Abstract

Smart factories are characterized by increasing automation and increasing customization. In these dynamic environments flexible and adaptive work organization is crucial, both for productivity and work satisfaction.

The Factory2Fit project will support this development by developing worker empowering workplace adaptation solutions as well as engaging solutions for participatory design, knowledge sharing and learning. With the Factory2Fit solutions people with different skills, capabilities and preferences can become motivated and productive members of the work community in manufacturing industries.

This deliverable describes the adaptation concepts that the project is considering, based on thorough analysis of industrial needs.

Keywords: Adaptation, quantified worker, participatory design, knowledge sharing, training, learning at work
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement no 723277
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Executive Summary

In the Factory2Fit project, we aim to take human-centered manufacturing to a new level by giving the factory workers a leading role in adapting and developing their own job. The objective of the project is to develop and pilot adaptive human-automation interaction solutions that improve the flow of working, support the worker in understanding and developing his/her competences and engage workers to share knowledge and to participate in designing their own work and training. This will support our vision of smart factories of the future that will fit perfectly for workers with different skills, capabilities and preferences. Adaptive automation supports fluent human-automation cooperation and supports current and forthcoming workers to develop their competences to become smart, satisfied knowledge workers of future factories.

In this deliverable we have introduced the adaptation concepts that Factory2Fit project is proposing based on a thorough analysis of industrial needs. The concepts have been developed in close collaboration between the industrial partners Continental, Prima Power and UTC, who will provide the pilot environments for the forthcoming development of the concepts, and all the other Factory2Fit project partners. The main principle is that the worker is an expert of his/her own job and thus (s)he shall have an active role in the adaptation. The adaptation solutions are divided into two main categories: solutions to empower the worker and solution to engage the work community.

Empowering the worker solutions are based on a worker model. This category includes three concepts: 1) a Worker dashboard to give the worker motivating feedback of his/her well-being and performance; 2) an Adaptive user-machine interaction for personally and situationally relevant support and functions; and 3) Adaptive task assignment for personally and situationally relevant and motivating tasks.

Engaging the work community solutions encourage and activate workers to active participation at the work place. This category also includes three concepts: 1) Participatory design with motivating tools that contribute to designing one’s own work environment along with related tools and practices; 2) Knowledge sharing tools to make tacit knowledge visible and accessible; and 3) Training solutions that support efficient adoption of new machines and practices, engage workers to contribute to the training materials and support continuous competence development on the worker’s own pace.

The concept descriptions include the theory and the central ideas. We have illustrated the concepts with scenarios of future factories. The aim to illustrate how the concepts would show in the factory floor and how workers would think about them. The Factory2Fit industrial partners Continental, Prima Power and UTC have described tentative industrial use cases for the concepts, resulting in a total of 12 different industrial use cases. During the next phases of the project we will start implementing the most potential use cases, targeting to start the industrial pilots in autumn of 2018.
1 Introduction

1.1 Purpose of the Document

This deliverable introduces the adaptation concepts that the Factory2Fit project is proposing based on a thorough analysis of industrial needs. The concepts have been developed in close collaboration between the industrial partners Continental, Prima Power and UTC, who will provide the pilot environments for the forthcoming development of the concepts, and all the other Factory2Fit project partners.

The purpose of this deliverable is to describe the common vision of the Factory2Fit project, i.e. the proposed adaptation concepts. We describe the concepts and their industrial and scientific background. The concepts are illustrated as scenarios that describe foreseen usage situations in future factories. For each concept we also describe industrial use cases foreseen by the industrial partners of the project. The aim of this deliverable is to share within the project but also externally the planned adaptation concepts. Within the project, the most promising industrial use cases are then worked further to be implemented and piloted during the third project year. The remainder of this report is organized as follows: In Section 3 we describe the overall Factory2Fit concept and an overview of the proposed two groups of concepts: concepts to empower the workers and concepts to engage the work community. The two groups of concepts are then described in sections 4 and 5. In Section 6 we present the conclusions.

1.2 Intended readership

The deliverable is a public one, so in addition to sharing the concepts within the Factory2Fit consortium, we want to share the ideas also with a wider audience.

1.3 Relationship with other Factory2Fit deliverables

A confidential deliverable, D1.2 Industrial requirements described the Industrial requirements based on interviews and observations at the pilot sites. A public deliverable, D1.1 Enabling technologies gave an overview of technical enablers. These deliverables constitute the basis from which the concepts have been defined. The technical enablers for the adaptation solutions are described in two confidential deliverables: D1.4 Adaptation architecture and D3.1 Adaptation features and modules. Public deliverable D2.1 Dynamic user model describes the user model and public deliverable D2.3 Worker feedback dashboard describes how the worker gets feedback of his/her well-being and performance.

Deliverable D7.6 Ethics report describes ethical procedures to be taken into account when implementing and evaluating the concepts. Deliverable D1.5 Design and evaluation framework and
measuring tools describes the work well-being evaluation framework to be used in designing and evaluating the implementation of the concepts.

