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Technology Monitoring: Report on Information Needed For Workers in the Smart Factory

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About this document

Executive Summary

D2.2, Technology Monitoring: Report on information needed for the Industrial Challenges workers with taxonomy is part of the work in progress of "FACTorieS for WORKERS" (FACTS4WORKERS). It is the result of the execution of T2.1 in 2016. T2.1 is an activity of WP2 aiming to highlight the current state of the applicable technologies (both hardware and software) which can be used for implementing Worker Centred Industry 4.0 solutions, which are already applicable and under which risks.

D2.2 advance in objectively answering questions like: Which are the available HCI enabling technologies that can support the creation of Worker Centred Industry 4.0? Have the available HCI enabling technologies a TRL enough for supporting FACTS4WORKER goals? Is it possible to objectively determine the TRL level of a technology? Which is the TRL level of a system of technologies? Once we evaluated our technologist of interest, how we can read it?, Which are the conclusion we can obtain from it?.

D2.2 takes D2.1 as base for answering these questions. We tried to answer them by following an iterative three steps process: define a methodology for creating, evaluating and reading a taxonomy of (HCI) enabling technologies; apply the methodology for creating a taxonomy; use the not clearly resolved issues or not resolved at all ones by the methodology to identify opportunities of improvement of the methodology

This report summarizes the work we did during last year. It redefines the methodology introduced in D2.2, it applies the methodology to the FACTS4WORKERS project and it shows our conclusions about the industrial readiness of the technologies of interest and about the methodology.

The FACTSTWORKERS taxonomy is published as a digital appendix of this report (please, see references).

Keywords

HCI critical taxonomy, Industry 4.0, Factory of The Future, Shop floor, Smart devices, Wearables, Augmented Reality.

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App ..... Application

B/M ..... Binocular/Monocular

CP ..... Cross-Platform

DOD ..... Department of Defense

ESA ..... European Space Agency

FoV ..... Field of View

GAC ..... Gyroscope, Accelerometer, Compass

HCI ..... Human Computer Interaction

HMI ..... Human Machine Interaction

NASA ..... National Aeronautics and Space Agency

NF ..... Natural Feature

OSS ..... Open Source Software

OST ..... Optical See Through

SaaS ..... Software as a Service

SDK ..... Software Development Kits

TRL ..... Technology Readiness Level

UC ..... Use Case

VS ..... Visual Search

1 Introduction

D2.2, Technology Monitoring: Report on information needed for the Industrial Challenges workers with taxonomy is part of the work in progress of "FACTorieS for WORKERS" (FACTS4WORKERS). It is the result of the execution of T2.1 in 2016. T2.1 is an activity of WP2 aiming to highlight the current state of the applicable technologies (both hardware and software) which can be used for implementing Worker Centred Industry 4.0 solutions, which are already applicable and under which risks.

D2.2 is the second release of D2.1 [13] which was finished by the end of November of 2015. The purpose of D2.1 was to introduce the reader in the world of the HMI/HCI technologies which could be used for supporting shop-floor workers in their daily tasks. This is the reason why D2.1 includes a theoretical background trying to briefly introduce the reader in the foundations of the HCI and then, after presenting the foundations of HCI, it presented taxonomy of the technologies supporting HCI technologies which could support worker tasks. The taxonomy consists of two main branches:

- The *HCI-Enabling Technologies* branch introduces technologies that, in most cases, are self-contained subsystems and which are usually embedded in other more complex systems, such as computers, smart-phones or smart-watches. Examples of these technologies are touch-screen, touchpads, etc.
- The *HCI-Systems* branch introduces the available technologies that offer an advance in ubiquitous computing, IoT or Industry 4.0 vision from the HCI perspective (i.e. mobile devices, wearable devices and augmented reality).

Since we finished D2.1, both the FACTS4WORKERs project and the technology have evolved. During this year, we have completed gathering requirements for implementing the use cases. Simultaneously, we have started the development.

Considering D2.1 (its taxonomy), the project evolution and the technology evolution, this document aims to improve our taxonomy by evaluating its definition and population process. A second objective is to obtain a new picture with the current state of the referenced technologies (devices, SDKs, etc.) by assessing their TRL level when considering them for supporting the implementation of Worker Centred Industry 4.0 solution.

Because of the definition of the requirements and the beginning of the development, we took a more pragmatic approach for updating the taxonomy and creating this report. We focused our research in the *HCI System* branch of the taxonomy. We updated its sub-branches of technologies which could be directly matched to the UC requirements. Anyway, we keep an eye in the others branches with the purpose of keep them in the state of the art.

As a consequence D2.2 is structured as follows:

- Chapter 1 introduces the document itself and the methodology we follow for researching technologies as well as for evaluating them.
- Chapter 2 reviews the *HCI-Systems* branches which are updated. For each branch we created a couple of paragraphs. The first one introduces the new devices and their features. The second explains what happened and which our expectations about the technology branch are.
- Chapter 3 presents our general conclusions both about the taxonomy creation process and about the evaluation of the technologies.

In some sense the second paragraph of each technology branch and Chapter 3 correspond to the Technology Readiness chapter that was included by D2.1.

As we made when creating D2.1, we base our analysis on the creation of taxonomy of technologies; the addition of implementations of the technologies and devices as leaves of the tree; the evaluation of the technologies TRL levels in the Consumer and Industrial market; and the subsumption of the intermediate nodes TRL levels from the value of their children.

The taxonomy has two main purposes. First, it highlights which are the technologies which must be considered when implementing an ICT solution for solving a problem. Which technologies are applicable depends on the project objectives.

On second place, once the taxonomy is defined, the TRL levels of each of its nodes are assessed by following the rules we define in next paragraphs. Because the TRL level is associated with the technological risk of a given technology, by evaluating the TRL of the leaves of the taxonomy and subsuming their TRL levels to their parent, the taxonomy will support the decision about adopting a technological possibility or not and about which "*sub-technologies*" will guarantee the project success in a given time.

Figure 1 shows which we introduced in previous paragraphs. It presents 2 levels taxonomy of technologies and it shows the TRL evaluation based on a traffic light colours schema. Reading the taxonomy is very easy: if you want to assure the success of the project you should take the technologies under the Branch 1 because they are less risky than the others specially when comparing it with Branch n.

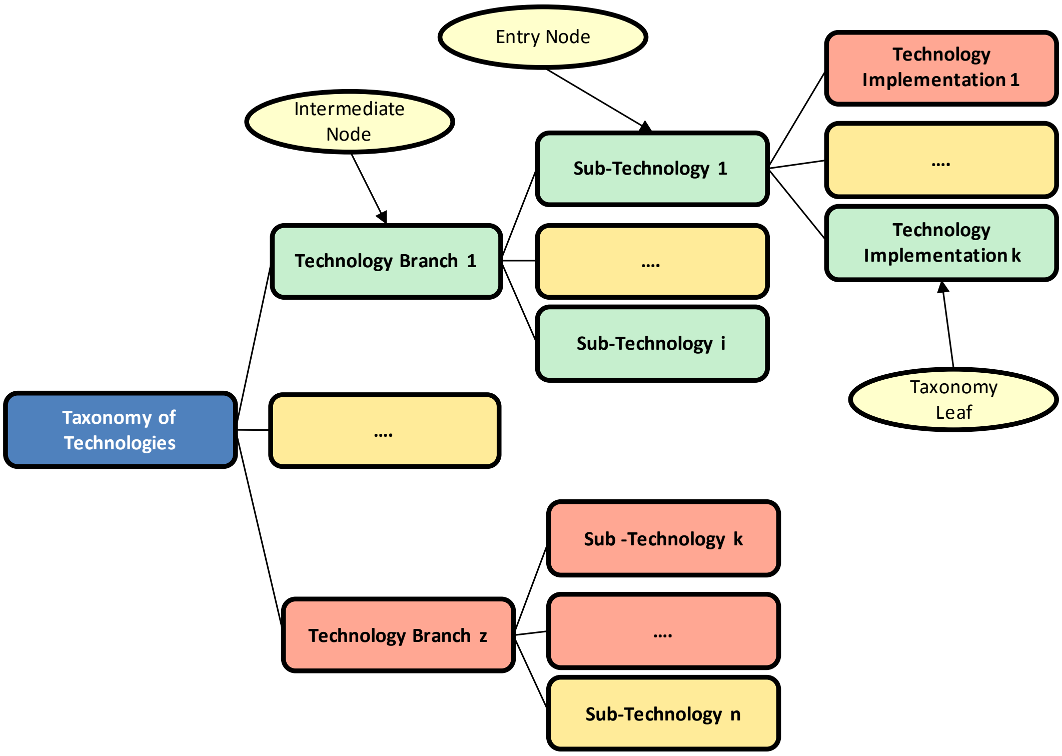

Figure 1. Simplified Schema of the Taxonomy and its TRL Evaluation.

FACTS4WORKERS taxonomy is the result of applying the methodology we introduce in next chapters. It tries to answer the questions: Which are the available HCI technologies that should be considered for creating Worker Centred Industry 4.0? Which are the risks (Industrial Readiness) to be faced when considering a specific technology or group of technologies?

Due to size reasons, we do not include the taxonomy in this document. We prefer to provide this such as a digital appendix which is publicly accessible [22]. By doing this, we reduce the size of the document but also we allow others to easily use it.

Next paragraphs briefly introduces the methodology we follow for updating the taxonomy, evaluating the TRL value and subsuming to the parent nodes in order to determine the real state of the technologies which are going to support the solutions FACTS4WOKERS creates.

FACTS4WORKERS taxonomy of HMI/HCI enabling technologies presents and evaluates TRL of the technologies of interest for interest for implementing worker-centred Industry 4.0 solutions. Second release is available at:
http://facts4workers.eu/taxonomyofhcitechnologies/

1.1 Methodology

Chapters 2 and 6 of D2.1 define the steps we consider for defining the taxonomy of technologies, populating it, evaluating the Consumer and Industrial TRL level of its leaves and subsuming for evaluating the intermediated nodes. Figure 1 presents a simplified taxonomy which results of an hypothetical execution of this process which can be as:

- Define the taxonomy by identifying its branches and hierarchical relations. For getting it, we reviewed FACTS4WORKERS objectives and industrial challenges; we considered other Industry 4.0 project approaches to solve interaction issues; we reviewed defined HCI in the Internet of Things and Industry 4.0 visions; we conducted a profound research on HCI theoretical background;
- Populate the taxonomy by searching on the web for implementations of the technologies which are "*entry nodes"* of the taxonomy;
- For each technology, an based on existing comparisons, select the set of features which will allow us to compare the implementations of a technology;
- Assets the TRL level of each node in the consumer market and in the industrial one by applying next criteria:

  All the technologies and devices presented in chapters 4 and 5 of D2.1 **belong to a leave of the taxonomy. We call the node they belong to "*entry node*"** (see Figure 1). In consequence, each of the tree leaves contributes to determine the TRL level of it entry node in the taxonomy.

