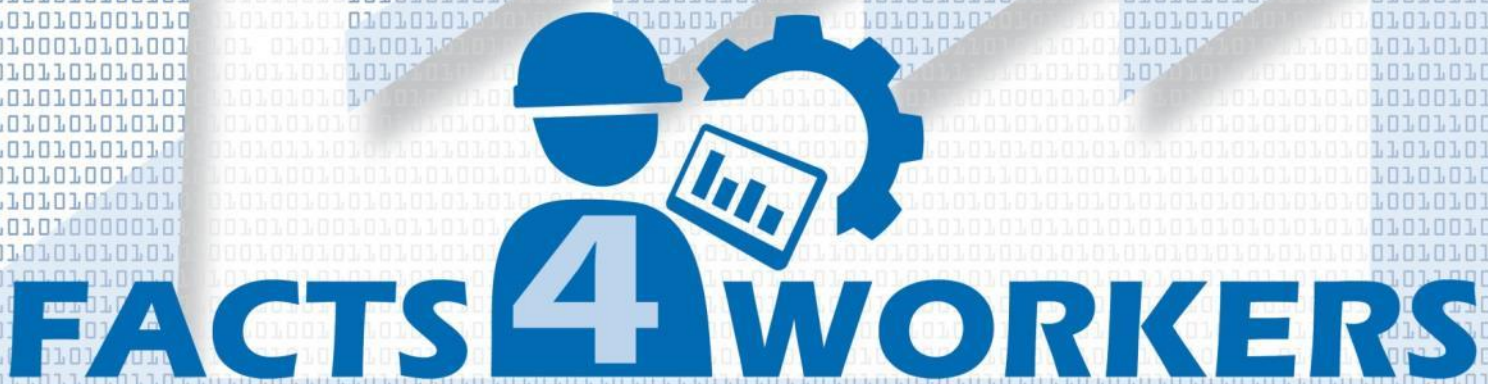


# Project Deliverable 6.3

## Industrial Challenges Specific Evaluation Reports (longitudinal)

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Layout and Setting: Florian Ott, Cooperation Systems Center Munich

FACTS4WORKERS: Worker-Centric Workplaces in Smart Factories

E-Mail: facts4workers@v2c2.at  
Internet: www.facts4workers.eu



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# About this document



## Executive Summary

This document represents deliverable 6.3 “Industrial Challenges specific evaluation reports (longitudinal)” of the H2020 project “FACTS4WORKERS - Worker-Centric Workplaces in Smart Factories (FoF 2014/636778).

The deliverable builds a deep understanding of the industrial challenges and the workers’ practices in the different use cases studied within the project. In addition, we present the evaluation process of the FACTS4WORKERS solutions/prototypes. This document is structured as follows.

First of all we will present a description of the industrial challenges and we will highlight the requirements considered. This will provide us with a clear view of the defined requirements and they will be linked with the main use case and the associated ones. These requirements will be considered as the basis for the evaluation analysis and we will present some considerations of the evaluation framework and methodology to explain how job satisfaction and innovation skills could be increased thanks to the FACTS4WORKERS solutions/prototypes. This document provides the evaluation process focusing on the specific challenges of the Industrial Partners and provides a generic overview of the process. We will conclude presenting the evaluation results at use case level with the aim to extrapolate the obtained results to the assessment of each Industrial Challenge with specific set of requirements.

## Document authors and reviewers

The following persons have contributed directly to the document. Please note that many other people have also supported our work, and we thank them all sincerely.

### Lead Authors

Name	Organisation	Role
Francisco J. Lacueva	Instituto Tecnológico de Aragón	WP 6
David Abadia	Instituto Tecnológico de Aragón	WP 6
Miguel Ángel Gracia	Instituto Tecnológico de Aragón	WP6

### Featuring Authors

Name	Organisation	Role
Ales Bizjak	Hidria Dieseltéc	UC-Evaluation Facilitator
Alexander Richter	University of Zurich	WP3- UC leader (SCA)
Alexandra Wassermann	Thyssen Krupp	UC-Evaluation Facilitator
Gianni Campatelli	University of Firenze	WP3-Leader (HID, HIR, THO)
Juliane Steffen	Thyssen Krupp	UC-Evaluation Facilitator
Marlene Schafner	Virtual Vehicle	WP3-UCs leaders (EMO, SCA)
Matjaz Milfelner	EMO Rodjana	UC-Evaluation Facilitator
Melanie Steinhüser	University of Zurich	WP3- UC leader (SCA)
Patrick Rosenberger	Vienna University of Technology	WP3- UC leader (TKSE)
Pedro Amoraga	Thermolympic	UC-Evaluation Facilitator
Rok Podobnik	Hidria Dieseltéc	UC-Evaluation Facilitator
Tanja Berglez	EMO Rodjana	UC-Evaluation Facilitator
Stelios Damalas	Virtual Vehicle	WP3-UCs leaders (EMO, SCA)
Stefan Dumss	Vienna University of Technology	WP3- UC leader (TKSE)

### Reviewers

Name	Organisation	Role
Martin Wifling	Virtual Vehicle	Coordinator
Lea Hannola	Lappeenranta University of Technology	WP1, WP6

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## Index of Abbreviations

AR.....Augmented Reality	IC .....Industrial Challenge
BB .....Building Block	IP .....Industrial Partner
CA.....Classical Approaches	KMS .....Knowledge Management System
EMO.....EMO Orodjarna d.o.o.	PQ.....Process of Quantification
HCI.....Human Computer Interaction	SCA .....Schaeffler AG
HID .....Hidria Technology Centre d.o.o.	THO .....Thermolympic S.L.
HMI.....Human Machine Interaction	TKSE.....ThyssenKrupp Steel Europe AG
IA.....Impact Analysis	UC.....Use Case



# 1 Introduction

This deliverable (D6.3) focuses on how the evaluations are carried out to match the requirements with the four Industrial Challenges (IC), at Use Case (UC) level. The purpose of this document is to present the evaluation process focusing on the specific challenges of the Industrial Partners (IP) and providing a generic overview of the process, while in the next deliverable D6.4, we will present the final evaluation with all the UCs and associated results.

In the chapter 2 the requirements of each IC are presented, with a general description of each IC and its related requirements as well as by presenting the UCs specific requirements, by taking into account the main UCs related as well as the related associated UC requirements. The overall idea behind is to define and to build the IC requirements based upon the IC itself as well as the related UC requirements. These requirements are considered the base for the analysis of the evaluation presented in the chapter 4.

In the chapter 3 the evaluation methodological framework is briefly presented, a framework balanced to enable on one hand scientific studies as well as on the other hand practical analysis of the solutions and methodological developed. The proposed framework is flexible, adaptable to several regulatory directives and its goal is not to evaluate the workers but their satisfaction, problems solving and innovation skills, as well as productivity.

In the chapter 4 the evaluation results at UC level are presented with the aim to extrapolate the obtained results to the assessment of each IC set of requirements.

Finally in the chapter 5 general conclusions about the deliverable are presented. Regarding the generalization of UC results to IC challenges results, we use the links established in D1.3 (Hannola, et. al., 2016) between the IC challenges requirements and the UCs requirements defined in D1.2 (Denner et. al., 2015). Figure 1 shows the update of these links based on the update of the IC requirements performed in D1.4 (Steinhüser et. al, 2016), D1.5 (Steinhüser et. al, 2017).

Although the deployed prototypes cover just a few of the potential UCs which can be developed for advance in the fulfillment of the FACTS4WORKERS ICs we think the results can be generalizable for other UCs. First, we base this affirmation, in the FACTS4WORKERSUC feature: the diversity of involved companies (multinationals and SMEs); the variety of covered production systems, see D1.3; the full covered of all the production areas (production, maintenance, quality), see D1.2; the workers' roles involved, see D1.2. Second, and more important, deployed BB used for imple-

menting selected UCs can be easily adapted or integrated for implementing other UCS. In some cases, it will require some developments but in many it will only require to create the Industrial Partner specific information.