1.4 Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>AHU</td>
<td>Air Handling Unit</td>
</tr>
<tr>
<td>AR</td>
<td>Augmented Reality</td>
</tr>
<tr>
<td>CAM</td>
<td>Computer-Aided Manufacturing</td>
</tr>
<tr>
<td>CoU</td>
<td>Context of Use</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision Support System</td>
</tr>
<tr>
<td>EFFRA</td>
<td>European Factories of the Future Research Association</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>LoAs</td>
<td>Levels of Automation</td>
</tr>
<tr>
<td>UTC</td>
<td>United Technologies</td>
</tr>
<tr>
<td>UTRC-I</td>
<td>United Technologies Research Centre - Ireland</td>
</tr>
</tbody>
</table>

Table 1: List of Abbreviations
2 Adaptation in factory environment - Factory2Fit approach

The fourth industrial revolution, often referred to as Industry 4.0, is already on its way. Enabled by advanced digitalization, industrial internet and smart technologies such as Internet of Things (IoT), it is expected that Industry 4.0 will result in shorter development periods, individualization in demand for the customers, flexibility, decentralization and resource efficiency (Lasi et al., 2014; MacDougall, 2014). Industrial internet and IoT have been widely studied from the viewpoints of management, business and technology. They are also expected to radically change many work roles, but this has been studied to a lesser extent. In the industry, there will be significantly greater demands made to all members of the work force, in terms of managing complexity, abstraction and problem-solving (Kagermann, Wahlster and Helbig, 2013). For the industrial workers, the revolution is expected to provide opportunities by the qualitative enrichment of their work: a more interesting work environment, greater autonomy and opportunities for self-development (MacDougall, 2014). Subsequently, the employees are likely to act much more on their own initiative, to possess excellent communication skills and to organize their personal workflow; i.e. in future industrial environments, they are expected to act as strategic decision-makers and flexible problem-solvers (ElMaraghy, 2005, Gorecky et al., 2014).

In our research project, which started late 2016, we aim to take human-centered manufacturing to a new level by giving the factory workers a leading role in adapting and developing their own job. The objective of the project is to develop and pilot adaptive human-automation interaction solutions that improve the flow of working, support the worker in understanding and developing his/her competences and engage workers to share knowledge and to participate in designing their own work and training (Figure 1). This will support our vision of smart factories of the future that will fit perfectly for workers with different skills, capabilities and preferences. Adaptive automation supports fluent human-automation cooperation and supports current and forthcoming workers to develop their competences to become smart, satisfied knowledge workers of future factories.
Figure 1 illustrates our approach to the worker-centered adaptation of the factory environment. The main principle is that the worker is an expert of his/her own job and thus (s)he shall have an active role in the adaptation. **Quantified worker** based solutions are built on a dynamic user model maintained based on measuring and monitoring the worker and the manufacturing environment. The model also includes worker skills, capabilities and preferences. The adaptation solutions utilize the user model to change automation level and other system features accordingly. The model is also used in adaptive task assignment. Measuring and monitoring of the user is based on a quantified worker approach: the measures and monitoring are not only used by the automation system to adapt, but also the worker him/herself gets empowering feedback of his competence and performance. This supports the worker in continuous development of his/her competences and the feedback is also utilized in adaptive learning solutions at work.

With the concepts defined to **engage the work community**, we aim to encourage and motivate workers towards active participation at the work place. The workers have a lot of tacit knowledge and development ideas that may benefit the whole work community. Participation also supports ownership and community building, thus contributing to work well-being. **Engaging the work community** solutions utilize a virtual model of the factory representing all essential functionalities the real factory has. The model supports seeing one’s own job, other worker’s jobs and their role in the manufacturing process. Virtual factory model also acts as a motivating and easy-to-use contextual platform for knowledge sharing with social media based tools for sharing e.g. good practices, notices and observations. Furthermore, the virtual factory model serves as a platform for contextual training.

These two approaches can be described as a) approaches to empower the worker; and b) approaches to engage the work community. The approaches are partially overlapping, especially regarding learning at work, as the empowering feedback on one’s competence and performance supports learning at work and taking responsibility of one’s own professional competence. In the following, we will describe in separate sections these two kinds of adaptation solutions:
1. Empowering the worker. Adaptation solutions based on a worker model, including the following concepts:
   - Worker dashboard, to give the worker motivating feedback of his/her well-being and performance.
   - Adaptive user-machine interaction for personally and situationally relevant support and functions.
   - Adaptive task assignment for personally and situationally relevant and motivating tasks.

2. Engaging the work community. Solutions that encourage and motivate workers towards active participation at the work place, including the following concepts:
   - Participatory design with motivating tools to contribute to designing one’s own work environment and related tools and practices.
   - Knowledge sharing tools to make tacit knowledge visible and accessible.
   - Training and learning at work solutions that support efficient adoption of new machines and practices, engage workers to contribute to the training materials and support continuous competence development on the worker’s own pace.

We have illustrated each of the concepts with one or two scenarios, which give examples how the solutions would be used in future factories. The scenarios should be seen as examples, they highlight a sub set of the features of the concepts, and they are not directly connected to the industrial use cases. The value of the scenarios is that they illustrate the worker needs (based on deliverable D1.2) and expected user experience with the concepts (also based on deliverable D1.2) and thus make the concepts easier to understand from the user point of view. The scenarios are listed in Table 2.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Scenarios</th>
</tr>
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<tbody>
<tr>
<td>Worker dashboard</td>
<td>#1 Following personal competence development</td>
</tr>
<tr>
<td></td>
<td>#2 Personal insights to well-being</td>
</tr>
<tr>
<td>Adaptive user-machine interaction</td>
<td>#3 Developing from a novice to a more experienced worker</td>
</tr>
<tr>
<td>Adaptive task assignment</td>
<td>#4 Managing work load</td>
</tr>
<tr>
<td></td>
<td>#5 Personally fit work tasks</td>
</tr>
<tr>
<td>Participatory design</td>
<td>#6 Developing work practices together</td>
</tr>
<tr>
<td>Knowledge sharing</td>
<td>#7 Support in problem-solving</td>
</tr>
<tr>
<td>Training and learning at work</td>
<td>#8 Online preparation course</td>
</tr>
</tbody>
</table>