  The TRL level of the entry node is **calculated as the maximum level of the nodes it contains** in the Consumer or the Industrial market. By considering the maximum function for aggregating the leaves TRL values we show the biggest expectation to be made on the represented technologies.

  So, if "Smart Glasses" gets a 9 in the Consumer market and a 5 in the Industrial market, we can interpret it as "*Smart glasses can be used by consumer for supporting activities at home, but as they are not certified they are only used in some experiments within the shop-floor*".

  It must be remarked, and it can be deduced from previous paragraphs, that once we move to the evaluation of the nodes of the taxonomies, we are not evaluating a concrete product or technology; we are evaluating the set of products or technologies included as a whole.

HCI Technologies				TRL Assessment	
Level 1	Level 2	Level 3	Level 4	Consumer	Industrial
HCI Enabling Technologies				6	4
	Conventional Technologies			6	5
		Text Entry		7	5
		Display Devices		7	5
		Screen Positioning, Pointing and Drawing Technologies		6	5
		Printers		7	7
	Touch-sensitive Screens (Touchscreens)			9	5
		Resistive Touchscreen		9	5
		Capacitive Touchscreen		9	5
		Infrared Touchscreen		9	5
		Surface Acoustic Wave (SAW)		9	5
	Image and Video Devices			9	7
		2D		9	9
		3D		9	6
	Computer Vision			6	4
		Recognition.		6	6
		Motion Analysis		6	4
		Scene Reconstruction		5	5
		Gesture Recognition, Behavioural or Gesture Analytics		7	4
		Eye Tracking		7	3
	Audio Input/Output Technologies.			7	6
		Speech Recognition		7	6
		Text to Speech		9	6
	Context Awareness Technologies			5	4
		Positioning, Location and Identification Technologies.		7	5
		Qualified Self		5	5
		Emotion Detection, Affective Computing, Mood Recognition		4	4
	Haptic Interaction			9	9
	Brain Computer Interaction			3	2
HCI Systems.				6	4
	Mobile Devices			9	7
		Mobile Devices		9	6
		Rugged Mobile Devices.		9	9
	Wearable User Interfaces.			5	4
		Smart Watches		7	5
		Smart Glasses		6	5
		Hearables		5	3
		Smart Clothing		3	3
		Nearables		9	9
	Cross Platform (CP) Software Environments			7	5
		Smart Operating Systems.		9	5
		CP Development.		7	7
	Data Visualization			9	5
		Scientific Visualization		9	5
		Information Visualization		9	7
		Infographic		9	6
		Visual Analytics		9	4
	Augmented Reality			5	4
		Augmented Reality Tracking Techniques		5	4
		Interaction Techniques and User Interfaces		6	4
		Augmented Reality Display Technologies		5	5
		Augmented Reality SDKs		7	5

Table 1. D2.1 Taxonomy Evaluation.

The same principle is applied for determining, **Intermediate Nodes Evaluation.** However, in this case, **the aggregation function is the truncated geometrical media of each sub-tree**. On the one hand, using the geometrical media allows all the children nodes to contribute the evaluation of the Intermediate Node level. In the other hand, by truncating the obtained value we give a bit more importance to the children having lower TRL level evaluation, in other words we take a more conservative point of view.

Table 1 shows the evaluation of the levels 1 to 5 of the taxonomy we presented in D2.1 by the application of the previous criteria. If we take a look to the "Augmented Reality" node and its children we can easily read it "*Augmented reality is a promise that is being fulfilled. The base technologies both for gathering information about the context and for providing the information to the user have already been developed, but content generation and the SDK is a very fragmented market that suffers the pressures of big companies. Just as an example, Metaio which provides the more popular SDK, was bought by Apple in June of 2015, but the company's subsequent disappearance has compromised many of its developments*"[13].

Although the taxonomy resulting of employing the methodology allowed us to obtain a clear picture of the state of the art of the technology, just after releasing it, we realized they are many opportunities to improve it. Some of them are:

- The first problem to be solved is how the taxonomy is going to be updated: there is a need for establishing an update process;
- A second problem to be solved is that although the judgment of each branch and node depends on particular technologies or devices implementation evaluations, these links are not included in the taxonomy;
- For each technology and device the common set of features to make them comparable must be included in the taxonomy. Together with it, in order to make the evaluation as objective as possible, we need to define a clear set of rules, both general (applicable to all the taxonomy) and particular (applicable to a particular "*entry node*").
- Because of the change of the criteria we would need to define a strategy to make the first years comparable with the results of the last year.

Part of the work we developed this year tried to solve these problems. Our purpose is to advance to the goal of defining a methodology for creating a taxonomy which will allow us to objectively determine the (real) TRL level of the enabling HMI technologies involved in the creation of Worker Center ICT solution. The objective is to determine if the TRL level of the enabling technologies which are going to be used in FACTS4WORKERS would support the project goal of creating prototypes having a TLR between 5 and 7.

Next paragraphs introduce the adopted solutions for the previously introduced problems.

1.1.1 Updating the Taxonomy Leaves

Updating the taxonomy leaves requires a huge effort. First, it is their number which is big enough for doing the search tedious and complicated. Second, because of the fact that they are in continuous improvement and there are new implementations of devices and SKDs continuously.

In order to reduce the invested effort we decided to follow a "*careful passive strategy*": as a result of D2.1 and according to the requirements for implementing Cases of Use of the FACTS4WORKERS project, we know which the taxonomy nodes of interest are.

This allows us defining the questions to be made to different search engines in order to obtain references to the technologies of interest. These questions are recorded as a property of the *entry nodes* of the taxonomy in order to self-document them. Apart from the items of interest, the results of the search queries also give us information about the features which must be considered in order to compare the items which belongs to a given *entry node*. In other words, search results help us keep the template of the technical descriptions of the *entry nodes* updated. Some search engines allow scheduling customized searches, we take advantages of this and we program weekly searches both in general websites, in academia sites and in patents sites in order to receive notifications of articles related with our queries. The notifications include links to articles which are visited in order to determine their interest for this report. If we find them interesting, we include them in a common database for a more detailed revision (see below).

In order to avoid problems with accuracy of the search questions, we quarterly review their definition. In the redefinition process we take in account the precision of the content of the notifications, the new technology concepts that could appear during the quarter under evaluation and new technologies of interest that can be suggested by partners not involved in WP2. We get last source of information by opening the inclusion of items in the database to all the project partners.

Once each six months we consolidate the taxonomy: we review the selected technologies for including more relevant in the taxonomy and for doing a first TRL evaluation.

Before releasing the taxonomy, all the included technologies and devices are revisited. Doing this, we try to keep the taxonomy evaluation up to date avoiding problems with the discontinuation of an item or highlighting features of the most recent version. For validity reasons, each time we evaluate an item, it is time stamped. This also saves us effort as because in future revision we will ignore articles which are older than the date of update.

1.1.2 Evaluating "*Entry Nodes*".

Each of the technologies and devices described in chapters 4 and 5 of D2.1 and in chapter 2 of this report **belongs to a leave of the taxonomy. We call it *entry node*** (i.e. Daqri Helmet belongs to "*Smart Glasses*" and it is its entry node). In consequence, each of the tree leaves contributes to determine the TRL level of it entry node in the taxonomy.

We calculate the TRL level of the *entry node* as the maximum level of the nodes it contains respectively in the Consumer or the Industrial market. By considering the maximum function for aggregating the leaves TRL values, we show the biggest expectation to be made on the represented technologies.

1.1.3 Towards an Objective TRL Evaluation of Leaves.

One of the FACTS4WORKERS project goals is to develop Worker Centred Solutions which achieve a TRL level between 5 and 7. We believe that it will not be possible if the enabling technologies do not provide these levels. In consequence, one of the objectives of the taxonomy is to show which the level of each of its nodes are.

TRL	Description
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies).
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Table 2. Technology Readiness Levels (TRL).

In previous paragraphs we introduced and justified the rules we follows for assessing the TRL levels of the *Entry Nodes* and the *Intermediate Nodes*. Here the problem, as we already said, is **how can we objectively asset the leaves of the taxonomy for inject its evaluation in the chain of nodes evaluation?** This problem was already highlighted both for obtaining public research founding [17] and when a company wants to invest for improving their working infrastructure [20].

Table 2 briefly introduces the Technology Readiness Levels (TRL) as defined by the European Commission [14]. TRL is a scale of maturity levels which can help to determine the risk of adopting a given technology. In this scale, items (technologies, hardware, software, etc.) having an evaluation from 1 to 6 present high risks and unknowns for handover, 7 is understood as the minimum level have to consider for handover and 8 and 9 should be the desired levels[15].

Each level in the scale provides a description of its meaning and each description is considered a rule for determining evaluating the TRL Level of an item. Because it is possible to subjectively interpret the rules, it is needed a more restricted way to provide an evaluation of an item [17].

TRL	Supporting Information
1	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Publications or other references that out-line the application being considered and that provide analysis to support the concept.
3	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	System concepts that have been considered and results from testing laboratory References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Results from testing laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the “relevant environment” differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?
6	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Operational Test and Evaluation reports.

Table 3. TRL Supporting Information Table 3.

While this problem has not already been faced in by all the sectors [17], it has been faced within the aerospace sector and both the NASA and the ESA have already developed their guidance and process for evaluation [16] [18] which are publicly available. Both of them follow the same strategy:

- First gather information about the item under evaluation by answering a set of established questions which include lower development level ones;

- Use the information for assessing the item TRL level.

Table 3 provides a brief description of the supporting information for evaluating the TRL level as described by the NASA in [16]. This information is similar to the information ESA requires for evaluating but simpler. Moreover, because of their position, they took a passive role as much of the information is demanded to the contractor when considering applying for the provision of an item.

As we already said, there are several entities which could be interested in using proposed methodologies. However, although they are not difficult to use, the process can be tedious. Moreover, not all the entities (in particular SMEs) have the importance of NASA or ESA for demanding information about their items of interest. In consequence, it is claimed by entities from different economic sectors [19], [20], [21], that NASA and ESA methodologies must be simplified in order to make them affordable by *"real world"* entities.

This motivated us to create an objective and simple way to determine the TRL level of the technologies of interest for implementing the FACTS4WORKER Use Cases. We always take as base the definition of the levels provided in Table 2.