## 2 Industrial Challenges, Use Cases

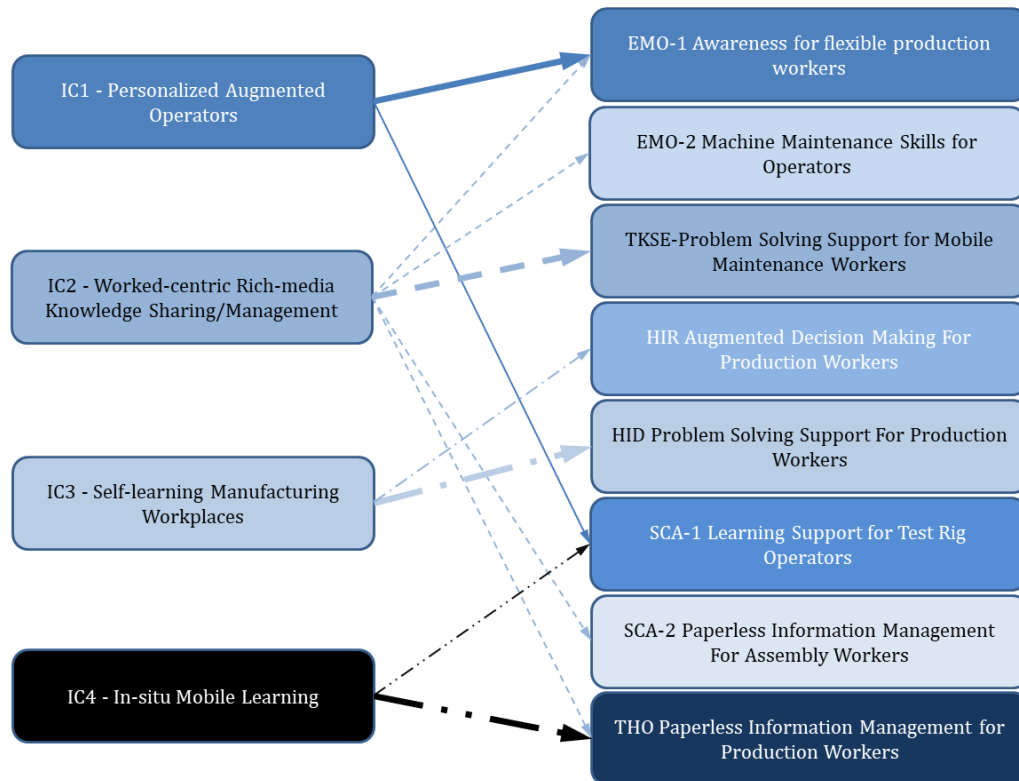
The results of FACTS4WORKERS project enable the advancement regarding to the four smart factory ICs by placing the worker as the central role within current and future forms of production. The achievement of these challenges is measured by using the methodologies defined in WP6.

According to DoA (2014), the IC are the following:

- IC1: Personalized augmented operators are workers using Augmented Reality (AR) tools through which they get an immediate, specific, visualized, and personalized provision of information at the shop-floor-level, which can be configured according to their needs, roles and preferences.
- IC2: Worked-centric rich-media knowledge sharing/management: ICTs adopted in factories are neither successful in capturing knowledge, nor do they support social interaction and learning. Such knowledge management systems (KMS) are usually developed for office environments, but shop-floor workers have specific needs.
- IC3: Self-learning manufacturing workplaces are established through linking heterogeneous information sources from the worker's environment and beyond, and extracting patterns of successful production, transferring the result as decision-relevant knowledge to the worker.
- IC4: In-situ mobile learning in the production will develop and demonstrate an on-the-job learning environment for shop floor workers by using rich media through the KMS, which is especially valuable for SMEs.

The ICs will be understood and managed in order to achieve the objectives of FACTS4WORKERS project. First, the objective is to offer immediately and specifically visualized information to the workers via different kinds of Augmented Reality tools. Secondly, a KMS for workers will be developed to support knowledge sharing and innovativeness in an open environment. Thirdly, one of the objectives is to establish self-learning manufacturing workplaces to speed up the analysis process of production parameters and the decision process of the responsible worker. Fourthly, an on-the-job learning environment should encourage shop floor workers to be more context-aware in real-life situations, in order to handle with the requirements of flexible production (Unzeitig et. al., 2015).

Relations between ICs and UCs is defined in D1.5 (Steinhüser et. al., 2017) as it is shown in Figure 1. In the figure, the widest arrows relate a given IC to its reference UC.



**Figure 1. Industrial challenges and F4W case contexts.**

In the following paragraphs we show a summary of the ICs definitions, related UCs and their requirements.

For each IC following information is presented:

- general description of the IC
- objectives addressed by the IC
- Industry challenge specific requirements
- Use-case specific technologies and methods

Within each IC the main related UC is also presented with:

- Short description of the IP involved
- General description of the UC
- Requirements of the UC

In addition, another associated UC which can also contribute to the requirements to be taken into account within the IC.

As information sources DoA of the project as well as D1.2, D1.3, D1.4 and D1.5 are used.

## 2.1 IC1: Requirements and Uses Cases

### 2.1.1 Industrial Challenge Requirements

IC1 - *Personalized augmented operators* are workers using AR tools through which they get an immediate, specific, visualized, and personalized provision of information at the shop-floor-level, which can be configured according to their needs, roles and preferences. In FACTS4WORKERS, the Augmented Operator has a wider definition, i.e. Augmented Operator means not only AR, but also provides all illuminating information to the workers, which could also be provided by other means.

IC1 addresses following FACTS4WORKERS objectives (O.1-4):

- Cognitive job satisfaction (O.2): To increase cognitive job satisfaction of workers participating in the pilots.
- Average worker productivity (O.3): To increase average worker productivity for workers participating in pilots.

<b>Industry challenge specific requirements:</b>	<ul style="list-style-type: none"> <li>-Better information visualisation for hands-free operation in production lines</li> <li>-Combination of intelligent data with seamless interaction/interfaces</li> <li>-Assistance of workers by AR content displayed in smart digital glasses/head mounted display in changing production settings</li> <li>-Personalisation of information</li> </ul>
--	--

Table 1. - IC1 Requirements.

### 2.1.2 EMO-1 Use Case Requirements

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.

EMO-1 UC is defined because of highly skilled workers utilize a large machine park to produce parts according to specifications. Each worker is assigned to a specific machine that he operates. The worker has detailed and specific knowledge of this machine and is generally the first one to realize that there are problems or deviations. The main challenge that the workers are dealing with is the missing awareness during assembly. By starting the shift the workers have to check the availability of the parts they need to complete their tasks. Workers are often prevented from working when there is missing information and then it is necessary to switch the tools. They are dependent on the help of other co-workers to obtain an overview of the current status of the tool and its related parts that have to be assembled. Because of switching tools the workers take over responsibility for other employee's work which causes bad feelings about the situation. If mistakes are made during the assembly process, it is difficult to identify whose fault it was afterwards, as the information about who has assembled which parts is only in the assembly workers' heads.

According to this definition of the activity scenario (desired working situation) and considering the existing problem scenario (existing working situation), the identified requirements are shown in the following table:

<p><b>Assembler</b></p> <p><b>Worker requirements</b></p>	<ul style="list-style-type: none"> <li>- Personalized access</li> <li>- Checking the status of the build process, including info about part packages that are ready to be assembled and those that are still waiting for parts.</li> <li>- Listing available parts</li> <li>- Reporting task progress, stop causes, etc.</li> <li>- Overview of the status of projects</li> <li>- Listing available tasks, assignment of tasks, ...</li> <li>- Overview of parts status, placing, responsible etc.</li> <li>- Communication with other workers (team leader, co-workers, etc.)</li> <li>- Quality control tracking, monitoring and fault reporting</li> <li>- Mobile access to information</li> </ul>
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Table 2. - IC1-EMO1 UC requirements

### 2.1.3 Associated Use Case Requirements.

Please, notice that in the previous UC we have derived the IC requirements to the particular UC of EMO-1. Once, we have these general requirements we could extend them to new associated UCs, such as the Hidria Rotomatika UC. In the following table, we will summarize the additional requirements needed for this UC.

IP: Hidria Rotomatika d.o.o. (HIR)
Use Case: HIR: Augmented decision making for production workers.
Additional Use Case Requirements: <ul style="list-style-type: none"> <li>• Monitoring the production by means of AR glasses or tablet</li> <li>• Automated checking of the measurements (from CAD dimensions and tolerances and measured form the automated measuring rig)</li> <li>• Measurement deviation detection and notification</li> <li>• Access to previous problem solutions</li> </ul>

Table 3.- IC1-HIR additional UC requirements

### 2.1.4 Associate Use Case Requirements

IP: Schaeffler AG (SCA)
Use Case: SCA1: Learning support for test rig operators.
Additional Associated Use Case Requirements: <ul style="list-style-type: none"> <li>-Required information (like settings sheets, engineering drawing) and instructions for the work are accessible via a tablet</li> <li>-Training multimedia materials are available such as short training videos, animations and commented photo galleries to illustrate how to use the measurement equipment</li> <li>-Detailed instructions on correct machine setup are supported by animations, avoiding the use of unclear textual descriptions</li> <li>-No need to use a printed version, as there is a digital version of every document, like inspection documents</li> <li>-Once a problem is detected in a measurement, by means of a tablet a worker can access a checklist provided by QA. These checklists describe several steps regarding how he can check, find and eliminate problems.</li> </ul>

- |  |
|--|
| <ul style="list-style-type: none"> <li>-Possibility to have communication via a live chat among workers if the info available in the system concerning the incidence is not enough</li> <li>-Possibility to have communications with other workers by commenting existing documents with questions/answers as well as to enable to document problems identified</li> </ul> |
|--|

Table 4.- IC2-SCA1 Additional UC requirements

## 2.2 IC2: Requirements

### 2.2.1 Industrial Challenge Requirements

*IC2 - Worked-centric rich-media knowledge sharing/management.* The challenge is one hand to equip the workers with efficient means to share and co-develop valuable work-related knowledge. On the other hand, since these tools have not been generally available so far, the practices and working models for utilizing them are undeveloped. Solving both sides of the challenge requires combining knowledge management, workflow design and ICT technology simultaneously to develop the solution in direct interaction with the workers. Knowledge sharing in a manufacturing company has the same relevance as in the office environment, but the applicability of ICT tools on the shop-floor implicates a lot of specific requirements such as that the interaction schemes need to be even more simple and intuitive (e.g., touch or gesture interaction instead of typing), taking also extreme conditions in production environments into account (e.g., extreme heat or noise), the tools need to be much more robust (e.g. “rugged devices”) and safety needs to be guaranteed throughout the whole production process as well as data and know-how security as well as the workers' privacy must be guaranteed. The challenge consists in introducing “open innovation 2.0” and knowledge sharing in production environments by most effective means.