Table 2. Factory2Fit scenarios

For each of the concepts we have defined potential industrial use cases as illustrated in Table 3. It should be noted that during the next phases of the Factory2Fit project, the most promising industrial use cases will be chosen for further design and implementation. Thus not all the use cases will be
developed further within the Factory2Fit project. However, defining these use cases has been beneficial for the whole project to study the possibilities of the concepts.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Continental use cases</th>
<th>Prima Power use cases</th>
<th>UTC use cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worker dashboard (similar in all use cases)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Adaptive user-machine interaction</td>
<td></td>
<td>x</td>
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<tr>
<td>Adaptive task assignment</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Participatory design</td>
<td>x</td>
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<tr>
<td>Knowledge sharing</td>
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<tr>
<td>Training and learning at work</td>
<td>x</td>
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</table>

Table 3. The defined industrial use cases

In the following sections we first describe the concepts and then for each concept, the related industrial use cases as examples.
3 Concepts to empower the worker

3.1 Introduction

Factory work is getting more versatile and multi-skilled workers are needed. A dynamic database of workers and their competencies would help in work planning in order to find competent workers for each task. Adaptive task assignment should take into account task requirements, worker capabilities as well as worker preferences e.g., on which machines they would like to work or preferred working times. The database would also support following the individual competence development of each worker. Adaptation of the manufacturing system can facilitate identifying operator role, skills and capabilities as well as the production situation to provide information and support needed in that specific situation. Based on the worker profile and adaptation, the user interfaces of the machines could adapt to allow only such functions that the worker’s role is cleared to use. Adaptation should serve both user interfaces of individual machines and a systemic view of the machine entity. The aim should be to offer a smooth and clear user experience.

The concepts to empower the worker are based on the worker model that includes the dynamic characteristics of the user. The worker model is based both on information that the workers, or their superiors provide as input to the system and dynamic measures. The worker model is used to adapt the manufacturing environment to better support individual workers. The model is also used to take into account the individual characteristics and preferences in assigning tasks to workers. According to the Quantified worker principle, the workers get feedback on their well-being and performance, to support them in understanding their skills and competence, and well-being at work.

In the interviews with factory workers (Factory2Fit deliverable D1.2), they were not very keen on the idea of measuring workers. The idea raised negative expectations of highlighting differences between workers and comparing their efficiency at work. Measurements were also seen as a source of stress and panic generator. The expectations were based on previous experiences, so in Factory2Fit it will be important to develop early demonstrators of the worker dashboard to demonstrate the measures and how the feedback is for the worker’s own use only, and cannot be accessed by others. For worker modelling, it is important that workers know what kind of data is collected of them and how the data will be used. Information should not be used to measure the performance of individual workers.

3.2 Worker model and worker dashboards

Factory2Fit scenario #1: Following personal competence development

Matthew, 25, has been working in the factory for 2 years. Recently, his work has changed as he started to use a new multipurpose machine, and for three weeks, he has been using it independently. He has been a bit nervous about new tasks, and worried whether he remembers everything about using the machine and whether he can manage when something unexpected happens.
Matthew starts his work shift. Everything goes smoothly until noon, when the machine suddenly stops. He is working alone and feels a bit stressed out, as he is uncertain about how to solve the situation. He starts to nervously inspect the machine, but is soon pleased to realize that the instructions provided by the machine itself on how to get it running again are detailed enough and easy to follow. However, as a diligent person, he feels that it takes too long to solve the problem and is a bit frustrated.

During the coffee break, he views his Worker Feedback Dashboard from his smart phone, and looks over the day’s statistics. He is delighted to see a notification that he had handled the problem situation quicker than before and realises that the machine stoppage was only a short one, after all. Soon his work mate joins him for coffee, and they start to discuss the evening’s football game.

On the bus, after the workday, Matthew is browsing his phone. He remembers the Dashboard and wonders, how the rest of the day went at work. After seeing through the day’s statistics, he browses the data of the past two weeks, and notices that the trend of machine running time has increased, whereas the trend of his resting heart rate has decreased. This reflects his own feelings of gradually decreased anxiety after starting with the new job. He feels confident that he is becoming already quite competent with the machine, and puts his phone away, satisfied and relaxed.

**Factory2Fit scenario #2: Personal insights to well-being**

Brenda, 45, has worked in the same factory for several years. The work has become somewhat routine-like for her and she feels completely confident with her work. Brenda wants to spend her free-time on activities she truly enjoys, such as exercising regularly and spending time with her family.

Brenda starts her work shift, third night in a row. The night shifts usually go quite smoothly, without major problems with running the factory machines. Brenda has grown fond of the Worker Feedback Dashboard introduced at her workplace a few months ago, since it has provided her new insights about her well-being. Often, during night shifts she has time to study her personal trend statistics presented by the Dashboard regarding various well-being and work performance measures. She has learned that getting enough sleep is important for her, since after a good week of sleep, her attention at work usually improves and her resting heart rate decreases. As she is keen to keep herself fit, she knows that fluctuations in one’s resting heart rate reflects the body’s stress state. Since noticing these sleep-related relations, she has been making a special effort in prioritizing sleep over other activities and is happy to observe from the Dashboard that also during the weeks of night shifts she has managed to keep up with a good sleep rhythm. In addition, she has realized that when she feels tired after work she does not have to be too concerned about exercising during her free-time, because on a typical work shift she accumulates more than 10 000 steps anyway.