TRL	Supporting Information
1	Not considered in this release.
2	Not considered in this release.
3	Not considered in this release.
4	Not considered in this release.
5	Does the public available information show the item was tested in laboratory?
6	Does the public available information show the item was tested in a real environment? Are the results of the test available?
7	Does the public available information show the item prototype was tested by an external entity in a real environment? Are the results of the test available?
8	Does the public available information give an idea of the integration of the item with other systems?
9	Does the public available information give example of real use case implementations? Are the performance, costs and determinant condition available?

Table 4. FACTS4WORKERS HMI TRL Evaluation Criteria.

The first problem to be solved was how to make comparable items within a given category (*taxonomy leaf*). We introduced the solution in chapter 1.1.2 of D2.1. It consists in the creation of a common set of features for each device or technology for doing the different implementations comparables. Table 5, Table 6 or Table 7 are some example which are present in this document describing Rugged Devices, Smart Watches and Smart Glasses respectively.

The second problem we faced was the different level of maturity of the evaluated technologies in the Consumer or the Industrial fields of application. As we described in D2.1, our solution is based on the separated evaluation of each item (devices, software or technology) for each application field. Because of the higher requirements Industrial field have (user security, devices certification, etc.), we applied the rule that an industrial level will never be higher than the consumer level.

The final problem to be solved is creating a set of rules for evaluating the item under study as objectively as possible. For doing it, we take the supporting information requirements introduced in Table 3 and we try to simplify them in order to serve to our actual necessities (TRL levels 5-9, software and hardware) and capabilities.

Considering all these we created the criteria presented in Table 4.

A final couple of rules allow us to avoid problems when trying to asset items which are under development and when they are discontinued:

- If an item is on a beta release or in a pre-order state the maximum level of TRL level assigned should be 5 or 6 depending on the reported experiments;
- When an item is discontinued or is going to be discontinued, the maximum level of TLR assigned should be 7. We consider this rule in order to highlight the possible risks a project can affront if using the evaluated item. Although it can be argued that for being consistent with the definition of the level in should never have a level over 6 we prefer to maintain 7 as the higher possible level.

  We follow this criterion for simplicity, in order to avoid different criteria for hardware and software. They are many libraries which although are not maintained work right and they can be used without any risks, in particular if they are OSS as the errors can be corrected. This trust cannot be applied to hardware and probably a level 6 would be required in the case a device is not supported in the future.

By considering these rules, Google Glass, for example, can be considered to have a 6 or 7 TRL level in the Consumer market but just 5 or 6 TRL level on the Industrial one: in other words we can have a commercial product available but it could not have 9 level because it does not demonstrate to be usable in the consumer or industrial level.

1.1.4 Comparing Different Releases of the Taxonomy.

As we realized the taxonomy and the way of evaluating will evolve during the project, we decided to include a strategy to make them comparable. It is very simple.

We decided to maintain already included items (devices, software, etc.) and to review their state (version, discontinuation, new features, etc.) each time we review the taxonomy.

On the one side it allows us to make them comparable, on the other side we will be able to provide readers with the more recent information about their interest.

As we signalled in previous paragraphs, we restricted the updates of the technologies to the ones directly related with the Use Cases defined by the industrial partners. In addition, we try to keep an eye in the rest of the taxonomy in order to look for new improvements in the technology and possible new branches of the taxonomy.

1.1.5 Overview of the Methodology.

In order to increase the clarity of this document, these paragraphs summarize the process we followed for creating, populating, evaluating the TRL level of the taxonomy nodes, create D2.1 and this document reports and for evaluating the process itself.

Figure 2 briefly introduces the process we follow for the creation/revision of the taxonomy, its population, the assessment of the TRL levels of the nodes and the final evaluation of the result (the taxonomy release) and of the creation process itself in order to improve this series of yearly reports. The complete process is very similar to those described in [16], [18], [19] or [21]. Presenting the process in these steps we want to allow the use, adaptation or improvement of the methodology and the resulting taxonomies both within FACTS4WORKER and other projects. Next paragraphs briefly introduce the steps we follow.

Steps under the *Taxonomy Creation* box are the ones we follow for (re)defining the taxonomy as a tree structure, for defining the features of the leaves (devices, software, etc.) allowing their comparison and for defining the set of TRL evaluation rules of each taxonomy node. These steps are:

- Determining the enabling technologies of interest based on other Worker Centred Industry 4.0 projects, Use Case requirements (as they were available) and WP2 partners' experience.

- Creating the taxonomy, the tree structure, in order to clearly classify the technologies of interest. Initially it was a pure tree (vertical relations) but current version also identifies other horizontal relations such as the inclusion of the *Speech Recognition* node in the *Text Entry Innovative Ways* one.
- Next step is the definition of the taxonomy evaluation flow. As we explained in previous chapters, we use two rules:
    - The first tries to determine the impact of the taxonomy leaves evaluations within the entry node ones. We consider here the maximum function for assessing an *entry node* TRL base on the leaves one.
    - The second tries to subsume the *intermediate nodes* evaluation based on the evaluation of their children. We use the truncated geometric mean function.
- Once we identify the *entry nodes* to the taxonomy, the “enabling technologies of interest”, we define a common feature set for evaluating a particular item (an implementation of the technology) and doing all the items under an *entry node* comparable.
- Finally, we created a set of rules for applying the TRL model for assessing the technologies items (devices, SDKs) based on their features and the information reported by their producers.

After creating the taxonomy and populating it, we evaluate the leaves and we subsumed the evaluation to the root of the main two branches *HCI Enabling Technologies* and *HCI Systems*. Figure 2 shows the detailed steps in the *Taxonomy Population and Evaluation* box. More concretely they are:

- We populate the taxonomy with items of interest: we search for existing items (devices, SDKs, etc.) which are considered to belong to the categories identified by the *entry nodes*. We save the search engine queries for clarity and reproducibility reasons.

  In order to reduce the required effort for updating the leaves we take advantage of the possibility of scheduling customized searches some search engines have. We schedule search and perform a preliminary evaluation of search results program weekly. We review search queries quarterly looking for accuracy and the inclusion of new terms of interest. We consolidate the taxonomy with search results of interest biannually.
- Ones we populate the taxonomy we evaluate the items independently using the rules we introduced in chapter 1.1.3.

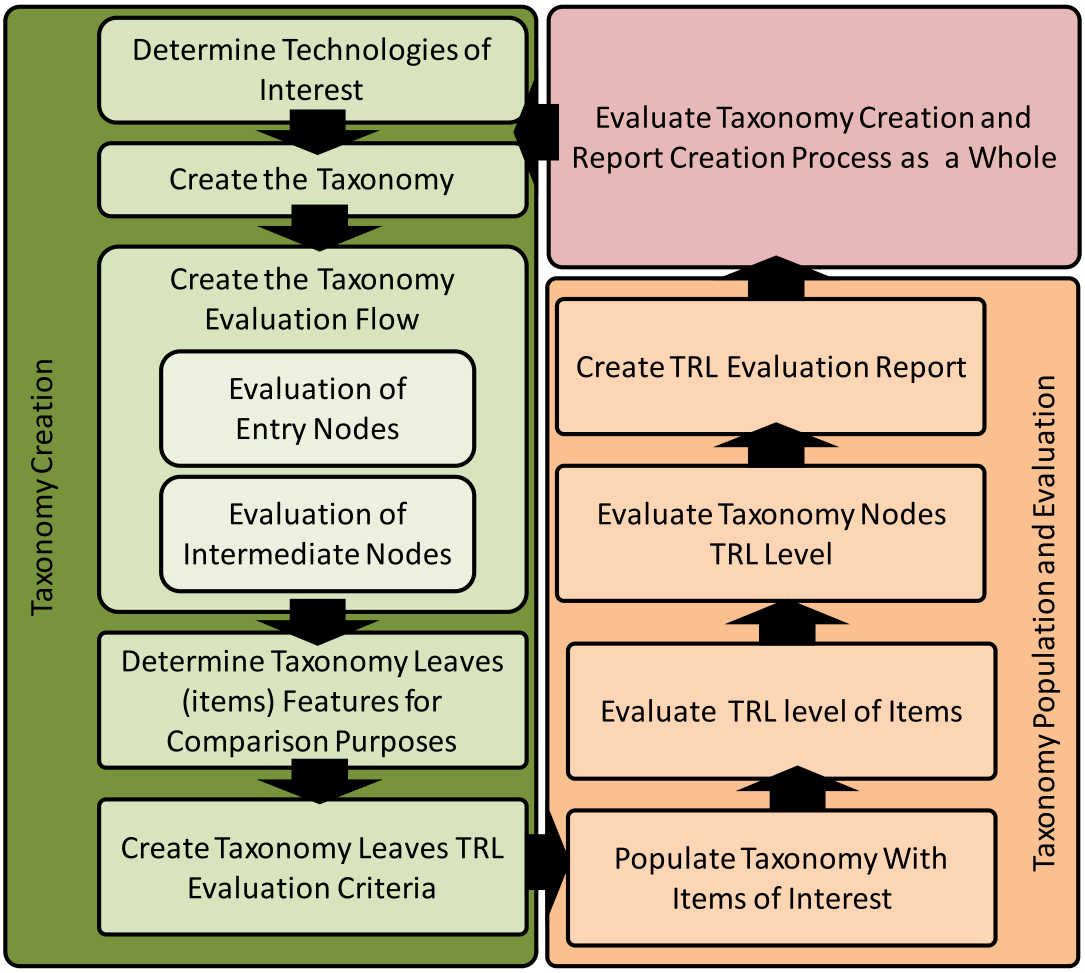

Figure 2. Process of Creation, Evaluation and Correction of Taxonomies.

- Then we automatically subsume the evaluation to the higher level using the tool we developed [22].
- We create the D2.2 report based on the evaluation.

The final step *Evaluate Taxonomy Creation and Report Creation Process as a Whole* is created under the perpetual beta philosophy of the FACTS4WORKERS project. The aim is clear: trying to improve the taxonomy definition and the process of creation.

Figure 3: FACTS4WORKERS will improve working conditions life by using Smart Technologies

2 HCI Systems

As we introduced in previous chapters, D2.2 is focused on the evaluation of the technologies that can be applied to the implementation of Use Cased defined by the Industrial Partners in particular those which could be involved in the development of Augmented Reality solutions.

In consequence we present here the HCI Systems evaluation of the technologies, both hardware and software technologies, which enable the creation of the desired solutions. The goal is to obtain a realistic TRL evaluation which will allow us to determine which will be the real expectations FACTS4WORKERS can have based on the foreseeing TRL evolution of the technologies in the near future.