IC2 addresses following FACTS4WORKERS objectives:

- Problem-solving and innovation skills (O.1): To increase problem-solving and innovation skills of workers participating in the pilots
- Cognitive job satisfaction (O.2): To increase cognitive job satisfaction of workers participating in the pilots.

#### Industry challenge specific requirements:

- |  |
|--|
| <ul style="list-style-type: none"> <li>- Enable production workers to interact and share knowledge while adding value to raw materials</li> <li>- Introduce Web 2.0 and Open Innovation into the shop-floor</li> <li>- Allow know-how exchange, especially between younger &amp; senior workers</li> </ul> |
|--|



Table 5.- IC2 Requirements.

### 2.2.2 TKSE Use Case Requirements.

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 and demanding applications in various industries. Customized steel material solutions and services complement the business activities. TKSE values the knowledge of skilled workers as a crucial factor in meeting constantly increasing demands for quality and efficiency. Simultaneously, these demands also increase the work complexity. A decreasing number of employees and shorter familiarization phases of young employees require continuous operational and extra-occupational development of the employee knowledge and competencies.

TKSE UC is considered because of the activities of the fault repair and maintenance team that is responsible for the servicing and repairs of electrical and air-conditioning devices. While troubleshooting, the employees face a number of challenges: Initially, faults are reported via telephone, e-mail or fax. Subsequently, this coarse-grained information on the type of fault and system is handed to the mobile maintenance staff in the form of a paper document. Frequently, neither the direct route to the fault's location is known, nor is a map available on the fault's surroundings. Depending on the location of the faulty part, personal protective equipment might be necessary and/or special entry and exit procedures have to be executed. A process to acquire the required knowledge concerning their way around in this environment, conditions in most of the factory buildings and being able to troubleshoot autonomously takes about two years. This required knowledge has to be acquired through experience which happens through mutual assistance provided by experienced colleagues, or through systematic trial and error iterations over time. With the large number of units to be serviced and possibly repaired, maintenance employees rarely have all the relevant information at hand to solve a specific problem. Similarly, when spare parts are needed the workshop has to be contacted, or personally visited, as information on the availability of these parts and the status of order transactions are unavailable to the maintenance personnel when they are mobile.

As in the EMO-1 UC, we present the identified requirements in the following table.

<p><b>Worker (craft master, electricians, installers)</b></p>	<ul style="list-style-type: none"> <li>-To enable to spend the time to discuss the problems themselves and to avoid wasting time to get the needed information</li> <li>- To provide the workers with all relevant information in a bundled, contextual and mobile way (including e.g. info about required tools and protective equipment and maintenance history or for example the important information about a device to be repaired, its location and the contact person for security check-in)</li> <li>- To enable to find the right location of a repair more easily and even more important to be prepared for the maintenance work at the device on site</li> <li>-To see which spare parts are needed or important during a shift and put them in-side the transporter</li> <li>- To provide necessary context-specific information on all systems with the potential for disruptions which can be called up by the employee through a mobile information system (i.e. yellow pages concept to find the right person for the right topic or to provide the profile of a colleague who can assist).</li> <li>- Possibility for the maintenance staff to access colleagues' practical knowledge through collaborative knowledge exchange when required.</li> <li>- For the worker to have access to the necessary knowledge on fault elimination on the site.</li> </ul>
---	---

**Table 6.- IC2 - TSKE UC requirements**

### 2.2.3 Associated Use Case Requirements.

IP: EMO Orodjarna (EMO)
Use Case: EMO1: Awareness for flexible production workers.
<p>Additional Associated Use Case Requirements:</p> <ul style="list-style-type: none"> <li>-Checking the status of the build process, including info about part packages that are ready to be assembled and those that are still waiting for parts.</li> <li>-Listing available parts</li> <li>-Reporting task progress, stop causes, etc.</li> <li>-Overview of the status of projects</li> <li>-Listing available tasks, assignment of tasks, etc.</li> <li>-Overview of parts status, placing, responsible etc.</li> <li>-Communication with other workers (team leader, workers, etc.)</li> <li>-Quality control tracking, monitoring and fault reporting</li> <li>-Mobile access to information</li> </ul>

**Table 7.- IC2-EMO1 Additional UC requirements**

IP: EMO Orodjarna (EMO)
Use Case: EMO2: Machine maintenance skills for operators.
<p>Additional to above Associated Use Case Requirements:</p> <ul style="list-style-type: none"> <li>-Access through a tablet to preventive maintenance guidelines and suggestions</li> <li>-To enable to require maintenance staff assistance, if non-registered incidences happen</li> <li>-To enable to update periodic maintenance procedure</li> </ul>

**Table 8.- IC2 - EMO2 Additional UC requirements**

IP: Schaeffler AG (SCA)
Use Case: SCA2: Paperless information management for assembly workers.
<p>Additional Associated Use Case Requirements:</p> <ul style="list-style-type: none"> <li>• Access via a tablet to be used as a guide of the maintenance process through the steps of execution as well as the opportunity to check the provided information.</li> <li>• Information describing the process can also be enriched with images</li> <li>• To enable confirmation of each tasks of the maintenance process via a tablet</li> <li>• To enable dynamic adjustments of maintenance plans</li> <li>• To enable to have a task planning and monitoring</li> <li>• To use analyse additional information provided by the system to discover and analyse special incidents, e.g. frequency of readjustment of a special measuring device is higher than expected</li> <li>• To access via a tablet to information provided manually as well as information automatically generated during the execution of tasks that were led by the system, e.g. tasks like maintenance work or retooling</li> <li>• To enable to provide documents and photos to provide coherent view that includes all activities and incidents at a particular machine</li> <li>• To aggregate information stored centrally to have access the data as well at any given time</li> <li>• To improve management of workforce resources, e.g. by indicating if some persons are needed in a machine or if there are too many</li> <li>• To store centrally who was working at which machine to make easier to find out whom to address if problems, that correspond with past incidents, occur</li> </ul>

**Table 8.- IC2-SCA2 Additional UC requirements**

IP: Thermolympic (THO)
Use Case: THO: Paperless information management for production workers.
<p>Additional Associated Use Case Requirements:</p> <ul style="list-style-type: none"> <li>• To make relevant and current knowledge updated, available and easy to access to the employees</li> <li>• During the access to the information to enable to keep an eye at the same time on the production line</li> <li>• To have access to the information by means of mobile devices</li> <li>• To enable the operators to have easily access of the detailed knowledge about the machine they are currently working on</li> <li>• To enable to have access to the current combination of moulding module, machine configuration and error statistics, so that a better understanding of critical combinations is given</li> <li>• To enable, in the case of idle times, to gather more information as well (e.g. about other machines or processes)</li> <li>• To notify the worker by the tablet if some parts present an error, to avoid to miss it</li> <li>• To take into account long-term experience, to enable to indicate that process improvements are possible without spending much time</li> <li>• To help the operators to gain relevant knowledge and competencies, in order to improve their ability to tackle problems appropriately</li> </ul>

Table 9.- IC2 - THO Additional UC requirements

## 2.3 IC3: Requirements

### 2.3.1 Industrial Challenge Requirements

*IC3 - Self-learning manufacturing workplaces.* Manufacturing companies are encouraged to invest in new and more integrated monitoring and control solutions in order to optimize the production processes to facilitate quicker fault detection and reduce breakdowns during production (Orio et al., 2015). Automotive manufacturing companies are especially sensitive to production disruptions and sudden production changes, due to the multiplicity of demands that they are required to comply to. Responsiveness and resilience to production changes needs to be improved while maintaining or improving efficiency, worksafety and satisfaction. This is possible by a process of continuous intelligent and self-learning optimization relying on timely

product/resources/process data and diagnostics tools. By involving the shop-floor workers through proper data presentation and a user-friendly interface to the system, as well as automating production-related services, together allow much more efficient operations to evolve dynamically according to actual needs. Active monitoring and responding to problems with the utilized machinery and devices helps keep production predictable, safe and efficient. Collecting and interpreting data patterns in the manufacturing process make it possible to identify where in the manufacturing process and its services problems and bottlenecks arise and how they will be most effectively addressed, as well as assess the time that the repair and maintenance process will take.

IC3 addresses following FACTS4WORKERS objectives:

- Problem-solving and innovation skills (O.1): To increase problem-solving and innovation skills of workers participating in the pilots
- Cognitive job satisfaction (O.2): To increase cognitive job satisfaction of workers participating in the pilots.
- Average worker productivity (O.3): To increase average worker productivity for workers participating in pilots.