In Factory2Fit Deliverable D2.1 Dynamic worker model, a work-related abstract profile of an employee has been described as well as a dynamic worker model, called Adaptive Worker Model. This Adaptive Worker Model will be used to find the suiting adaption level for each individual worker. In addition, the workers will be enabled to view the empowering parts of their own profile supporting work well-being and competence improvement, visualized by the Factory2Fit Dashboard (Deliverable D2.3 Worker feedback dashboard).

To find the best matching between the workers and machines or tasks, the User Model consist of specific characteristics that are descriptive. It is being distinguished between characteristics describing the worker, characteristics describing the machine or task, and contextual characteristics.
To characterize the worker, relevant variables have been gathered. These variables can be summarized under the topics **Wellbeing**, **Generic properties** of the worker, and **Skills** of the worker. Also, **Preferences** and **Aversions** as well as the current work context are considered (see Figure 2). Preferences can be specified by the workers themselves and will directly impact the adaptation process between worker and machine or task by determining the proper Level of Automation option for that machine or task (D3.1).

![Worker Model characteristic's categories.](image)

The complete list of characteristics and variables of the Worker Model and the Adaptive Worker Model is described in Deliverable 2.1, *Dynamic worker model*. The derived parameters to measure the variables are described in Deliverable 2.2, *Online and offline measures*. Both are Factory2Fit public deliverables.

To provide the worker with feedback and a possibility to see and alter his/her profile, Factory2Fit will implement two separate dashboards to be used by the workers: Worker Profile Dashboard and Worker Feedback Dashboard.

Some categories of the worker model are such that the employer generates and maintains the data in collaboration with the worker in question, e.g. worker role, skills etc. For this purpose Factory2Fit has developed a tool, the **Capability Editor**. The Capability Editor was introduced in Factory2Fit Deliverable D1.4 “Adaptation architecture” and is described in detail in Deliverable 3.1 “Adaptation features and modules” (both confidential deliverables).

The **Worker Profile Dashboard** gives the worker access to his/her own profile so that (s)he can see the profile and can also change some aspects of the profile, such as his/her preferences. Personal data, i.e. preferences and wellbeing data, can be used for adaptation only if the worker allows access to it, so the Worker Profile Dashboard should include tools to control the access rights.

The purpose of the **Worker Feedback Dashboard** is to provide personal feedback to factory workers regarding their well-being and work performance outcomes with the objectives to improve job satisfaction and establish self-awareness about possible relations between the well-being and work performance metrics. The Feedback Dashboard attempts to influence job satisfaction by providing data-driven feedback that is positive and encouraging – highlighting personal achievements during the work day and demonstrating the development in one’s work competence. The personal data collected for and presented in the Feedback Dashboard can be accessed only by the workers themselves.
The ideology of the Feedback Dashboard originates from the Quantified Self movement, which promotes self-knowledge and self-improvements through numbers acquired with the help of technology, such as wearables and mobile devices. The Quantified Self movement is largely about collecting personal data for private purposes, only, and finding personal meaning in the data by monitoring personal aspects of interest in order to raise self-awareness and facilitate self-improvement. These principles are supported also by the Factory2Fit Worker Feedback Dashboard.
Well-being and production metrics together

Figure 4. Screenshots of the Worker Feedback Dashboard Day view: part 2.

Figures 3 and 4 present example views of the Worker Feedback Dashboard. The data shown in the test account is off-line and predefined, expanding over a two week period from 1st to 14th of June 2017. The well-being and work performance metrics presented in the test account are real-life data, but collected in separate contexts. Hence, looking for associations between these metrics will not make sense with the example data.

The Worker Feedback Dashboard is described in more details in the public deliverable D2.3 Worker feedback dashboard.
3.3 Adaptive user-machine interaction

Factory2Fit scenario #3: Developing from a novice to a more experienced worker

Clive has been working in the factory for half a year now. When he started, the model of his skills, capabilities and preferences were fed to the factory system so that the user interface of the machinery always provided personally relevant hints about how to proceed and the tasks allocated for him were relatively simple. As Clive has dyslexia, complex written texts are challenging to him. That is why the support the system provides is mostly in the form of images with simplified text. Furthermore, as the system provides tasks quicker or slower in accordance with the identified alertness of Clive, he feels constantly good with the level of difficulty of his tasks. Gradually, the work had become more familiar and Clive feels he really does not need so much guidance any more. He is also interested to get new tasks that could be a bit more challenging. Thus, Clive goes to his supervisor to tell about the changed situation, wishing for changes in his user profile. After a discussion, supervisor agrees and the changes are made accordingly. Now, the user interface does not provide any support to the familiar tasks unless specifically asked for, unless there is a longer pause in working. Furthermore, earlier all complexities were allocated to other workers but now the system starts to offer more complex tasks to Clive too. As the tasks are still new to him, the system adds complexity only gradually and provides support to the new tasks proactively. When the new procedure is performed correctly long enough, the system automatically stops providing automatic support, transferring to the mode where the support is given only if asked for. Clive is satisfied. He feels the work challenging again and is happy that if feeling insecure, he can still ask for help very easily.