Next paragraphs show the evaluated technologies. First it makes a pure evaluation of each technology and next we provide our Industrial Readiness Analysis.

2.1 Rugged Mobile Devices

There are a huge range of Rugged Mobile Devices (smart-phone or tablets) available at the moment. Table 5 shows a selection of some of them highlighting their main features. These features are shared with the consumer devices but adding the certified Ruggedness Level which determine the strength of the defined devices.

For a more detailed description of the features of the devices, we recommend interested readers to take a look to the taxonomy file [22]. Table 5 and the rest of the tables of this report are extracted from it.

A more detailed analysis of the features shows that smart-phones and tablet providers follow different approaches. Rugged smart-phones can be considered "*advanced*" smart-phones in the sense they provide similar characteristic to consumer smart-phones but they warrant their use under more heavy environmental conditions. Some of them provide sensors which can be of special interest under certain working conditions. In example, CAT S60 provides a thermal camera which can be useful in order to increase security of the worker.

Probably the use of harder materials and the need of lab support to determine their strengths determine both, the higher cost of rugged smart-phones in comparison with their consumer peers or their provision of less (mainly software) advanced capabilities.

	Name	Verykool RX2 Rock	CAT S60	Sonim XP7 IS	Torque KC-S701	xTablet T1200	FZ-M1	Galaxy Tab Active SM-T360	Latitude 12
FeatureS	Producer	Verykool	CAT	Sonim	Kyocera	Mobile Demand	Panasonic	Samsung	Dell
	Ruggedness Level	IP68	IP68	IP68	IP68	IP65	IP65		MIL-STD-810G
	Screen Size	4.3" IPS qHD 540x960	4.7" a-Si AHVA HD,720x1280	4.0" WVGA 480 x 800	4.5" IPS HD 720x1280	10.4"	7" 1280x800	8" 1280x800	11.6" HD (1366x768)
	GPS	Yes	Yes	Yes	Yes	Opc.	Opc.		Opc.
	Light Sensor		Yes		Yes				
	Bluetooth	3.0	4.1	4.0	4.0	4.0			
	NFC		Yes	Yes	Yes		Opcional	Yes	Yes
	Wifi	Yes	Yes			Yes	Yes	Yes	Yes
	Memory (GB)	16	32	16	16	128	256	64	128
	RAM (GB)	1	3	1	2	16	4	1.5	4
	Battery (mA)	1900	3800	4800	3100	5200	3320		
	Weight (g)	202	223	290	182	2200	540	393	1620
	Size (mm)	137 x 70 x 15	148 x 73 x 12	137 x 72 x 20	137 x 71 x 14	285x222x41	285x222x41	213 x 126 x 10	312 x 203 x 24
	OS	Android 4.2	Android 6.0	Android 4.4	Android 4.4.2 t	MS-W 10 Pro	MS-W 10 Pro	Android	MS-W 10 Pro
	Pricec (€)	407	700	439	390			239	
Comments			Thermal Camera	3 years warranty; Microphone filter noise		keyboard, Opc. barcode scanner, Opc. HD, 4G Communication	Hot Swap Battery, 2D barcode reader, Opc. 4G		Opcional 4G
TRL	Consumer	9	9	9	9	9	9	9	9
	Industrial	9	9	9	9	9	9	9	9
Overall TRL	Consumer	9							
	Industrial	9							

Table 5. Rugged Devices.

The other two main differences with the consumer mobiles are their larger dimensions and higher weight. They are due to their special requirements. For rugged smart-phones we can consider them within the same range of the consumer smart-phone and, in consequence, they will do not (heavily) affect their use on the shop-floor.

A final remark about rugged smart-phones, although Samsung produces a rugged version of its S7 smart-phone, smart-phone manufacturers are specialized companies more than general (consumer market) ones. On the other side, rugged tablet manufactures are both specialized (Mobile Demand) and general ones (Panasonic, Dell, Samsung).

xTablet T1200 and Dell Latitude 12 are in the "specific-PC" group. They have the same screen dimensions of a consumer tablet but they are much heavier. It will affect their use to support daily tasks. It is highlighted by the fact that manufacturers recommend their use with a bracket which will also affect their mobility. These tablets provide more (physical) connection ports than consumer tablets and they could provide internal hard disk. So we believe the can be considered "*specific-PCs*".

Panasonic FZ-M1 can be considered a medium way tablet between former group and "*pure Rugged tablets*". Although it is heavier than a common tablet it is not as much as the ones we present in the previous paragraph. Like xTablet T1200 and Dell Latitude 12, it runs on a Windows 10 Operating System but it is closer to a consumer tablet. An important feature is that it provides a barcode scanner which could be useful for many industrial scenarios.

Finally, Galaxy Tab Active SM-T360 is provided by Samsung and their characteristics correspond to the one provided by a consumer tablet. Apart from the operating system, which in this case is Android, the manufacturer does not provide any information about it ruggedness level.

2.1.1 Industrial Readiness Analysis

Rugged devices have been used in the industrial sector for years. Portable wireless terminals were used in the warehouses for more than fifteen years and have been tested and are therefore well accepted.

Would rugged devices support the Industry 4.0 in the near future? The answer is clearly yes, they are currently doing it. As the industrial processes will be digitized, the training material or the working procedures will be virtually created, rugged devices will well support these developments. Moreover, as more indoor positioning technologies will be available on the industrial shopfloor, more advanced interaction will be possible.

However, the downside of this technology is that the workers need to carry the device or find a place to store it in case they need their hands free for working.

Solutions for these problems already exist as some producers recommend brackets for using them. More innovative solutions will arrive in the near future. For example, we can consider the Lenovo's flexible phone prototype which allow to carry a smart-phone like a smart-watch**Fehler! Verweisquelle konnte nicht gefunden werden.**.

Figure 4. Lenovo's New Flexible Phone Prototype [23].

2.2 Wearable User Interfaces

2.2.1 Smart Watches

During this year the smartwatch market has not grown significantly and only few devices have been released: Alcatel Go Watch, Apple Watch, Gear S. When working on the creation of the features comparison table, see Table 5, we were surprised because their "rugged" features were certified using a standard reference (ISO 22810 or IP/MIL). Nonetheless, they are still not specially designed to be used on the shop floor of a factory. Similar objective of the main market currently is aiming at sport activities (by some of the smart-watch releases).

2.2.1.1 Industrial Readiness Analysis

Smartwatches sales reduced during the first half of the year [25]. It could be due to the fact that there are not new available devices. However, it is expected that sales will increase as new devices will appear. While during 2015 pure consumer products completely dominated the sales and they are guided by design, nowadays some of the smart-watches start to present a certified rugged level. Although they are intended for practicing sports more than for being used on the industrial shop-floor, this seems promising.

	Product	Motorola Moto G 360	LG G Watch R	Sony Smartwatch 3	Asus Zen Watch	Huawei Watch	Alcatel Go Watch	Apple Watch 2	Samsung Gear S3
Features	OS compatibility	Android 4.3+	Android 4.3+	Android 4.3+	Android 4.3+	Android 4.3+	iOS7+, Android 4.3+	iPhone 5+	
	Operating System	Android Wear	Android Wear	Android Wear	Android Wear	Android Wear	Custom Android	Watch Os 3	Tizen
	Screen Size	1.56"	1.3"	1.6"	1.64"	1.4"	1.22"	1.5"	1.3"
	Screen Resolution	320x290	320x320	320x320	320x320	400x400	204x204	390X312	360X360
	Battery (mah)	320	410	420	370	300	210		
	Sensors	Heart rate, pedometer, nine-axis accelerometer, ambient light	Heart rate monitor, barometer, accelerometer, gyroscope	Ambient light, accelerometer, compass, gyroscope, GPS	Heart rate, accelerometer, gyroscope, barometer	Heart rate, barometer, gyroscope, barometer	Heart rate, accelerometer, gyroscope, altimeter	Heart rate, pulse oximeter, GAC barometer ambient light, force touch	multi-touch, GAC, heart rate, ambient light, UV sensor, barometer
	Storage (GB)	4	4	4	4	4	4		
	NFC	No	No	Yes	No	No		Yes	Yes
	WI-fi	Yes	Yes	Yes	No	No	No	Yes	YEs
	Speaker	No	No	No	No	No	No		Yes
	Waterproof	30' at 1.5 m	30' at 1.5 m	waterproof	water-resistant	30' at 1.5 m	30' at 1.5 m	water-proof (50m)	Water-proof
	Ruggedness Level						IP67	ISO 22810:2010	IP68 + MIL-STD-810G
	GPS						No	Yes	Yes
Comments									Wireless charging
TRL.	Consumer	9	9	9	9	9	9	9	9
	Industrial	6	6	6	6	6	6	6	6
Overall TRL	Consumer	9							
	Insdustrial	9							

Table 6. Smart-watches Comparison.

If we do not consider ruggedness certification, main problem for being used on the industrial shop-floor is the sizes of the screens: they are too small for being used with gloves. However, patents such as the obtained by Samsung [24], which is shown in Figure 5, are very promising. This patent aims to support the interaction with the watch using a projection of the screen on the user's hand.

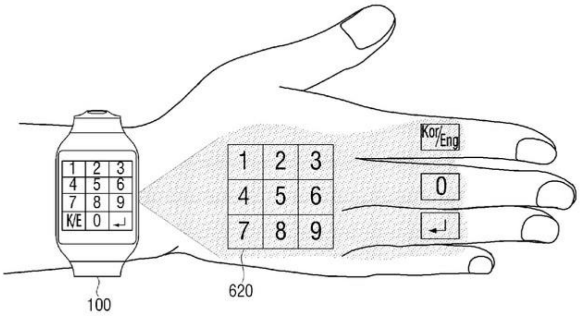

Figure 5. Samsung Patent for Interacting with Smart-Watches using Projection.

A more embryonic experiment is ViBand[3][4]. It is being developed by the School of Computing of Carnegie Mellon University. As it is shown by Figure 6, it tries to use IMU measurement for identifying some user movements in order to use them as commands for the smartwatch. Getting it requires the use of advanced IMU sensors which are not available for current smart-watches. In addition, required *intelligence* is provided by a desktop computer. In other words, implementing it will take a time and it will be limited by the size and weight requirements of the smart-watches which also limits their computation power.

