioned by the workers.

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About the project

PROJECT PARTNERS

The FACTS4WORKERS project is composed of 15 partners from 8 different European countries:

Virtual Vehicle Research Center	Austria
Hidria TC Tehnološki center d.o.o.	Slovenia
Universita degli Studi di Firenze, Department of industrial Engineering	Italy
Technische Universität Wien	Austria
ThyssenKrupp Steel Europe AG	Germany
Hidira Rotomatika d.o.o., Industrija Rotacijskih Sistemov	Slovenia
iMinds VZW	Belgium
Sieva d.o.o.	Slovenia
University of Zurich, Department of Informatics	Switzerland
Thermolympic S.L.	Spain
EMO-Orodjarna d.o.o.	Slovenia
Evolaris Next Level GmbH	Austria
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Industrial Challenges Specific Evaluation Reports (longitudinal)

The ultimate goal of the H2020 project "FACTS4WORKERS – Worker-Centric Work-places in Smart Factories" (FoF 2014/636778) is to develop and demonstrate socio-technical solutions that support smarter work, i.e. providing employees with the information they need to perform their day-to-day work at the right time and in an appropriate manner in order to improve decision making, support the search for problem solutions and strengthen employees' position on the factory floor.

This document represents deliverable 6.4 "Final Evaluation Report)" of the H2020 project "FACTS4WORKERS - Worker-Centric Workplaces in Smart Factories (FoF 2014/636778).

This deliverable is the last report of WP6. It presents the results of four years of work performed by the members of the FACTS4WORKERS consortium. More specifically, this document presents the results of the evaluations of eight prototypes implementing IT worker centred solutions for meeting workers information requirements as defined by the eight use cases identified in the six industrial partners of the consortium.

After briefly presenting the evaluation framework, the evaluations of the 8 proto-types implementing the worker centered solutions use case requerirements are presented. From the industrial partner description, the use case definition and the evaluation selected methods the results and conclusions of each evaluation are presented.

Use case results are uses for extracting project level conclusions, both from the validation of the prototypes point of view and from the impact derived of their introduction. Validation results can be considered technological challenges, risk or actual limitations to be considered when an Industry 4.0 is started. They can explain the obtained project results, the degree of objectives achievement, which are deter-mined based on the use case assessed impact.

Finally regarding for future framework improvements, this document also pr-sented the learned lessons found during the different evaluation processes.