Factory2Fit scenario #4: Managing work load

Tina is having her usual day at the factory: she has had a slow start for the day, as she prefers to talk a bit with her colleagues before really starting to work. She also tends to have longer pauses than some of her colleagues because talking with other people is, as she says, sweet for her soul. Now, however, she reads a notice on the screen: a new order has arrived, requiring more work than expected as the order originates from an important customer and this time the customer needs the products more rapidly than usually. There is a question on the display: Do you want to work today with faster pace, with shorter pauses, with both options, to work in a more demanding position or without any alterations to the normal working day? Tina is glad that the question appears, for many reasons. Firstly, earlier, before the new system, the supervisor just announced that everybody had to work longer that day due to an urgent order and nobody was asked anything. Now it was possible that the order can be managed by only part of workers if the most efficient ones have applied to work more. Secondly, Brenda usually uses this opportunity to earn some extra free time – that is why the question has appeared for her in the first place – but in the form of having shorter pauses. Today she feels perkier than usually so she chooses the option of working faster and even with slightly shorter pauses. The machinery adapts to her choice, sets the pace to the higher level, which has been proved still good for Tina. Now Tina can have her busy day as it suits her today and can have a free morning some day later, perhaps going swimming with her friend, without any reductions in her salary.

In the manufacturing process, interfaces have to be designed in such a way that they can be operated by user groups with different characteristics, e.g. computer knowledge, training, and in varying interaction contexts (Akiki et al., 2014). Requirements in the manufacturing process request the development and adoption of new methods concerning the topic of user – machine interaction, achieving greater motivation from workers and raising their productivity. For the development of efficient and pleasant user-machine interaction, user characteristics such as capabilities, skills and preferences should be taken into account. Preferably, the interaction should adapt to the momentary
status of the user. Additionally, the interface should meet and take into consideration safety rules, e.g. allow access only to authorized users, and enhance legality and quality, in order to achieve simplicity and effectiveness in user-machine interaction.

3.3.1 Literature Review – State of the Art

Multiple interfaces and methodologies have been developed concerning the adaptation of the user-machine interaction, based on the different needs, knowledge and characteristics of each user. Akiki, et al. (2014) have developed an adaptive user interface using CEDAR method. The aim of this interface is to simplify its functionalities by using the Role-Based UI Simplification (RBUIS) mechanism. This interface allows the user to import his/her preferences, and some elements such as font size, in order for the system to be adapted to the user’s needs. Methods used for the development of this interface have been evaluated as far as efficiency and scalability are concerned.

Furthermore, there are also other methodologies for user interface adaptation. In literature, human-machine interaction design method is commonly used in designing manufacturing interfaces, which adapt on-line to different users (Pfeiffer et al., 2016). This method aims at the personalized development of an interface for better and more direct user-machine communication. Alongside, this method aims at user’s satisfaction with a product by improving the usability, accessibility, and generally supporting their needs in the interaction with the manufacturing processes (Kujala et al., 2014). In order to design an interface that covers the user’s requirements, by taking into account their characteristics available in their profile: the tasks that he/she will perform, the tools / information needed in everyday work, safety issues and the general context of production.

Alongside, agile development processes for better user-machine interaction are presented in literature as key factors in the development of an efficient and adaptive interface, which can adapt on-line to users with different characteristics (Sohaib et al., 2010). These processes are based on the ISO 9241-210 (2010) and belong in the context of Industry 4.0 (or Industrie 4.0). ISO 9241-210 concerns the requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems.

3.3.2 Methodological Approach

The main aim of the adaptive user-machine interaction concepts is to achieve a more effective, easy and efficient interaction of users’ and-machines’, by taking into account the user’s requirements and needs. In this respect, machine interfaces should be able to adapt to user characteristics as well as the situational status. Factory2Fit Deliverable 1.2, Industrial requirements, introduces the user requirements of two Prima Power customer sites, at Continental and at Carrier, a unit of UTC, collected by interviews made in each industry. Some additional requirements to the ones described in Deliverable 1.2 are:

- Workers need feedback on different tasks or certain training.
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- Monitoring needs to be accepted by the workers.
- The data shall not be shared to others than the worker him/herself.
- Adaptation could be utilized in help systems and in wizard type of guidance.
- Personal statistics available to the users.
- Association of the workers’ names with their suggestions.
- The update of the user’s profile, skills and abilities to be continuous.
- The operator needs to know that workers work according to schedule in order to feel satisfied or readapt the work schedule accordingly.
- All tasks should have priority and criticality ranks.
- Real-time access to necessary knowledge for tasks.
- Continuous access to training procedures.

To approach the adaptation of machine interfaces within Factory2Fit adaptation solutions, the concept of Levels of Automation (LoAs) has been examined in terms of user-machine interaction. LoAs refer to the degree to which a task is automated, and define “the allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic”. LoAs can either be physical-related, i.e. refer to the technical level (fully manual to fully automatic operations) of manufacturing systems, while cognitive related LoAs intend to determine the degree to which cognitive activities such as situational assessment, fault monitoring and management are performed by human operators or in a fully automated fashion. The utilization of LoAs as manners in which tasks operated by machines and supervised by humans can be executed offers adaptation concepts for proposing changes to machine interfaces according to roles, situational awareness and other parameters expressed in terms of LoAs. LoAs are therefore defined within Factory2Fit as the extent to which UIs can be adapted according to the given situational Context of Use (CoU), which is a description on worker, task and contextual characteristics to achieve effectiveness, efficiency and satisfaction of the manufacturing system (human and non-human resources operating on a specific task).

Furthermore, there are not only the user’s requirements that will be taken into account, but also the machine’s requirements in this two-way interaction. One of the main machine’s requirements concerns the modification of critical values for their function, by any user without specific authentication. Machines should allow only such functions that the user is mastering. Yet, the system should recognize the production’s situation in order to provide information and support needed in that specific situation. Alongside, aspects of worker training and knowledge sharing should be made more accessible and provide secure and easy access to the desired information.