<b>Industry challenge specific requirements:</b>	<ul style="list-style-type: none"> <li>- Predictive decision support for workers and services</li> <li>- Integration of MES, SCADA, ERP data for shop floor assistance</li> <li>- Suitable visualisation of context aware information by adaptive Human Computer Interaction (HCI)/Human Machine Interaction (HMI) concepts</li> <li>- Creation of a self-learning workplace based on predictive data analysis</li> <li>- Automated, adaptive control of the services involved in the process</li> </ul>
--	--

**Table 10.- IC3 Requirements.**

### 2.3.2 HID Use Case Requirements.

The Hidria Technology Centre d.o.o. (HID) designs and manufactures a wide spectrum of partially or fully automated assembly lines, ranging from simple conveyor 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 engi-

neers. 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 in the previous cases, we include the identified requirements in the table:

<b>Worker (Line operator, maintenance)</b>	<ul style="list-style-type: none"> <li>-To reduce time-consuming setup and maintenance activities or lacking supplies</li> <li>-To enable the operators to predict up-coming problems or breakdowns, instead of working mainly on tasks related to reactive maintenance</li> <li>-To provide supporting tools for shifting operators' workloads towards more predictive maintenance tasks</li> <li>-To provide support with problem-solving activities by means of a new integrated knowledge base of the production line fault analysis</li> <li>-To enable to share the knowledge of the more experienced workers to less experienced workers for enhancing peer-learning at workplaces</li> <li>-To enable to store, share and analyse the information and knowledge of manufacturing processes, technologies and solutions according to the present needs of the worker at the shop floor</li> <li>-To have a self-learning approach to monitor a combination of human, process and machine parameters, and supports human-machine interaction in order to offer a reactive (alarms), predictive (warnings) and proactive (maintenance) decision support to shop floor workers</li> <li>-To store and sort the problems systematically to combine them with user generated solutions into the digital machine book in order to enable self-learning workplaces</li> <li>-To rate solutions to a specific problem by the workers</li> <li>-To generate new solutions in forms of comments, videos or pictures by an employer</li> </ul>
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**Table 11.- IC3 - HID UC requirements**

### 2.3.3 Associated Use Case Requirements.

IP: Hidria Rotomatika d.o.o. (HIR)
Use Case: HIR: Augmented decision making for production workers.
Additional Associated Use Case Requirements: <ul style="list-style-type: none"> <li>• Automated checking of the measurements (from CAD dimensions and tolerances and measured form the automated measuring rig).</li> <li>• Measurement deviation detection and notification</li> <li>• CNC setup parameters recommendation</li> <li>• Fine adjustment of recommended-based setup parameters</li> </ul>

Table 12.- IC3 - HIR Additional UC Requirements.

## 2.4 IC4: Requirements

### 2.4.1 Industrial Challenge Requirements

*IC4 - In-situ mobile learning.* Small and medium-sized production enterprises (SME) in the automotive value chain and networks need to comply with a serious number of specific requirements and regulations. Additionally, compared to large enterprises, the workers do not always have clearly specified roles, but rather need to perform very different tasks and share responsibilities in production. This causes the pervasive need of overall on-the-job knowledge, available at the right time in the right place. Furthermore, knowledge is subject to continuous change as work practices evolve and requirements change. The IC of in-situ mobile learning in production develops and demonstrates an on-the-job learning environment for shop floor workers by using rich media through a KMS, which is especially valuable for SMEs.

IC4 addresses following FACTS4WORKERS objectives:

- Cognitive job satisfaction (O.2): To increase cognitive job satisfaction of workers participating in the pilots.



<b>Industry challenge specific requirements:</b>	<ul style="list-style-type: none"> <li>- Unlock the potential of mobile learning for work-based training in the right time and right place, directly in the situation and work context (in-situ)</li> <li>- Contextual learning especially for younger workers, based on previously prepared learning material with experienced staff</li> <li>- Learning content and interaction models taking into account worker roles, experience &amp; gender aspects and multilingual learning system</li> </ul>
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Table 13.- IC4 Requirements.

#### 2.4.2 THO Use Case Requirements.

Thermolympic (THO) is a family-owned business that has been in operation since 1971. It has 60 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. Much information is not yet digital, and due to this fact most of the information quickly becomes outdated. Therefore, THO needed to improve real-time data collection and analysis

Here, we summarize the identified requirements:

<b>Worker, Quality manager Team leader</b>	<ul style="list-style-type: none"> <li>-To make relevant and current knowledge updated, available and easy to access to the employees</li> <li>-During the access to the information to enable to keep an eye at the same time on the production line</li> <li>-To have access to the information by means of mobile devices</li> <li>-To enable the workers to spend the "saved" (as the machine operators are from time to time faster than the machine) time in between for some self-improvement</li> <li>-To enable the operators to have easily access of the detailed knowledge about the machine they are currently working on</li> <li>-To enable the employees to learn about the machine and the</li> </ul>
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	<p>production process on various levels of detail supported by rich media in the form of textual description, pictures and interactive videos</p> <ul style="list-style-type: none"> <li>-To enable to have access to the current combination of moulding module, machine configuration and error statistics, so that a better understanding of critical combinations is given</li> <li>-To enable, in the case of idle times, to gather more information as well (e.g. about other machines or processes)</li> <li>-To notify the worker by the tablet if some parts present an error, to avoid to miss it</li> <li>-To take into account long-term experience, to enable to indicate that process improvements are possible without spending much time</li> <li>-To help the operators to gain relevant knowledge and competencies, in order to improve their ability to tackle problems appropriately</li> <li>-To provide the employees with a greater autonomy concerning their decision about what, where, when and how fast to learn</li> </ul>
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Table 14.- IC4-THO UC requirements

### 2.4.3 Associated Use Case Requirements.

IP: Schaeffler AG (SCA)
Use Case: SCA1: Learning support for test rig operators.
<p>Additional Associated Use Case Requirements:</p> <ul style="list-style-type: none"> <li>• Training multimedia materials are available such as short training videos, animations and commented photo galleries to illustrate how to use the measurement equipment</li> <li>• No need to use a printed version, as there is a digital version of every document, like inspection documents</li> <li>• Once a problem is detected in a measurement, by means of a tablet a worker can access a checklist provided by Quality Assurance (QA). These checklists describe several steps regarding how he can check, find and eliminate problems.</li> </ul>

Table 15.- IC4-SCA1 Additional UC requirements

## 3 Evaluation Process

### 3.1 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).

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 either 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.

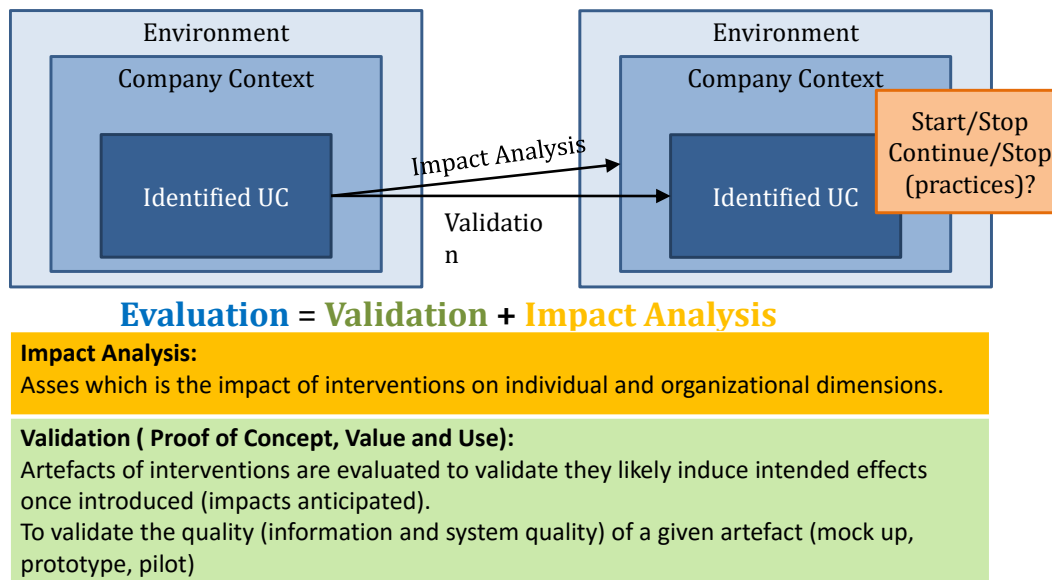


Figure 2. Overview of the evaluation

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 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 3 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.

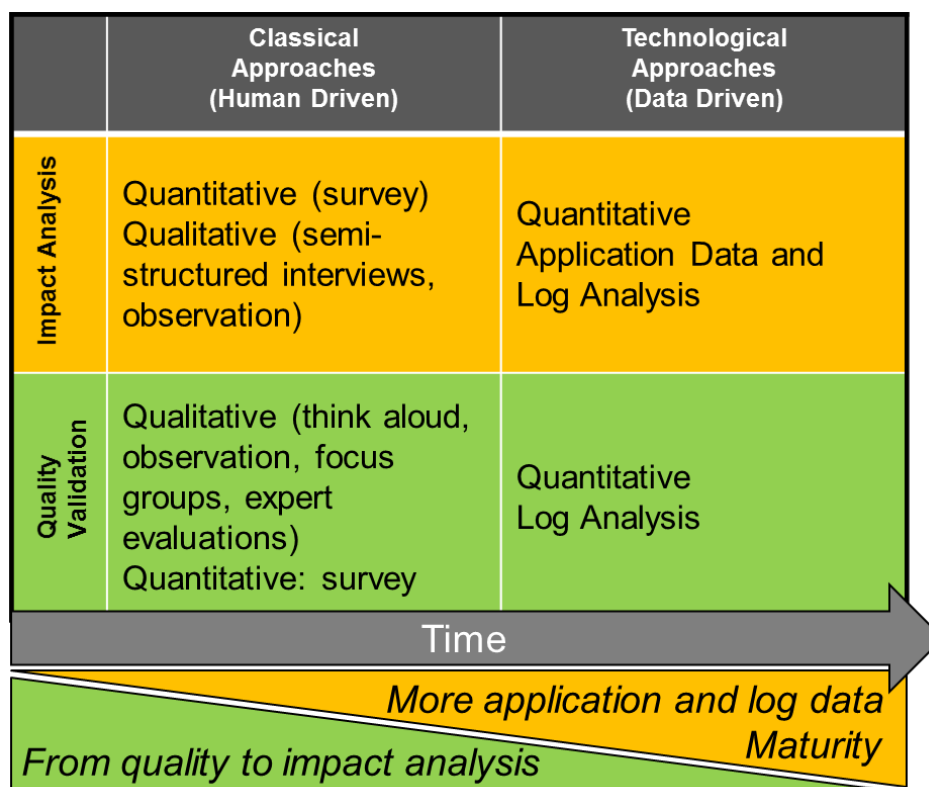


Figure 3. Tools and methods for the evaluation framework

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.