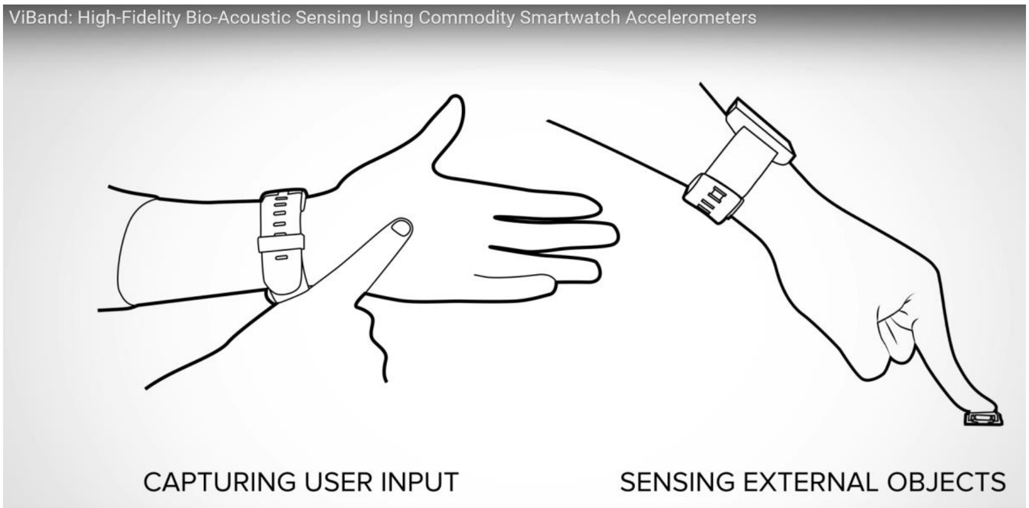

Figure 6. ViBand Prototype [4].

Limited computation power and limited power determine another disadvantage of smart-watches: most of them need to connect to another device (i.e a smart-phone or a tablet). The connected device acts as router for interacting with a cloud application or it provides computation power.

The consequence of the reduce capabilities of the smart-watches is that its use is reduced to notifying events to the user and to receiving feedback from the user using simple interaction schemas. This can explain why the sales of smart-watches reduced this year: smart-watches are not perceived as useful devices by users.

When we compare smart-watches with smart-phones or tablets, we can say they are less invasive. Smart-watches have a lower impact in the task under performance. However, they still require the worker to move their hand (making it difficult some tasks) and requiring changing its eyes attention.

2.2.2 Smart Glasses

As expected, the market for smart glasses constantly evolved during 2016. Previously announced devices finally became available as a product while a number of new devices have been advertised. While some new players entered the market there have been updates of existing smart glasses like the Vuzix M100 or the LUMUS DK-40. However, the perfect industrial smart glass that generally can be applied at the shop floor has not been invented yet. Nevertheless, a constant improvement towards smart glasses' industry readiness can be recognized. Especially in the area of augmented reality smart glasses a lot of innovation happened. In the following chapter, we're describing the most important updates from 2016 in detail and present an updated overview table summarizing the current smart glasses market.

Microsoft HoloLens

Microsoft announced the HoloLens back in January 2015, the device was finally available a year later at the beginning of 2016. First the smart glasses were only available for developers in USA and Canada, half a year later they were available for public in USA and Canada. Finally, in October 2016 Microsoft announced that it starts selling the devices in Australia, France, Germany, Ireland, New Zealand and the United Kingdom.

With $3.000 costs the device is positioned in the upper segment of smart glasses. It appears to be well manufactured, unlike some other smart glasses that still seem to be prototypes.

The main difference between HoloLens and other smart glasses is the number of built-in sensors. It rather appears like a pair of VR-glasses but actually is a real AR-headset. At the front of HoloLens two Kinect 3D-scanning modules are integrated the permanently scan the environment and build a virtual space. This is the technical foundation for the best AR implementation that smart glasses currently offer. Within this virtual space, augmented reality content is placed without jigger and with the additional capability to handle occlusions with the real world. Thus, 3D objects can be hidden behind real objects or attached to surfaces like walls. This is a unique feature that currently only HoloLens provides. There is no need for markers to enable augment reality tracking anymore.

The wearing comfort is good, although the glasses are quire heavy but well balanced. One major improvement that HoloLens introduces is the interaction concept. Unlike other smart glasses that use touch interaction, HoloLens uses gesture and audio control. Both input modalities are quite sophisticated and work intuitively. Gesture control is based on two gestures: the opening blossom and the finger tip. The first one is used to bring up the main menu at any time. This menu floats in front of the user and can be controlled by pointing and selecting via the finger tip gesture. This works really well after a short initial learning phase. Voice control is based on Microsoft's Cortana and works stable.

A downside of HoloLens is the fact that the display is not covering the user's whole view but only a certain area. Hence, like other smart glasses, HoloLens can't create a full immersive impression.

In summary, the HoloLens is currently the most sophisticated smart glass with real AR capabilities on the market. However, it is not a device that can be worn all day long due to its weight and also not during walking around on the shop floor, for example. Nevertheless, tasks like maintenance work or assembly steps could be well supported. Moreover, HoloLens provides great potential for training and simulation scenarios.

ODG R-7

ODG published their smart glasses called „ODG R-7"in 2016. They can be in a way compared to Microsoft's HoloLens but there are some major differences.

The ODG R-7 is available for a comparable price of $2.750. The smart glasses feature a stereo see-through display that supports 3D stereoscopic visualisation. The glasses are not as comfortable as the HoloLens, the weight seems not to be well distributed, hence there is a little too much pressure on the nose. It comes with the usual combination of sensors that are known from other smart glasses. The ODG R-7 runs a custom ReticleOS operating system atop Android Kit Kat.

One interesting accessory is the wireless finger controller. With this small ring that connects via Bluetooth Low Energy with the glasses, applications can be controlled in very intuitive ways. First, it allows interacting through a small touch pad on the ring. Further it can switch to gesture mode that uses the ring's integrated sensors to detect the user's hand movement. Both ways of interacting work quite well. And still enable hands-free control.

The ODG R-7 also supports gesture control via third party software. First tests proved that gesture control works, some gestures like "thumbs up" work really well, others are rather weak. There is no native voice control supported.

The big difference compared to the HoloLens is the performance of augmented reality applications. The ODG R-7 originally features Qualcomm Technologies Vuforia Mobile Vision Platform for enabling augmented reality. This framework works generally well for augmented reality but relies on a standard single camera tracking. HoloLens instead uses two Kinect 3D-scanning modules and therefore provides a more stable and accurate tracking. The difference is obvious when interacting with augmented reality content. On the ODG-R7 there is a noticeable jitter, objects don't appear to stick to their location. With the HoloLens, this effect doesn't appear and in addition objects can be occluded by the real world which provides a way more realistic AR impression.

In overall, the ODG R-7 are a pair of interesting smart glasses for the industry. They are an alternative to Microsoft's HoloLens, although their Augmented Reality capabilities can't compete with the HoloLens.

Vuzix M300

Vuzix has been one of the first players on the smart glasses market with their M100 smart glasses. For a while, these glasses have been one of the few alternatives for the Google Glass. In 2016, Vuzix announced the update of the M100, now called M300. There have been some improvements that are directly addressing the industry readiness of these smart glasses.

For instance, the M300 features a hot-swappable battery that supports longer work shifts. Moreover, the display can be rotated out of the user's field of view which is a comfortable feature if not using the glasses for a while. Interaction is supported via Voice, button press, and a new touch pad with gesture controls. The M300 is ruggedized against water, dust and dirt. In addition, the camera has been upgraded to 13 megapixel photo and 1080p video capability. Especially for documentation tasks or video support cases this is a very important improvement. With these specifications, the M300 currently features the best camera on the market.

Vuzix's focus with the M300 is clearly enterprise applications. They consequently improved the M100 in critical points where industry requirements weren't met in the past. The glasses are shipping in fall 2016, so the first pilot tests on the shop floor will prove if the update can deliver on this promise.

Recon Jet Pro

Recon Instruments announced a variation of their already existing Recon Jet smart glasses called Recon Jet Pro. The hardware of both smart glasses is the same, but the Recon Jet Pro is tailored for industry use while the Recon Jet was addressing the sports and activity sector.

Recon Jet Pro removes all the sports/activity tracking apps and launcher. It's built for enterprise deployments where users would launch directly into an enterprise software solution. Moreover, Recon offers an enterprise development kit for building software on the Recon Jet Pro. It includes features such as a white label launcher and WebRTC video optimization instructions, especially interesting for remote video support use cases.

Lumus DK-50

The update of the Lumus DK-40 has been announced at CES 2016. The new smart glasses called DK-50 will feature a binocular 720p display with a large 40-degrees FOV. Compared to other smart glasses providing 15 or 20 degrees FOV, this is a huge improvement. As mentioned earlier about the HoloLens (featuring 20 degree), the small FOV is currently one of the main drawbacks for Augmented Reality applications.

In addition, atop the frame of the DK-50 is a stereoscopic camera array and an Inertial Measurement Unit (IMU), with an onboard Qualcomm Snapdragon processor running Android for markerless augmented reality. With this combination, the DK-50 is able to support Augmented Reality without any markers. The InfinityAR system can identify elements of the surrounding environment.

Lumus is not creating product level smart glasses its own – they are selling their display technology to third-party manufacturers who package it and produce smart glasses products. This is the reason why Lumus only shows reference designs to demo the technology.

EPSON Moverio BT-300

EPSON updated it's already second generation Moverio BT-200 in 2016 and announced the new Moverio BT-300. The improvements include a new OLED-display and a reduced weight of 70 gram. The smart glasses still are connected to a portable computer via cable.

ChipSip SiME

With ChipSip, a Taiwanese company, a new player appeared 2016 on the smart glasses market. They are selling a developer version of a smart glass called SiME that is similar to Google Glass. However, it seems like SiME is still in a very early stage, since the hardware appears rather like prototype than a product. The design is quite bulky and lacks important adjustment options that make it quite uncomfortable to wear.

On the right frame side the SiME features a touchpad. However, navigating the cursor with the touchpad is really cumbersome. One benefit of the SiME is the fact that it runs a full Android 4.4 and therefore any app. However, the standard Android interface is not tailored for the small display and in combination with the difficult to use touchpad the experience is not convincing.