By improving the accessibility of the user and respecting his/hers needs and preferences, the user experience and satisfaction will be enhanced and productivity is expected to gain a significant boost. Furthermore, with interface adaptation, the system is expected to meet requirements for better work and product quality and safety.

Concepts and functionalities

User authentication should be addressed both in terms of flexibility and as the extent to which the authentication is done manually or automatically. At first, the design of the system must support
flexible roles with more levels, not just for managers/employees. There should be more than the two major role categories and levels of users in the UI, for better categorization, requirement analysis and system adaptation. For example, the machine must recognize the user, by the credentials entered, and be able to set limits according to his/hers hierarchy and rights as mentioned before. Hence, there should be a system that recognizes the user’s location in the shop floor as well as his/hers identity. User identification is an important element in the UI development and has to be easy, quick and confident. An accurate and efficient technology should be used, such as Radio Frequency identification (RFID). Accuracy is the most important aspect, because according to the credentials entered by the user, the system will filter its functionalities and give grant access to the user only to the appropriate ones.

As far as the user’s location concerns, vision cameras and Wi-Fi triangulation are the most common methods used in research. Vision cameras can be used in multiple applications, such as user’s identification and tracking. Several algorithms have been developed to track a user, capturing his/hers location and course. On the other hand, Wi-Fi triangulation (Quan et al., 2010) aims to map received signal strength indicator (RSSI) as a function of distance.

Furthermore, system adaptation should take into consideration the worker’s role, abilities, working schedule and real-time data acquired from different sensors showing his/her condition. Based on the credentials provided by the user, the system will acquire all the proper information from his/her Worker Profile, in order to adapt depending on his/her needs and situation. In this way, efficiency, functionality and user performance will be increased. In its architecture description in Factory2Fit Deliverable D1.4, Factory2Fit has overseen the development of a series of modules in different areas across the project’s Work Packages that will aim to empower workers in terms of adaptive user-machine interaction. It should be noted here that when it comes to dynamic adaptive user-machine interaction, specific tools and applications should be developed, largely depending on each industrial case.

**Integrated Decision Support System.** As previously mentioned, machine interface adaptation should capitalize on the proper description of LoAs in terms of the characteristics that describe the situation’s Context of Use (CoU). As described in Factory2Fit Deliverable D3.1, four types of automation have been identified:

- data collection;
- data proceeding;
- decision making;
- task implementation

Additionally, ten levels of cognitive automation have been identified which represent different ranges between totally human-controlled and totally machine-controlled operations:

1. The computer offers no assistance, and the human must take all decisions and actions.
2. The computer offers a complete set of decision/action alternative;
3. Narrows the selection down to a few choice;
4. Suggests one alternative;
5. Executes that suggestion if the human approves;
6. Allows the human a restricted time to veto before automatic execution;
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7. Executes automatically, then necessarily informs the human;
8. Inform the human only if asked;
9. Informs the human only if the computer decides to;
10. The computer decides everything, acts autonomously, ignoring the human.

As is described in detail in D3.1 Adaptation features and models the Factory2Fit project implements an approach for achieving proper matching of LoAs (e.g. user machine parameters) to user preferences and situational data, which is based on properly defining task CoU and determining the LoAs as different ways in which a specific task can be executed. An example is shown in Figure 5. LoA options for cognitive adaptation describe different machine UI settings for each of the four types of automation mentioned previously in this paragraph. Therefore, matching LoAs to worker preferences and situational status can be approached via multi-agent adaptation architectures utilizing capability-based matching, as is described in D1.4 Adaptation Architecture. This matching utilizes a set of rules, which can take into account elements of efficiency (e.g. if the workload of workers is high, consider raising the automation level on task implementation parameters), effectiveness (e.g. if reliability of situation awareness of a machine is high, consider to increase the automation level of data collecting and data analysis parameters), safety (e.g. if the tasks are with high risk, consider to increase the utilization of machines within the task implementation stage; and possibly decrease the automation level within the decision making process), emotional satisfaction (e.g. selecting the LoA option with the appropriate lighting condition) and sensorial information (e.g. if the heart rate measured is found to be above a specific threshold, consider to raise the automation level of task implementation).

Up to now, the technical enablers have been discussed. However, a significant part of this section focuses on how adaptation shows to the user, as described below, including dynamic adaptation based on user's momentary status. At this point, it should be mentioned that the following points, refer to different scenarios relevant to the interaction between the users and system's interfaces in various cases in order to assist users at certain occasions or help them to evaluate their cognitive status regarding their work and condition. These concepts should be commonly found in the industrial environments of the future and they will act as lighthouses for the concepts discussed herein, while some of them will also be incorporated within the Factory2Fit pilots. The solutions presented, categorized into groups based on main functionalities provided by the Factory2Fit ecosystem, define a more user-centric description of concepts concerning the interface adaptation to different users.
Guidance Solutions. In case of user’s confusion, system will show the proper notifications to the user in order to guide him/her through the procedure. These notifications may be instructions or videos concerning the task’s execution. In this way, the user can request and receive access to the appropriate assistance required instantly and conveniently, through the user interface, which takes into account geo-located and task-specific information to display task-relevant content stored in the knowledge base.

The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n°723277
**Defect Detection Toolkit.** Alongside, if a user tends to make errors while executing a task, or missing some steps of its execution (such as pushing a button or change a value on the interface), the system should display again notifications in order to inform the user about the right execution of this procedure. In addition, in case the user makes many errors, the system should be able to display alert messages and instructions of the task’s step-by-step execution.