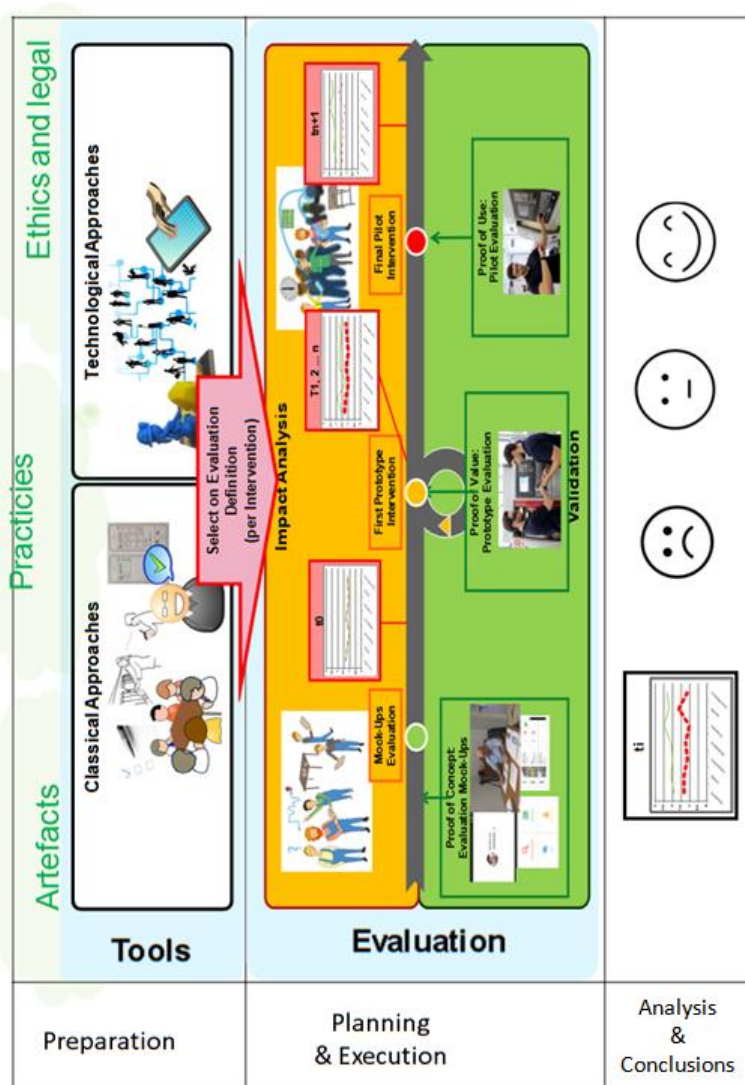


Figure 4. Evaluation setting up overview.

### 3.1.1 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

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, 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 5 shows, they can compromise the results of an evaluation.

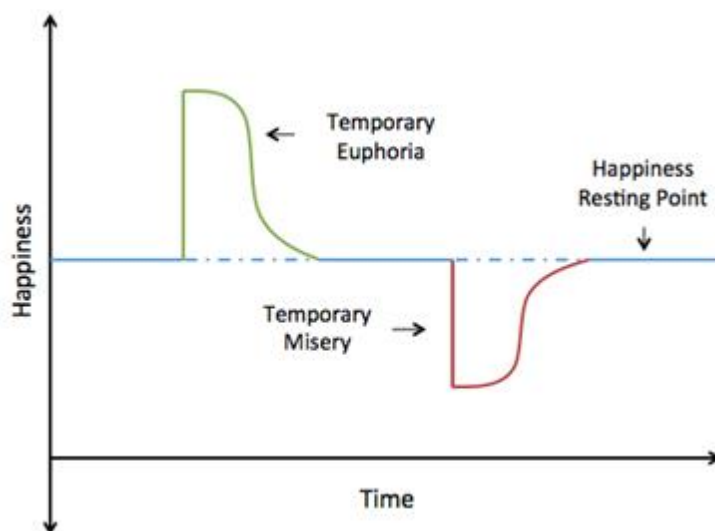


Figure 5.- Time Evolution of Temporary Events on Happiness (Kothari, 2015).

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 then 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 assumes 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 or negative sign 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 need 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.

Similarly, as the framework's tools are thought to measure specific issues of the IDs, their measurement 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 6 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 3.2.3.

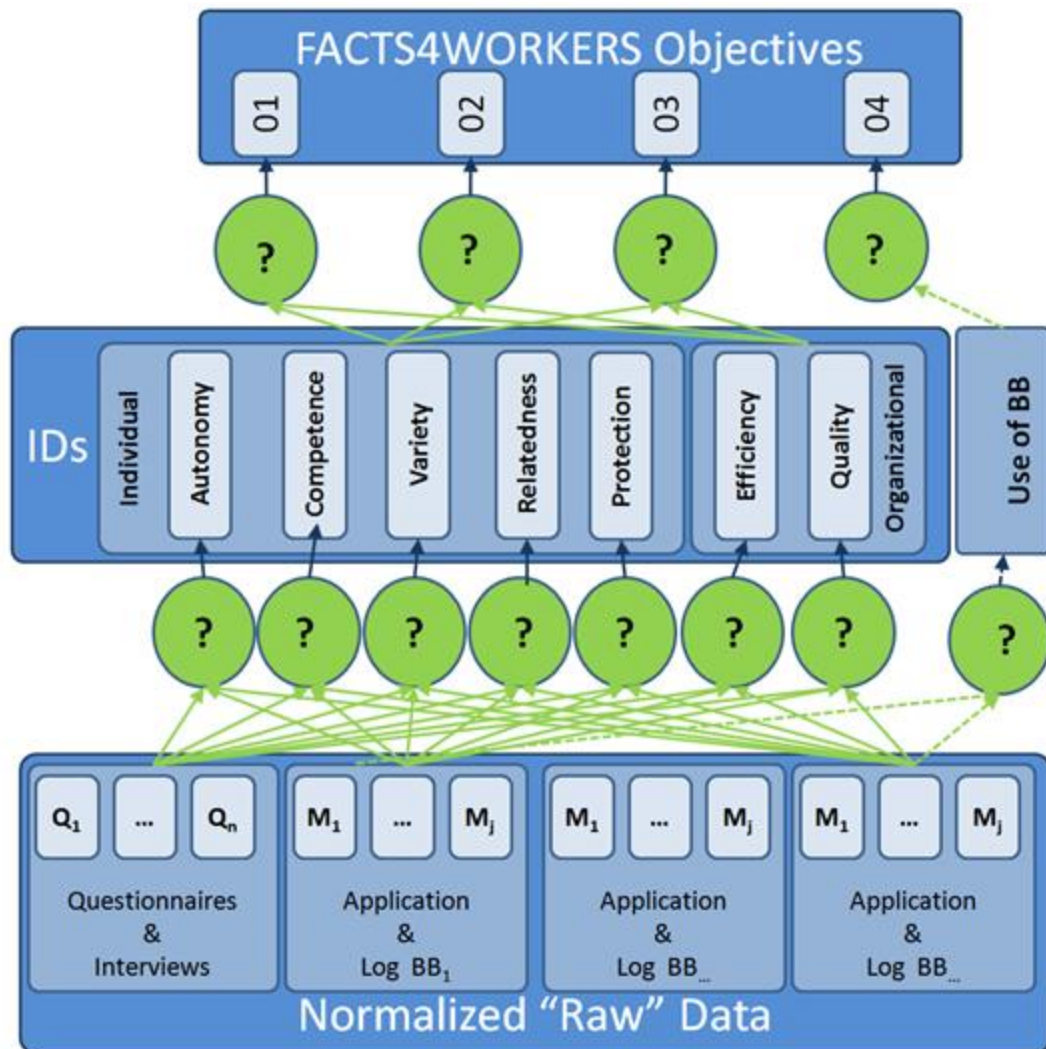


Figure 6.- Detailed Raw Data-Objectives Measurement Formulation.

## 3.2 Evaluation Setting

These paragraphs provide an overview of the general setting up of an evaluation process. **Fehler! Verweisquelle konnte nicht gefunden werden.** summarizes the evaluation setting up process. It is composed of three main steps: preparation, planning & execution and analysis & conclusions.

### 3.2.1 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 needed to be measured.

Regarding artefacts two facts must be considered. First, the maturity of the artefact to be deployed must be clearly 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 evaluation's logistics (choosing participants, translating documents, supporting evaluations, etc.).