	Name	Daqri Smart Helmet	Recon Jet Pro	Vuzix M3000	Lumus DK-50	GlassUp Industrial	Moverio BT-300	Shinma-Lagforge	ODG R-7	ChipSip SiME	Hololens
Features	SDK	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes
	M/B	B	M	M	B	B	B	M/B	B	M	B
	Resolution		428x240	640x360	720	640x380	1280x720		720	800X480	
	Battery (h/ mAH)	12/	5/	12/100-5000	4/	12/4000			/1300	/610	2/
	Int. Memory (GB)		1	2				1	3	1	2
	Memory(GB)		8	64		1		8	64	8	64
	Speaker/Micro.		Y/Y	Y/Y		Y/Ys		Jack	Y/Y	Y/Y	Y 4/Y
	WiFi		Yes	Yes					Yes	Yes	Yes
	Microphone		Yes	Yes		Yes			Yes	Yes	4
	Bluetooth		Yes	4.1		Yes		4.1	4.1	4.0	4.1
	Others		ANT+			Thermo camera					
	Weight (gr)	997	60			70	59				579
	Others		ANT+			Thermo camera					
	Availability	Preor.	Avai.	Preor	Avai.	Preor.	Preor.	Beta	Avai.	Dev. Version	Avai.
TRL	Consumer	5	5	8	8	5	6	5	7	7	7
	Industrial	5	5	7	6	5	5	5	5	5	5
Overall	Consumer	9									
	Industrial	7									

Table 7. Smart-glasses Comparison.

Since ChipSip is currently only selling development version of the SiME there might be some improvements in the future until the final product comes to market.

Table 7 provides information about the introduced smart-glasses as well as other which were introduced in D2.1.

2.2.2.1 Industrial Readiness Analysis

Smart glasses are one of the emerging technologies that are very promising for industry applications. The technology constantly advanced from prototypes towards product-level devices with a clear focus on industry use cases and according features. However, as initially stated, there is not one single product that can be recommended in general for all possible scenarios. Looking at the main differences of available smart glasses, there are three categories that should be considered when planning to use smart glasses in industry settings:

- Monocular smart glasses, using different imaging technologies (projection, LCD) with relatively small screens that are often placed in the peripheral line of view. Therefore, these devices are well suitable for casually checking information since they don't consume the user's whole field of view. On the other hand, one must actively look at the screen which is tiring over the time. A benefit of these smart glasses is that they often can be used in combination with prescription lenses and security glasses. Moreover, these devices generally are the lightest compared to the other two categories.
- Binocular smart glasses use (nearly) transparent displays for displaying information. Due to their design, they offer a much more immersive visualization experience for the user compared to monocular smart glasses. On the one hand side this offers enhanced options for displaying more complex information since the screen is considerable larger. On the other hand, the user is more distracted from other tasks and therefore cannot seamlessly perform his traditional work. Summarizing, this type of smart glasses is well suited for training, planning and simulation scenarios but only limited for tasks on the shop floor.
- Smart helmets are a special type of smart glasses that provide advanced capabilities such as longer battery life, more computation power and eventually more sensors. However, one must consider the special form factor that combines the displaying unit with a helmet and therefore prevents wearing of standard safety helmets. This fact might influence the decision to apply a smart helmet within an industrial setting.

Depending on the use case and the related requirements, one of the above mentioned types of smart glasses can add real benefit. Nevertheless, using smart glasses should always be motivated by the use case itself and not only by the intention to use cutting-edge technology. It might also turn out that smart glasses are used in combination with other mobile devices such as mobile phones or tablets. With this combination, each of the devices can support the worker through its individual strengths.

For the near future, we expect an ongoing trend of product updates on the smart glasses market. Most likely the current focus on industry use cases will be intensified since the advantages for certain domains are obvious. With this development, there will be advancements especially concerning battery lifetime, camera resolution, display size and resolution as well as rugged designs.

2.2.3 Hearables

As introduced on the previous version of this report, hearables promise a no intrusive way of HMI with the advantage of providing best self-awareness data than other devices due to their location. Nonetheless, there are not too many hearables that can be considered smart devices [1]. From the list it is provided there, we believe just The Dash, Moto Hint and Gear IconXcan be considered smart devices as they provide interaction capabilities with the associated device.

From the devices considered on previous release, it must be remarked that Elbee was discontinued a couple of years ago.

2.2.3.1 Industrial Readiness Analysis

There are not too many news about hearables during last year. All of them use a smart-phone as access point and so they can be considered not a complete smart-device. In any case, the apparition of new players, such as Samsung seems to be an indicative of the industry interest on it.

Probably this interest is based on some relevant features they present. On the one side they provide a very accurate measurement of the biometric values of the user. Moreover, in combination with the data gathered by a smartphone or a tablet, they can position very correctly the view point of the user which is really valuable for creating better Augmented Reality applications.

Finally the probability of filtering noises, listen both to the environment and another people talking to the worker provides high potential to be used on the shop-floor but first they must be certified both considering their rugged level but also for guaranteeing worker security.

Features	Name	Elbee	The Dash	Moto Hint	Gear IconX
	Producer	Elbee	Bragi	Motorola	Samsung
	Status	Beta	Production	Production	Production
	SDK	Yes	N.A.	N.A.	
	App Customisation	Yes	Yes (under development); iOS Android, Windows Mobile	Yes (iOS, Android)	
	IMU	Nine-axis accelerometer, two movement processors	Three-axis accelerometer, three-axis gyroscope, three-axis magnetometer	N.A.	HR, Accelerometer, Capacitive Touch
	Memoryv (GB)		4		
	Interaction	Capacity sensors, voice, proximity sensor on/off	Capacity sensors, voice, proximity sensor on/off, gesture interaction	Proximity sensor on/off	Touch
	Communication	Two devices, active noise reduction, voice triggering, speech recognition,	Two devices, active noise reduction, audio transparency (ambient sound)	One device, noise reduction and echo cancellation; volume and mute controlled through phone; advanced multipoint - simple pairing of secondary devices; pass through audio	
	Additional Capabilities	text-to-speech			
	OS Compatibility				Android 4.4 KitKat+
Comments		Home automation	4GB internal storage, heart rate, steps, duration, 1 m waterproof		Water Resist. Properly speaking they are more advance headphones than hearables.
	Discontinued	01/04/2014			
TRL	Consumer	5	9	9	5
	Industrial	5	6	6	5
Overall	Consumer	9			
	Industrial	6			

Table 8. Hearables Comparison.

2.3 Cross-Platform (CP) Software Environments

Not too much news within the Cross-Platform SDKs. The only exception is the discontinuation of Marmalade by the beginning of 2017. Apart from this, most of the SDKs update their releases during this year. Most of them provide a hybrid way to implement the application by running Javascript and HTML5 applications on environments which support the access to the native resources.

Their main features are presented in Table 9. This table also include WebRTC. Properly speaking it is not a cross-platform SDK. It is a library providing interesting BBs enabling high quality communications on the web (network, video and audio) using browser plug-ins.

2.3.1.1 Industrial Readiness Analysis

Although Marmalade is going to be discontinued next year, cross platform development seems to be a quite market, at least when comparing with others (i.e. AR SDKS) where there are more discontinuations and new players.

As it happens with other types of SDKs there are OSS and commercial solutions. In this case, both of them provide the same TRL level in the commercial market but there exist more differences in the industrial one and just some of the SDKs show use cases, customers or users of the industrial sector. Probably as the Industry 4.0 solutions will get implemented these industrial use cases would appear.

An important issue to be considered is that some Augmented Reality SDKs can be used in combination with Unity. It is particularly important for the implementation of cross platform Augmented Reality applications. When it can be seen as an advantage because unity is really good for rendering 3D objects on different systems, it must take under consideration that Unity does not provide an easy way to create “classical forms” for gathering information from the user.

Name	Version	OS/Platf.	Programm. Language	License	Disconti. on	TRL Consumer	TRL Industrial
jQuery	v3.1.1	iOS, Android, WP8, HTML5	JavaScript	Apache License, Version 2.0		9	5
Adobe Air	V20.0	Windows and Mac OS, iOS, Kindle Fire, Nook Tablet, Android	Flash/ActionScript or HTML/JavaScript	Free for most users		9	5
Appcelerator Titanium	6.0	iOS, Android, WP8	JavaScript	Commercial		9	7
Marmalade	v8.2.1	iOS, Android, WP8, HTML5	C/C++	Commercial mobile is free with ads	March 2017	9	5
PhoneGap	0.41	iOS, Android, WP8, Windows 8, Mac OS 10.9	HTML/JavaScript	Apache License, Version 2.0		9	5
Qt	v5.5	iOS, Android, WP8, HTML5	C++	Dual-licensed commercial and OSS (LGPLv3).		9	6
Unity 3D	5.4.2	iOS, Android, WP8	Jscript, C++	Commercial (free for developing)		9	7
Corona	2016.2949	iOS, Android, WP8, W10, Kindle, HTML5	C++/OpenGL	Commercial (free)		9	5
Xamarin	6.1	iOS, Android, WP8, HTML5	C#	Commercial (free for OSS development)		9	8
Sencha Touch	6.2	iOS, Android, WP8, HTML5	HTML5/Javascript	Commercial		9	6
Angular 2	2.1	Windows, Linux, Mac,	TypeScript, Java Script, Dart	MIT		9	7
WebRTC	5	Implemented by browseron Windows, Android, Google Chrome	JavaScript	Commercial (royalty free).		9	6

Overall	
Consumer	9
Industrial	8

Table 9. Crossplatform SDKs comparison

2.4 Data Visualisation SDKs.

As introduced in D2.1 Data Visualization SDKs are a set of tools specialized in the graphical presentation of data in order to simplify its interpretation but also to allow navigate through the data. Table 10 presents some of the relevant visualization frameworks which can be considered when implementing the FACTS4WORKERS solutions. The table is based on the one presented in D2.1 which is updated and extended.

The table only shows the SDKs which are not discontinued when the report is created. If it is compared with the one we included in D2.1, at least nine of the existing SDKs were discontinued. All of them were OSS software. This highlights the risks of using this kind of software when they are not supported by a (big) community.

A first read of the table shows that most of the SDKs are libraries which can be used by programming in Javascript but also Java, Python and PHP. When most of the OSS libraries are provided as libraries, most of the pure commercial ones are provided as SaaS. This is an important issue to be considered because it will require the data to travel to the data visualization service server as well as to the visualization device. This will compromise data security and performance and it can be a handicap to be considered when considering the SaaS option.

It must be remarked that the documentation of the use of the existing libraries in industrial shop-floor is not provided neither by the OSS or the Commercial SDKs. Probably it is due to the fact that until now the presentation of visual data is not considered a worker requirement when it's for the management staff.

A final issue is that there is not a clear link between this SDKs and AR SDKs. This link exists with Cross-platforms SDKs.

2.4.1.1 Industrial Readiness Analysis

There exist a lot of SDKs for graphically presenting data and supporting the user interaction with it. While both OSS and commercial solutions seem to have a 9 TRL in the consumer market, just the commercial solutions reported industrial use cases and, in consequence, can obtain a high TRL level. Probably this is due to fact that Industry 4.O, and worker centred solutions are in a very early stage of development.