**Worker Dashboards.** The system will have access to user’s historical data, stored in the central database. By presenting past data of worker’s performance or work well-being to the worker, when requested, on relevant UI components the user will have the chance to evaluate these data, compare them and find ways to increase his/her efficiency or find the elements that help him/her have this upward course. Private information of a worker, such as preferences and measures, are utilized by Factory2Fit software components internally but can only be viewed by the worker in order to safeguard the privacy. Thus, the system should grant access to supervisor only to the data that are entered by the supervisor, for example during user registration process. Keeping the balance between operability and privacy when privacy-sensitive data are utilized, is an important aspect in order to keep users satisfied without privacy concerns.

### 3.3.3 Prima Power use case

#### 3.3.3.1 Context of use

Prima Power manufacturing lines are highly automated. Typically, automated lines are performing fast until something goes wrong, it then becomes challenging to identify the problem and get the line running again. With adaptive human-machine interaction, Prima Power targets to respond to the following challenges:

- Getting support when a complex part is arriving for the first time to a novice user for manufacturing, e.g How to get started easily?
- Getting support in problem solving
- How to continue production after an error situation
- How to report failed parts
- Estimating production schedule
- Reducing operator stress and improving well-being
- Taking care of the special needs of elderly operators

The line has several control desks, each with their own application and user interface (Figure 6.).
3.3.3.2 Proposed solution

A separate system user interface (Figure 8) gives the operator an overview of the status of the whole manufacturing line. The operator can zoom to individual machines as needed. The user interface is adapted according to the usage situation and the user.

The system should support both role-based adaptation and user status-based adaptation. In role-based adaptation the user and his/her role is identified (e.g. with username and password). Then the corresponding role is identified and based on that, the privileges are set. The worker roles may change even during the work day, and as a result, this should be supported by the system.
User status-based adaptation supports taking into account the worker’s current mental and physical condition. To support situational awareness, the location may also be useful.

The operators could get feedback on the state of the production additionally on their phone, smart watch etc. to free the operator to move at the factory. This feedback should include also information about the type of the problem and estimated time for maintenance.

Figure 8. Early sketch of the System UI

3.4 Adaptive task assignment

Factory2Fit scenario #5: Personally fit work tasks

Shirley is a factory operator who has been in a serious accident. She has returned to work after a long rehabilitation period and she’s now using a wheelchair. Shirley insists to continue with the same tasks she had before the accident. However, during the first day she experiences a hazardous incident that poses danger to her and her colleagues. That makes Shirley realize she really can’t go on like before. Because of the incident, Shirley and her supervisor Sam have a discussion and conclude that they should together update Shirley’s Factory2Fit user profile with her current capabilities. Shirley also updates her preferences for machines and tasks to work with, as well as her preferences for working hours.

Sam, the supervisor is using the Factory2Fit task distribution engine to plan daily production and to assign workers to assembly stations and machines. The engine has eased his work a lot as it takes into account not only the skills and capabilities of the workers but also their preferences. Thus people are much happier with their tasks and Sam received less complaints. Better personal fit in work tasks already shows in increased work satisfaction and better productivity.

After working for a while with the new tasks, Shirley starts to formulate an idea of her personal competence development targets. She discusses the targets with Sam, and they together update the user model with those targets. The targets are taken into account in the task assignment is such a way that Shirley gets regularly also new tasks, which support the competence development. In these tasks she gets personalized guidance to support learning at work. From her Factory2Fit Worker Dashboard Shirley can follow her competence development and also her well-being at work.
Manufacturing, or other types of processes occurring in factories’ shop floors use usually complex procedures, which may include several steps. Such processes, which can be defined as tasks that may be comprised of sub-tasks, involve different entities such as workers, machines, and perhaps other resources as well. Industrial shop floors are highly dynamic environments, as unexpected events can occur. For example, machinery equipment is subject to failures due to malfunctions. Furthermore, the performance of human resources when performing a particular task is dependent on various factors such as their cognitive status, well-being status, already assigned work, characteristics of the task etc. Likewise, in the case tasks are executed by machines, the assignment of a task to the most suitable machine at a given time is an important topic towards the optimization of the manufacturing process, as stochastic events can affect the execution of a process. In that case, action is usually required in order to detect and deal with possible bottlenecks.

Real-time monitoring of machines’ current status and human resources’ availability and well-being allows to evaluate the progress of a process. Therefore, in case an issue is detected, recommended actions can be proposed or applied in order to resolve the issue and re-adapt the manufacturing process if required. Furthermore, decisions about the starting time of a process and the allocation of a process to the most suitable workers or/and machines can be made by exploiting the data models and the information acquired in real-time.

3.4.1 Literature Review – State of the Art

In this Section, state-of-the-art work found in the literature about task scheduling, resource assignment and re-adaptation of manufacturing processes, is presented. Tasks, machines and human resources are usually the most important entities that are engaged in the operation procedures of a shop floor. Proper management of these interdependent entities is crucial for the efficient operation of the shop floor and for keeping a high level of productivity. To this end, various factors have to be taken into account, such as the restrictions of the entities involved, the company’s policies etc.