### **3.2.2 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 thinkaloud notes, fulfilled questionnaires, log detected errors.

### **3.2.3 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 prioritized 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 0, 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.

### 3.3 Industrial Challenges Evaluation Process

Framework evaluation enables to analyse specific UC requirements. Each of the FACST4WORKER UCs is related mainly to one IC, consequently the requirements of each UC are determined by the corresponding IC and the specific UCs issues. Therefore, the analysis of the fulfilment of the requirements of each UC enables to extrapolate the fulfilment of the corresponding IC.

In order to analyse how the ICs & UCs requirements are fulfilled, the evaluation results are presented in such a way which enables to visualize easily the UC fulfilment structured in the following items:

- Insights: according to the validation questionnaires and the experts observation, remarks and conclusion concerning the UC BB are presented
- Changes in work practices: according to the workers comments and the experts observations, evidences of changes in work practices are presented
- Suggested improvements: functionalities modifications and updates of the UC BB requested by the workers

According to the FACTS4WORKER evaluation methodology, the fulfilment of the UCs results is extrapolated to the fulfilment of the ICs.

During the FACTS4WORKER project and according to the DoA an evaluation for each of the UCs has been carried out. At the same time, in order to analyze longitudinally, in terms of improvements and adaptations based on the analysis of the feedback of the workers and the experts observations, along the life time of the project one representative UCs have been selected to carry out more evaluations across the FACTS4WORKERS project life time. These UCs will present the evaluation results for each of the evaluation executions.

Each evaluation execution of a UC is represented by a  $t$  (execution at time  $t$ ), with a number to indicate the order), i.e.  $t_1$  means the first execution and  $t_2$  the second one.

## 4 Industrial Challenges Evaluations

This section abstracts the results of the evaluation performed at the reference UC level to draft the conclusions that can be derived to the IC. For making it, we consider the available results of the performed evaluations which availability depends on the development and deployment state of each of the BB required for implementing UC needs.

The presentation for each IC is based on the results of the evaluation of its reference UC.

### 4.1 IC 1. Evaluation

#### 4.1.1 EMO-1 UC Evaluation

EMO-1 evaluations were performed linked to deployments in June of 2017 and June of 2018. They were performed considering both FACTS4WORKERS workers group and Control Group workers in order to be able to determine external biases in the results. In order to obtain significant insight and results we tried to have representatives 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 they were performed using questionnaires and, for validation, using some open questions looking for clear explanations of what is working and not working on the worker opinion. Next table summarizes the framework tools used for evaluating the deployment solution:

<b>Impact Analysis</b>	Translated Questionnaire using the survey created at: <a href="https://ec.europa.eu/eusurvey/runner/F4W_IA_QUESTIONNAIRE_V2">https://ec.europa.eu/eusurvey/runner/F4W_IA_QUESTIONNAIRE_V2</a> Productivity was measured using a specific questionnaire for EMO.
<b>Validation</b>	It was performed by assigning task to be performed by workers using the prototype in two rounds. The evaluated prototype consider the project management application (t1 and t2) and Evocall BB (t2) In round A workers are requested to provide their feelings, impressions, etc. thinking aloud and evaluator (facilitator) notes it as objectively as possible. In round B workers are requested to perform other tasks after receiving a brief training on the use of the provided solution and their feels are obtained using UMUX-LITE questionnaire and an open questionnaire looking for quality (satisfaction with system, information and system quality) issues and their intention to use the system.

### 4.1.2 EMO-1 Evaluation Results

#### From the validation:

As we mentioned when defining the framework, the goal of the validation of the prototypes is to validate 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.

In this section we present the results of the UMUX-Lite along with the insights obtained from the validation process.

## UMUX-LITE Questionnaires

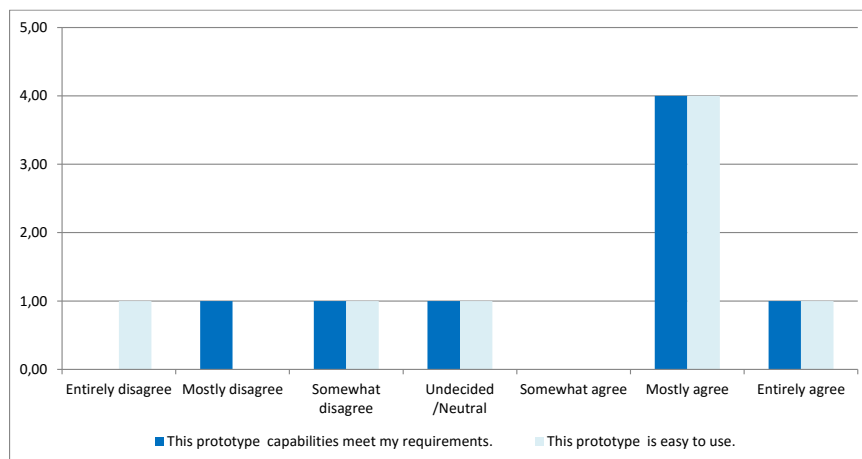


Figure 7.- UMUX-LITE Results in EMO at t1.

## Insights of the validation

Insights .	
t <sub>1</sub>	<p>-Workers appreciate the prototype: “easy to use”, “looks very promising”, “brings many advantages”, etc.</p> <p>-Meets requirements: 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.</p> <p>-Error notifications: Immediate information about errors and ability to act quickly and in consequence improve productivity.</p> <p>- Positive aspects: touch screen monitor, better traceability in production</p> <p>-Workers are worried about the scalability of the solution (“congestion problems during peak working hours”, “limited number of screens at the beginning”, etc.), possibility of actuators based on the error notifications and the disturbing factor when using the prototype.</p>
t <sub>2</sub>	<p>- Although some workers requested more use time for having an opinion as well as, to improve their performance using the solution, in general most workers like the solution which fits their needs and they find the system useful. The system is considered easy to use and to learn and it is perceived both issues improved from the beginning of the project. This perception can be partly due to the Slovenian adaptation which is per-</p>

	<p>ceived as really good.</p> <ul style="list-style-type: none"> <li>- Workers perceive the solution completely integrated with the work (tasks) to be performed. However, some concerns are expressed in relation with its use by all the workers, the feeling of being controlled, the need of training in use the system and of knowing the EMO productive processes. Regarding the general use of the application some concerns are reported about the administrative work to be done for creating the content to be used with the system.</li> <li>- Workers appreciate the provided information which seems clear, good, correct, specific and useful to them. However, some workers consider they do not have the capacity of determining its correctness which can be determined after using the solution in real conditions.</li> <li>- Regarding functionalities supporting workers' tasks, their appreciation and acceptance 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 move the orders and instructions with the workers is also appreciated.</li> <li>- Multimedia capabilities (taking pictures, recording video, Evocall) are seen quite interesting for supporting workers. However, although taking pictures is really appreciated for reporting errors, it is requested cameras having a biggest resolution in order to provide the required accuracy for error reporting.</li> <li>- Main concern of workers are related with the used devices: many workers rejected using smart-glasses (they have been tested on a lab environment even 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.</li> <li>- Some concerns about the glasses and Evocall are referred. However, most of the workers do not find any special issue to report.</li> </ul>
<b>Suggested Improvements.</b>	
t <sub>1</sub>	<ul style="list-style-type: none"> <li>- Include error priorities</li> <li>- Connect the prototype with mobiles or at least, being able to get the notifications on the mobile.</li> </ul>

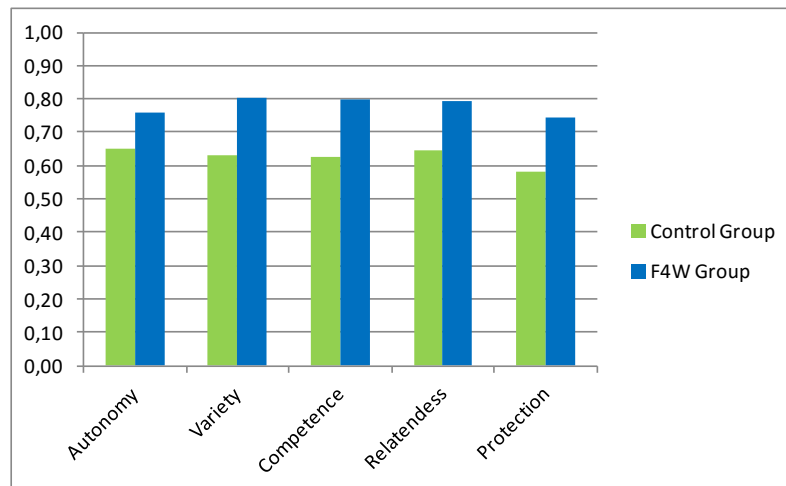
t <sub>2</sub>	<ul style="list-style-type: none"> <li>- Most improvement requests are related with changing the devices (even for workers requesting time for using the system). Desktops are thought as better computers because they can make easy to report errors.</li> <li>- Functionalities of "edit" and "start" buttons are not well understood by workers. The edit and start button are functionalities within the maintenance application. The edit button provides the opportunity to edit maintenance tasks and type in comments to any descriptions of an error from a machine. The workers perceive this button as confusing and not intuitive.</li> </ul>
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### From Impact Analysis

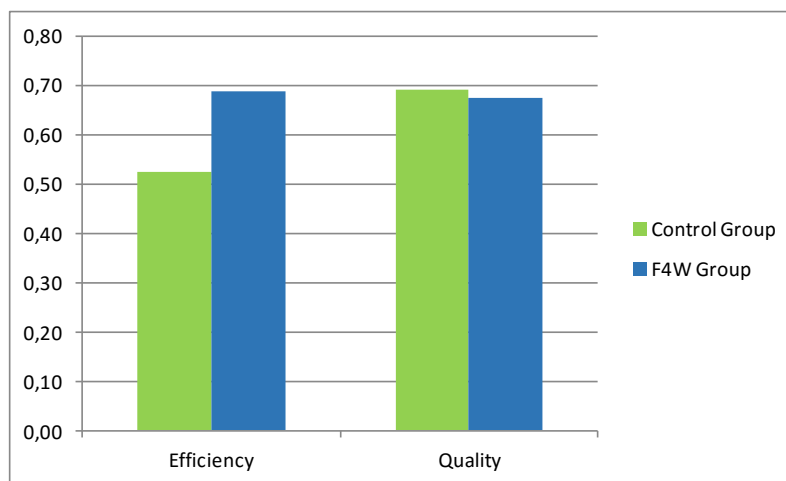
We are interested to know if the **F4W applications** increase the problem solving and innovation skills and, the cognitive job satisfaction and productivity of their users.