Most of the OSS SDKs use Javascript for programming the applications and they are released as libraries. This guarantees the possibility to use them in different platforms and to be used within other SDKs as the ones presented in chapter 2.3.

2.4 Data Visualisation SDKs.

	Features					TRL		Comments
Name	Programm. Language	License	Version	Type	Supported OS	Consumer	Industrial	Comments
Circos	JavaScript, Perl	MIT	0.69	Library	Windows, Unix	8	5	Circular charts
D3.js	JavaScript	BSD	4.3.0	Library		9	5	Several charts
Google Chart Tools	JavaScript	Free to use		Library		9	5	
Google Fusion Tables	JavaScript, Flash	Free to use		API, Desktop		9	5	
JavaScript InfoVis Toolkit	JavaScript, Python	MIT	2.0.1	Toolkit		8	5	Several charts
NVD3.js	Java	Apache	1.8.4	Bookmarked on d3.js		8	5	Based on d3.js
Paper.js	JavaScript	MIT	0.10.2	Library		7	5	
Peity	JavaScript	MIT	3.2.1	Library		7	5	Pie charts
Prefuse	Java	BSD		Library		8	5	
Processing	Processing, Java, Python	GPL	3.23	Programming Language		8	5	Several charts
Processing.js	JavaScript	MIT	1.6.3	Library		8	5	
Rickshaw	JavaScript	MIT	1.6.0	Library (on d3.js)		9	5	Based on d3.js
Sigma.js	JavaScript	MIT	1.2.0	Library		9	5	
TimeLine.js	JavaScript	MPL	3.3.13	Library		9	5	SaaS, Time line series visualization
Vega	JavaScript	BSD	3.0.0	Library		9	5	Several Applications
Visage	JavaScript	Commercial		Web Application		9	5	SaaS
ZingCharts	JavaScript	Commercial	2.5.0	Library		9	5	
IBM Watson Analytics		Commercial				9	9	SaaS,
KeenIO	JavaScript, Rubi, Python	Commercial			Windows, unix, android	9	9	SaaS
BabylonJS	JavaScript, Typescript	Apache 2.0	2.4.0	Library		8	5	Unity, 3DS Max API, mainly for VR
Threejs	Javascript	MIT	82	Library		8	5	
R	R	GPL	3.3.2	Programming Language		9	5	Several charts
Mapbox		Commercial	0.26	Library		9	8	
					Overall	9	9	

Table 10. Data Visualization SDK.

Most commercial solutions are offered as services. This means data should be transported to the server and, in consequence, it could compromise both the security of the data and the performance of the application.

A special issue to be considered is there is not a clear connection with the Augmented Reality SDKs. This could represent a problem for the development of this kind of applications.

2.5 Augmented Reality

If we do not consider Pokemons, there has not been too much news within the Augmented Reality SDKs during the last year in particular within the SDK area. There are a lot of different development frameworks [6] and although big players (such as Google, Microsoft and Apple) demonstrate their expectations and interest in the future technology impact, their actual proposals are close related to the provision of a device together with some APIs for working with them.

Table 11 is an update of the one provided in D2.1 corroborating the fact of not too much news within the AR SDKs. We can divide these tools in 3 different groups.

First, we can consider the "*general purpose tools*": SDKs which support the creation and execution of AR applications which are independent of the device. ARToolkit, Aurasma, NXT, Vuforia or Wikitude are included in this group. Their applications can run in tablets and smart-phones and some frameworks start to incorporate support for smart glasses, i.e Wikitude.

An interesting issue to be considered is that some of these general purpose frameworks such (i.e. ARTToolkit, Vuforia, Wikitude or Tango) already include APIs to integrate them with Unity developments. By creating this symbiosis both the VR world created by Unity and the AR ones will converge in a Mix Reality which can be to support needsof the worker on the shop floor. Unity will be used for render in real time 3D figures while the AR frameworks will be used for tracking user movements and use them to transform the projected reality.

A second kind of AR toolkits is the ones offered as SaaS. In this group they are included Zappar, Total Immersion, Hoppala, Catchcoom or Aurasma. They provide a user interface for creating AR based on the identification of a marker or a picture by browser applications. While they are very easy to use, they have low flexibility and they are designed more for catalogue visualizing and advertising than for a real AR application.

The third group of SDKs is the one which provide together a specific hardware and a SDK. Daqri and Tango belong to this group. The first provide a SDK, based on ARToolkit, and a helmet to be used to interact with the user. The second provides a tablet with "special" sensors (such as 3D cameras for tracking) and an API (for Unity, Java, C) for execute the AR application. While they can be consider similar to the first group of SDKs, the assumption of use of a particular device will limit the applicability of the developed applications. On the other side, the use of particular sensors (not commonly included on common smart-phones or tablets) will allow more innovative ways of HMI.

	Features				TRL Evaluation	
Name	Version	Features	Platform	Licensing	Consumer	Industrial
ALVAR	2.1	Marker, NF	Android, iOS, Windows, Flash	Comm. and Free (GNU LGPL 2.1)	5	5
ARLab	N.A.	GPS, IMU, VS.	Android, iOS	Free, Comm. SDK	7	5
ARmedia	2.1	Marker	Android, iOS, OS X, Windows, Flash	Free, Comm. SDK	7	5
ARToolkit	5.3.2	Marker, NF, GPS and compass, camera calibration, OST.	Android, iOS, Linux, OSX, Windows	OSS, Comm. SDK, LGPL3	7	5
ArUco	2.0	Marker	Linux, OSX, Windows	BSD	5	5
Aurasma		NF, VS.	Android, iOS	Free, Comm. SDK	7	5
Beyond Reality Face	3.0.16	Face tracking	Flash, HTML5, Adobe Air, Ios, Android	Comm. SDK	7	5
Catchoom		VS	Android, iOS	Free, Comm. SDK	7	5
DAQRI 4D Studio		VS, ContentAPI, NF.	Android, iOS	Free, Comm. SDK	7	5
HOPPALA		Content API	Android, iOS	Free, Comm.	7	5
IN2AR		NF	Flash, iOS, Android	Free, Comm.l SDK	5	5
Instant Reality	2.8.0	Marker, NF, GPS, IMU, face tracking, VS, content API, SLAM, tracker interface	Android, iOS, Linux, OSX, Windows	Free, Comm. SDK, Closed source	7	5
Koozyt		Marker	Android, iOS	Comm. SDK	7	5
Layar		NF, GPS, IMU, VS, content API	Android, iOS	Free, Comm. SDK	7	5
Mixare	0.8.2	GPS	Android, iOS	OSS, GPLv3	4	4
Rox Odometry SDK		Marker, NF	Android, iOS, Linux, OSX, Windows	Free, Comm. SDK	7	5
Total Immersion		Marker, NF, face tracking	Android, iOS, Windows, Flash	Free, Comm. SDK	7	5
Vuforia	6	Marker, NF, VS	Android, iOS	Free, Comm. SDK	7	5
Wikitude	5.3	GPS, IMU, content API	Android, iOS, BlackBerry OS	Free, Comm. SDK	7	5
ZappCode Creator		Marker, image tracking	Android, iOS	Comm. SDK	6	5
			Overall Evaluation		7	5

Table 11. AR SDK Comparison.

2.5.1 Industrial Readiness Analysis

When comparing Table 11 with the one provided in D2.1 the first thing we can see is that current table is smaller. Some of the SDKs included in the first release of the table were discontinued and we do not consider them in this release. As we advised in D2.1 (and probably also goings to happen with devices) it is foreseeable in the near future this enabling technology become stable.

For the survival SDKs we can differentiate two main trends. On the one hand there are the SDKs which are provided as SaaS and on the other hand there are the ones which are provided as a SDK in the classic meaning of the term.

SaaS SDKs are licensed software. Most of them provide an environment which allows the creation of contents and interaction flows. While these SDKs are facing one of the challenges AR frameworks should solve in the near future, the generation of the content by the user, they are very restricted in the kind of contents that can be used and the interaction capabilities they provide. In consequence, they limit possible applications to watching catalogues in 3D or showing very simple 3D models. In other words they can difficult be used for implementing shop-floor solutions.

"*Classic SDKs*" provide a programming environment and a deployment runtime. Although there are OSS and commercial SDKs, many of them provide both kinds of licenses. This will help developers to test (even to prototype) the framework and move to the license schema when a support for production will be needed.

If we consider the capabilities of this second kind of SDKs, they provide more rich interaction capacities, they increase the flexibility for creating new applications and most of them run on different operating systems. However, most of them do not run on smart-glasses. Some of the frameworks try to face this problem by integrating with Unity which, as a cross-platform, provides portability to the applications, the 3D rendering of the images to project and even of the data stream from the server.

We already said that this second type of SDKs provides flexibility for creating different applications. It's the good news. The bad news is that for the moment the application must to be created by a programmer. Daqri 4D Studio tries to solve this problem although it is not available at the moment. Another problem to be solved, for example when creating maintenance AR applications, is the automatic transformation of CAD models to more simple models which can be rendered by the available devices (which will have less computation power, memory capacity and storage capacity than the computers used for creating the models).

Also related with 3D model is the issue of integrating the 3d data stream with the data coming from Cyber-physical-systems or enterprise systems. How it must be showed and how it can be manipulated by the worker is something does not seem to be well solved by existing systems.

Finally it must be remarked that more advanced devices for running Augmented Reality Applications currently are smart-phones and tablets as they provide the required computation, memory, storage and networking. Smart-glasses are still under development. If we look to all the Augmented Reality technologies with perspective, they are advancing fast but not as fast as we all would want them to be.

3 Conclusions

This document presents the results of the work we performed in task T2.1 of WP2 of FACTS4WORKERS. During this year, our work focused on two main issues. At first, we worked for improving the process of creation, population and evaluation of the enabling technology taxonomy we created when developing D2.1. Then we worked on the update of the first version of the taxonomy, its evaluation and finally we created this report. These paragraphs summarizes the conclusions we achieved during the whole process and whereas we wrote this document.

3.1 Evaluation Methodology

Here we consider the methodology we created for evaluating of the enabling HCI /HMI technologies which could be used by FACTS4WORKERS solutions. In D2.1 we based the evaluation on the TRL level as defined by the European Commission. One of the goals of the FACTS4WOKERS project is to provide solutions which are between the levels 5 and 7 of the TRL scale which will require at least the same TRL for the enabling technologies.