- Problem Solving Skills: ability to solve unexpected situations by yourself 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 you are responsible for or of the product you are working with as well as, to exchange them with your colleagues and company.
- 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).

These data could be obtained from questionnaires in an anonymized way, and here we include the figure with the results



**Figure 8: Individual Impact Dimension in EMO**



**Figure 9: Organizational Impact Dimensions in EMO**

And also gathering the data from the interviews will 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. We present in this section some examples of these statements and how these quotations are mapped to the dimensions.

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"	Efficiency	High



and parts" "The system provides better traceability and over-view of the work" "This systems helps to plan activities better"		
"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 over-view 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

### Impact Analysis Conclusions

All together we could expect that introducing solutions like the ones provided by FACTS4WORKERS in these industrial challenges will expect to increase workers' competences by providing the detailed information about measures, positions, parts; the relatedness and also we will increase protection of workers by making the tasks solving process easier and increase the efficiency of the organization.

## 4.2 IC 2 Evaluation

### 4.2.1 TKSE UC 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 the next table we summarize the framework tools used for evaluating the deployment solution:

<b>Impact Analysis</b>	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.
<b>Validation</b>	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.

### 4.2.2 TKSE Evaluation Results

From the validation:

UMUX-LITE Questionnaires

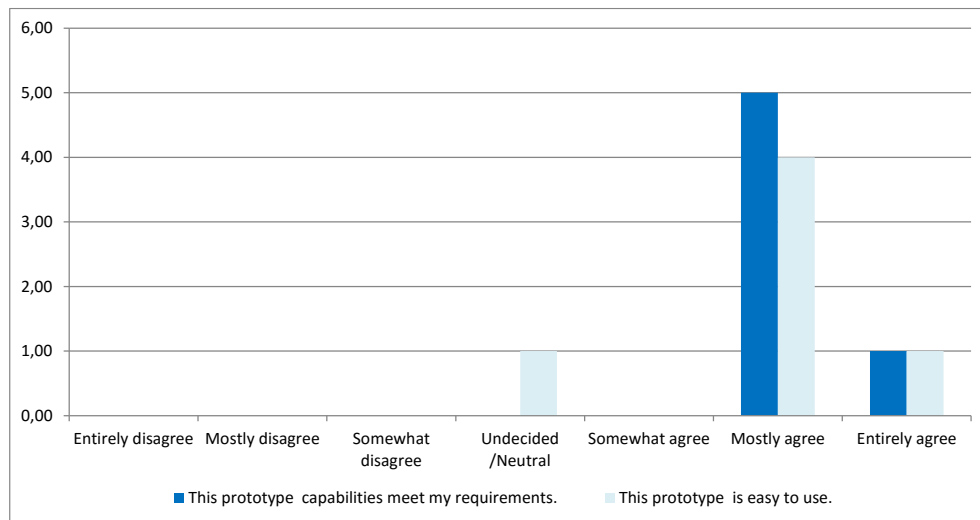


Figure 7.- UMUX-LITE Results in TKSE at t1.

### Insights of the validation

#### Insights .

t <sub>1</sub>	<p>It was observed by evaluation team that every worker stated clearly that the app with its functions covers the existing requirements, although the evaluation was challenged by the missing data of the app. Nevertheless every worker looked forward to use this application whenever a full dataset would be provided.</p> <p>The tablet was used for data entry and the order generation. One employee mentioned that the solution wasn't helpful in order to overcome the work tasks, because e.g. most of the climate devices weren't stored. 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).</p> <p>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 (and the current need of making it twice).</p>
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#### Suggested Improvements.

t <sub>1</sub>	<p>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.).</p> <p>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.</p> <p>Usability of the prototype is good, although some minor changes are recommended:</p> <ul style="list-style-type: none"> <li>- Add a "save"-button at the end of edit screens would make the creation process easier.</li> <li>- Scrolling would be helpful as sometimes the keyboard hides some points.</li> <li>- Create a New Location short-cut in the Unit Creation screen.</li> <li>- Highlight the active entry field of screen where entering data.</li> <li>- Drop down menus are better readable than check-boxes.</li> <li>- Heading for the different search topics would help for making clear which is current search.</li> <li>- Finally a new functionality is requested: the possibility of creating and accessing guidelines for supporting accessing the devices and the maintenance tasks.</li> </ul>
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## From Impact Analysis

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

Here, we collect a summary of important quotations and their major impact on the dimensions addressed on this use case.

Quotations	Impact Dimension	Relevance
<p>"The prototype could reduce the shift handover time with the provided information"</p> <p>"The solution will help us to lead an easier shift handover"</p> <p>"Workers save time when locating the air conditioning unit to be maintained and to prepare the needed materials/tools in advance"</p>	Efficiency	High

"It is good. Now we know which spare parts are needed when we are still at the base"		
<p>"I like the option of having tips from colleagues. It is a great advantage"</p> <p>"Maps and descriptions prepared by other colleagues are very helpful"</p>	Competence	Medium-High
"The application is really useful and it will be more when all the devices will become included. For me, a particular valued app functionality is the possibility of taking a look to colleagues' tips, its support for shift handover, and the possibility of getting guided by the maps and descriptions provided by other colleagues."	Relatedness	Medium-High
<p>"I will be able to make better decisions for determining my task orders"</p> <p>"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)"</p> <p>"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 incomplete"</p> <p>"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)."</p>	Autonomy	High
"It helps to reduce stress, specially stressful periods during summer time"	Protection	Medium-high

## 4.3 IC 3 Evaluation

### 4.3.1 HID UC Evaluation

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.

A group of 6 workers participated in the evaluation: 1 *technologist* (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.

During July of 2018 after deployment the solution at HID, an assessment of the impact was performed in this case, 23 workers participated on the evaluation 8 of them using the solutions in the two lines where it was deployed and the 15 in the other two lines.

<b>Impact Analysis</b>	The assessment of the impact was performed using paper questionnaires because of the language issues.
<b>Validation</b>	For validating, it was presented to worker during 5 minutes using a PC and then workers was requested to perform some tasks using a tablet. Then observation and think-aloud was used for receiving the feedback from the workers.

### 4.3.2 HID Evaluation Results

From the validation:

Insights .	
t <sub>1</sub>	<p>The presentation of the tool has been appreciated and took only 5 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.</p> <p>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.</p> <p>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 to a problem. However, they said while tablets work correctly for creating a single solution, it would be better to use a PC for a massive inclusion of solutions.</p> <p>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").</p>
Suggested Improvements.	
t <sub>1</sub>	<ul style="list-style-type: none"> <li>- It was requested to replicate the solution for other production lines.</li> <li>- Include support documentation and existing reports on defect and solutions.</li> <li>- Include the timestamp to the solution used.</li> <li>- Automatically assign some events to the maintenance leader (<i>technician</i>).</li> <li>- The documentations is ok, but some of workers have suggested to include the most frequent defects of the piece (From THO evaluation)</li> </ul>

## From Impact Analysis

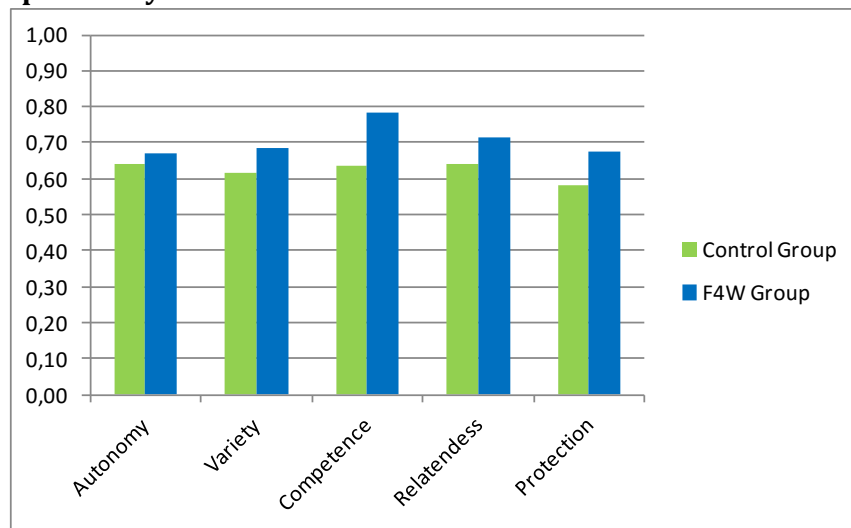


Figure 8.- Impact Dimensions Measured at  $t_2$  in HID.

Figure 8 shows the measurement of the dimensions at  $t_2$  in HID. It shows that the introduction of the solutions has good impact in all the considered dimensions on the workers by comparing the results of the workers using the solution and the control group.

### Impact Analysis Conclusions

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 and also on the workers productivity.

From the very beginning, workers appreciate the prototypes as they answer to extend it 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 more impact on workers. They appreciate the solution, the information it provides and the capability of accessing it anywhere, anytime. It will make more easy operators works and save time when they think they are not able to solve a problem which can easily communicate to the maintenance leader.



## 4.4 IC 4 Evaluation

### 4.4.1 THO UC Evaluation

The evaluation of the use case has been done assessing the impact via interviews and questionnaires. The first prototype of the Training BB was deployed in THO in June of 2017. The evaluation was performed by WP6 members supported by the UC leader. In this case the deployed solution is based on an existing OSS Moodle which provides both front-end (web based and app based).

These solutions have been adapted to the Worker training philosophy at THO, which is based on a scale of 4 levels of knowledge (ILUO). For a new worker, he/she is assigned the initial level I (for each machine/part) combination. As the worker gets trained by a tutor, he/she advances in the knowledge level receiving the approval of the tutor: he/she passes to U, L or O for the given part and/or machine. As worker gets certified in more advanced levels for more machines/parts, he/she is assigned a higher initial level for starting to learn about machines/parts which are new for he/she: the knowledge to be acquired at levels I and L is related to more general factory issues than the acquired at levels U and L which is close related to parts and machines.

In the next table we summarize the framework tools used for evaluating the deployment solution:

<b>Impact Analysis</b>	Impact was assessed using questionnaires and considering both 7 workers using the solution as well as, 6 workers of control group.
<b>Validation</b>	The validation was executed after a brief training using interviews, questionnaires and observation methods.

#### 4.4.2 THO Evaluation Results

From the validation:

UMUX-LITE Questionnaires

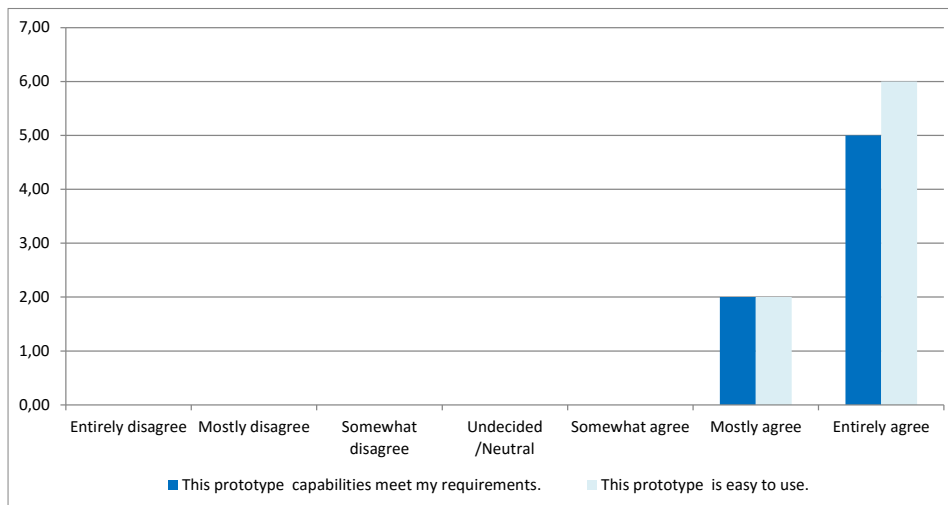


Figure 9.- UMUX-LITE Results in THO.

#### Insights of the validation

##### Insights.

t <sub>1</sub>	<p>The application was 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.</p> <p>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.</p> <p>ILUO test are appropriate when considering the dimensions: required time for gathering information and difficulty for answering the questions. 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 it an extra effort on their daily basis.</p> <p>While most of them fill comfortable using the prototype, they think receiving a</p>
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	little training once the solution will be deployed would be great.
<b>Suggested Improvements.</b>	
t <sub>1</sub>	<ul style="list-style-type: none"> <li>- Increase the font size</li> <li>- Facilitate the login access</li> <li>- They would like to link the training with the manufacturing process, so once they have to start to manufacture a piece they would be able to receive the training and have access to this information</li> <li>- In the questionnaires, the links providing added information are not highlighted enough so workers do not use them.</li> </ul>

### From Impact Analysis

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. In this case we present the results of the questionnaires.

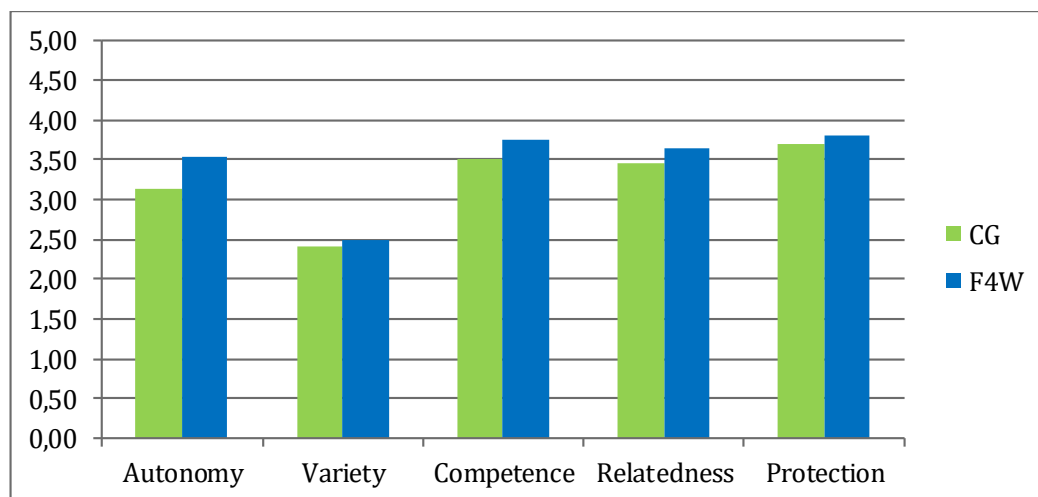


Figure 10. Impact Dimension Results at THO.

And also relevant information related to the impact from the interviews. In this use case most of the relevant statements are mapped to the competence dimension which is the most representative for this use case.

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
<p>"Once I receive the production order, I would like to have this information as a support tool".</p> <p>"This tool could support our training process anywhere, anytime, not only on the shop-floor but also outside of the factory".</p> <p>"I would like to use it. I would like to have it in my mobile so I could take some courses at home"</p> <p>"Yes, I would like to use it. I think training is very important"</p>	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

## 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. To achieve this goal, FACTS4WORKERS considers four Industrial Challenges that are tackled as reference examples. These ICs are generic contexts which can be applied to many companies so a general description is provided and the addressed objectives and the specific requirements are presented.

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 four 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. From the results of the interventions, we have presented Industrial Challenges using as a reference the main use case and we have tried to link the results with the impact that they have on the dimensions as it has been detailed in previous section.

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 facto-

ries, 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.

To conclude, we must highlight that this evaluation shows preliminary results and next evaluation deliverable, Deliverable D6.4, will present the results in more detail way. With all these considerations in mind, we think that the draft presented in this document is a good starting point to clarify how the evaluation process has been done and to extract preliminary conclusions and the workers and organisational constraints that we have faced in the process.

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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
Università degli Studi di Firenze, Department of Industrial Engineering	Italy
Technische Universität Wien	Austria
ThyssenKrupp Steel Europe AG	Germany
Hidria 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
Itainnova - Instituto Tecnológico de Aragon	Spain
Schaeffler Technologies AG & Co. KG	Germany
Lappeenranta University of Technology	Finland

### PROJECT COORDINATOR / CONTACT:



VIRTUAL VEHICLE Research Center  
Inffeldgasse 21A  
8010 Graz, AUSTRIA

Tel.: +43-316-873-9077  
Fax: +43-316-873-9002  
E-Mail: facts4workers@v2c2.at

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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 sociotechnical 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 6.3 “Industrial Challenges specific evaluation reports (longitudinal)” of the H2020 project “FACTS4WORKERS – Worker-Centric Workplaces in Smart Factories (FoF 2014/636778).

Building on a deep understanding of the industrial challenges and the workers’ practices in the different use cases studied within the project and in addition to the evaluation process we present this document that is structured as follows.

First of all we will present a description of the industrial challenges and we will highlight the requirements considered. This will provide us with a clear view of the defined requirements and they will be linked with the main use case and the associated ones. These requirements will be considered the basis for the evaluation analysis and we will present some considerations of the evaluation framework and methodology to explain how job satisfaction and innovation skills could be increased thanks to the FACTS4WORKERS solutions/prototypes provided if these meet the requirements previously defined. This document provides the evaluation process focusing on the specific challenges of the Industrial Partners and providing a generic overview of the process and we will conclude presenting the evaluation results at use case level with the aim to extrapolate the obtained results to the assessment of each Industrial Challenge set of requirements.