But, how can we objectively evaluate the involved technologies? Is it possible to provide a way for subsuming the evaluation of a high level technology based on the evaluation of the enabling technologies it uses?

The answer to the first question comes from the revision of the existing TRL methodologies. The TRL model was developed by the NASA 40 years ago. It has been adapted / adopted by the ESA and, probably because of the high requirements of the space industry, it was adopted by the Commission for evaluating the founding of projects.

The aim of the TRL model is to allow the evaluation of the risk level associated to the use of a given technology for solving a technical problem. Both NASA and ESA deploy guidance for performing the evaluations. However, the proposed process can be complex and tedious for organizations having resource restrictions. As the model became interesting for other sectors, it was argued that it must be simplified for being applicable. We worked on it and the results were presented in chapter 1.1.3.

The second issue the subsumption of the evaluation process was already presented in D2.1. During this year we improved the tool we created for the evaluation which is publicly accessible [22].

When we used the methodology and we reviewed existing literature, we found new opportunities of improvement. Some of them have already been implemented and others will probably be implemented during the creation of the next year report. Some of the more relevant for being implemented are:

- Provide a method for clearly determine the needed enabling technologies;
- Extend the evaluation model created in chapter 1.1.3 to the levels 1 to 4;
- In general, improve TRL rules in the sense of making them more objective in order to improve the quality of the results of the evaluation;
- In order to improve the quality of the results (and of the methodology) it would be interesting to include a peer review of the evaluation as suggested by the existing guidance (individual, group, etc.);
- Analyze other subsumption evaluation possibilities

3.2 Enabling Technologies Evaluation

The population and evaluation of the taxonomy were developed in parallel with the redefinition of the taxonomy. This allowed us to validate the taxonomy, the already identified evaluation rules and whatever made us question something look for possible answers and solutions, in other words improve the taxonomy.

Table 12 shows the current taxonomy evaluation presenting the same levels as Table 1 in order to support the comparison of the assessment TRL levels.

Within Table 12 values which are being updated are labelled green. They mainly belong to the *HCI Systems* branch. The only exceptions are the *Speech Recognition* and the *Text to Speech* nodes which belong to the *HCI Enabling Technologies* branch.

The taxonomy does not only include hierarchical relations, it also includes transversal relations. They mean a given technology use other technologies. One of these relations exists between *Text Entry* node and *Speech Recognition* node. This relation explains why *Text Entry* is updated in the current taxonomy. The rest of the intermediate nodes modifications are explained by the re-evaluation of the leaves belonging to them as explained in chapter 2. Finally it must be signalled that the *Data Visualization* sub-taxonomy was simplified eliminating the nodes shown in Table 1.

HCI Technologies			TRL Assessment	
Level 1	Level 2	Level 3	Consumer	Industrial
HCI Single Technologies			7	5
	Conventional Technologies		7	6
		Text Entry	8	6
		Display Devices	7	5
		Screen Positioning, Pointing and Drawing Technologies	8	5
		Printers	8	8
	Touch-sensitive Screens (Touchscreens)		9	7
	Image and Video Devices		9	7
		2D	9	9
		3D	9	6
	Computer Vision		6	4
		Recognition.	6	5
		Motion Analysis	6	4
		Scene Reconstruction	5	5
		Gesture Recognition, Behavioral or Gesture Analytics	7	4
		Eye Tracking	7	3
	Audio Input/Output Technologies.		8	7
		Speech Recognition	8	8
		Text to Speech	8	7
	Context Awareness Technologies		5	4
		Positioning, Location and Identification Technologies.	7	5
		Qualified Self	5	5
		Emotion Detection, Affective Computing, Mood Recognition	4	4
	Haptic Interaction		9	9
	Brain Computer Interaction		3	2
HCI Systems.			8	6
	Mobile Devices		9	7
		Mobile Devices	9	6
		Rugged Mobile Devices.	9	9
	Wearable User Interfaces.		7	6
		Smart Watches	9	7
		Smart Glasses	9	7
		Hearables	9	7
		Smart Clothing	3	3
		Nearables	9	9
	Cross Platform (CP) Software Environments		9	7
		Smart Operating Systems.	9	5
		CP Development.	9	9
	Data Visualization		9	9
	Augmented Reality		6	5
		Augmented Reality Tracking Techniques	6	5
		Interaction Techniques and User Interfaces	6	5
		Augmented Reality Display Technologies	7	6
		Augmented Reality SDKs	7	5

Table 12. Taxonomy 2.0 Evaluation.

As expected, if we compare Table 1 and the current Table 12 most of the taxonomy nodes increase or maintain their TRL levels. The only exception is the Consumer evaluation of the *Text to Speech* node that can be explained by the application of more objective rules for evaluating its TRL. In any case, the evaluation is only reduced from 9 to 8.

If we try to interpret the TRL values from a general point of view, as it happened when we did it for creating D2.1, there is a clear differentiation between the TRL level in the Consumer and in the Industrial fields. As we argued in chapter 2, there is a lack of real demonstrations for most of the technologies in industrial environments. It is probably due to the fact that requirements for the devices are higher than for those in the consumer marker (although we think industrial requirements should also be considered for guaranteeing common users integrity).

Even considering the difference level between consumer and industrial TRL levels, our current evaluation shows an industrial TRL level bigger than 5 for most of the technologies and, in consequence, we think they can contribute all the FACTS4WORKER solutions get a TRL level higher than 5. There are some exceptions (*Emotion Detection*, *Eye Tracking*, *Gesture Recognition*, etc.) but we think they do not have influence in the developments.

When analyzing the HCI System Branch we can observe two main tendencies. On the one side consolidated technologies in the Consumer market are also consolidated in the Industrial market. *Mobile Devices, Cross Platform (CP) Software Environments* and *Data Visualization* demonstrate it. In the other side less mature technologies in the Consumer market are also less mature in Industrial market as shown the evaluations of *Wearable User Interfaces* or *Augmented Reality* nodes.

Augmented Reality node requires a more detailed analysis. While the software technologies for deploying "*Augmented Reality Applications*" have evidences of being in a high level of maturity (in the Consumer market), the other 3 technologies (which are hardware supported) do not provide evidences for demonstrating they are at the same level. As a consequence the TRL level for the Consumer and the Industrial market are respectively estimated as 6 and 5. In other words, initiating an Augmented Reality project is currently a high risk project. However as we said in chapter 2.5.1 we can mitigate the risk by considering the use or less advanced devices (such as smart-phones or tablets) and programming thinking in the future.

Although this report aims to provide a general view of the state of the art of the HMI/HCI technologies during the execution of FACTS4WORKERS, we think it would be interesting to provide some paragraphs relating these conclusions to the HMI/HCI technologies which are being used for implementing the use cases defined in WP1.

D1.4 [26](which was in progress simultaneously to this report) provides the most recent review of the industrial challenges which are handled by the FACTS4WORKERS project. From the HMI/HCI perspective, the following technologies are required: data visualization technologies (for supporting worker's analysis), data introduction technologies (for support worker's –real time-interaction with the system and other colleagues), context awareness (for determining the work place environmental conditions) and AR technologies. All they are reflected in current taxonomy.

When considering these technologies from the implementation and deployment persepective (workpackages 2 , 3, 4 and 5) some of the technologies have already been selected. For selecting them, there were considered: previous release of the taxonomy [13], the industrial partners understanding of the technologies depicted on the taxonomy and the overall REST architecture of the building blocks.

For example, following these criteria, Angular 2 was proposed and selected as the main platform for implementing general worker interaction with the provided solutions. Main reason is it is a crossplatform hybrid SDK and, because it is based on Javascript, it can be easily integrated with many data visualization SDKs. Moreover it can be integrated with AR SDK which run on Javascript or it can be integrated with Unity 3D too. It will allow us to (easily) extend functionalities as they would be required by the industrial partners and they would be supported to be used on the shop-floor by the available technologies. In other words, it will support the perpetual beta of the HMI/HCI developments.

Angular 2 is being used for implementing interactive mock-ups and prototypes of the current solutions provided by FACTS4WORKERS. Proceeding this way we ease the discussion with the workers. By presenting current developments on a tablet or smartphone we can visualize our interpretations of worker needs. The implementations create reference points both for discussion and for observation of the use which will allow feeding work packages 1 and 6.

In the same direction tablets and smartphones are being used because they can be considered mature technologies, both from their rugged certifications but also, and more important, because their general acceptance (on the consumer market). They can be used for running most of the applications available nowadays and, as they are well known and accepted by many workers, it is easier to explain their use and we can focus on the implementation of the Industry 4.0 worker-centred challenges.

Simultaneously, new emerging technologies (such as smart-glasses) will become more popular and can be potentially applied as complementary technologies for the industrial challenges.

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ABOUT THE PROJECT

- Personalized augmented operator,
- Worked-centric rich-media knowledge sharing management,
- Self-learning manufacturing workplaces,
- In-situ mobile learning in the production.

PROJECT PARTNERS

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

Virtual Vehicle Research Center	Austria
Hidria TC Tehnološki center d.o.o.	Slovenia
Universita degli Studi di Firenze, Department of industrial Engineering	Italy
Technische Universität Wien	Austria
ThyssenKrupp Steel Europe AG	Germany
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Technology Monitoring: Report on Information Needed For Workers in the Smart Factory

D2.2, Technology Monitoring: Report on information needed for the Industrial Challenges workers with taxonomy is part of the work in progress of FACTS4WORKERS. T2.1 is an activity of WP2 aiming to highlight the current state of the applicable technologies (both hardware and software) which can be used for implementing Worker Centred Industry 4.0 solutions, which are already applicable and under which risks.

D2.2 advance in objectively answering questions like: Which are the available HCI enabling technologies that can support the creation of Worker Centred Industry 4.0? Have the available HCI enabling technologies a TRL enough for supporting FACTS4WORKER goals? Is it possible to objectively determine the TRL level of a technology? Which is the TRL level of a system of technologies? Once we evaluated our technologist of interest, how we can read it?, Which are the conclusion we can obtain from it?.

D2.2 takes D2.1 as base for answering these questions. We tried to answer them by following an iterative three steps process: define a methodology for creating, evaluating and reading a taxonomy of (HCI) enabling technologies; apply the methodology for creating a taxonomy; use the not clearly resolved issues or not resolved at all ones by the methodology to identify opportunities of improvement of the methodology

This report summarizes the work we did during last year. It redefines the methodology introduced in D2.2, it applies the methodology to the FACTS4WORKERS project and it shows our conclusions about the industrial readiness of the technologies of interest and about the methodology.

The FACTSTWORKERS taxonomy is published as a digital appendix of this report (please, see references).

FACTS4WORKERS