Personnel scheduling problems have been studied widely in the last years, and various approaches have been proposed. Even though workers’ skills are well-incorporated into personnel scheduling problems, the personnel scheduling problem is hardly ever integrated with other scheduling problems such as machine scheduling and operating room scheduling (Varela et al., 2014). Furthermore, in the last decades, enterprises more and more consider employee preferences (e.g. preferred shifts or preferred co-workers) in order to keep the workforce satisfied. As a result, innovative personnel scheduling methods that take into account employee preferences have to be developed. Varela et al. (2014) propose an approach based on a dynamic multi-criteria decision model, which enables rescheduling strategies and trade-offs between different performance metrics. A need for rescheduling may be necessary in a dynamically changing environment in which real-time changes occur in production, such as arrival of urgent tasks, due date changes, machinery malfunctions etc. Wuest et al. (2014) present a method for monitoring product state using Cluster Analysis and Machine Learning in order to detect problems and increase quality in manufacturing. Huang etc. (2011) propose a mechanism which models the dynamic resource allocation optimization problem as a Markov decision processes. In that work the authors consider durable resources, which are claimed and released during the execution, but are neither created or destroyed. The proposed mechanism learns appropriate policies by observing the environment, in order to optimize resource allocation in
business process execution. Shpilevoy et al. (2013) propose a multi-agent based system for resource management in manufacturing workshops. The system supports rescheduling of resources when certain events occur such as an arrival of a new order, equipment failure, changes in priorities, etc. The model includes agent classes such as Order, Worker, Machine and other. Mourtzis et al. (2016) propose a service-oriented Cloud-based framework for process planning considering availability and capabilities of machine tools. An information fusion method processes the monitoring data (machine tools, input from operators, machine schedules) in order to feed the process planning service with the status, specifications, and availability of machine tools. Gradišar et al. (2015) present a platform that helps the production manager to make better decisions in order to improve a production process. Simplified KPI models identified from historical data are created and used as a decision-support tool.

### 3.4.2 Methodological Approach

The already mentioned entities (tasks, machines and workers) are the ones utilized by the engines of the Factory2Fit Decision Support System (DSS), such as the Workplace Adaptation Engine and the Task Distribution Engine. According to the Factory2Fit approach, the relations among all these three entities are taken into account, where applicable, when a new task has to be scheduled or re-adaptation to a process/task has to be made (Figure 9.).

![Figure 9. Main entities involved in a process](image)

Each industrial shop floor has its own operational policies, priorities and requirements. Therefore, a main challenge is to develop a generic framework for automated task distribution and work schedule adaptation, which is able to support various functionalities and be easily configurable in order to be adapted to each enterprise’s needs.

**Motivation and expected impacts**

The main goal is to provide the supervisors with a decision support system in order to assist them to perform their work efficiently. User-friendly interfaces showing performance metrics allow the supervisor to review the current status of the production in real-time, the assigned tasks per worker, and the assigned tasks per machine. Furthermore, through the presentation of task suitability scores that can be computed for each worker, the supervisor can determine the most appropriate workers for a task and identify the education needs of workers for particular tasks more easily.

Apart from the assistance offered to the supervisors, workers can also benefit from the adaptation functionality supported by a decision support system when their preferences are logged and taken
into account when making task allocation decisions. Respecting the preferences of workers is important for keeping the workforce satisfied.

New and unexpected events, such as a failure in a production line, are possible to occur resulting in the disruption of running processes. Normally, the supervisor is responsible for evaluating the situation and taking the appropriate actions. In the Industry 4.0 enabled Factory2Fit environment, these events can be detected via the use of sensors and processed by a decision making engine which notifies the supervisor and produces recommendations or automatically applies the proper rearrangements in the factory’s work schedule.

Different types of tasks are usually performed in a factory’s shop floor. Each task type has its own criticality level and requirements. Furthermore, more than one tasks of the same type can be running at the same time. By considering the various characteristics of a task and taking into account the current status of running processes, a priority score can be computed dynamically for each scheduled task or even for a new task that has to be scheduled. Automated task prioritization is a substantial functionality, as it allows the creation of efficient work schedules and the adaptation of existing ones. Additionally, the tasks of higher priority are considered more important than the others, and therefore, the system can highlight these tasks to draw the supervisor’s attention.

The expected impacts when a decision support system is employed for supporting an adaptive manufacturing process are multifold. When a change or unexpected event occurs, the decision support system can apply adaptation that minimizes the impact on the running and already scheduled processes of the shop floor. Furthermore, the response times required to deal with a new event can be significantly reduced, as the supervisor can accept the solution proposed by the decision support system. Work satisfaction and productivity of both supervisors and operators can be improved by assisting the former when making decisions and by respecting the preferences of the latter. Important tasks are highlighted through the use of the automated task prioritization functionality, in order to assist the supervisor to evaluate the current status and progress more easily.

Concepts and functionalities

The Factory2Fit decision support system will provide various functionalities in order to be able to apply diverse adaptation concepts, which are described next.

Matching resources (both human as well as machine) to tasks is a first step towards extracting the most competent and capable workforce to achieve a specific goal. The process utilizes a multi-agent adaptation approach in which all manufacturing resources are represented as agents, each with a set of capabilities. The sum of all agents’ capabilities therefore represents the full spectrum of capabilities offered by the system. Similar to the work of (Järvenpää, 2012), these capabilities, characterized by certain properties and behaviour, are used to match workers and resources to specific manufacturing tasks. In this respect, task characteristics become requirements against which the capabilities of the current system (e.g. resources and workers) are matched. D3.1 describes in detail the modules developed within Factory2Fit to define a formalized and structured representation of the functional capabilities, properties and constraints of the devices, as well as the workers’ skills and preferences and the manufacturing pre-process plan. The output of this process is the sum of all possible systems that possess the proper capabilities and are constrained by the right parameters for all tasks in pre-
process plan. This includes also all possible workers capable to be assigned to a task. The information can then be utilized for LoA matching (see Section 3.3.2) and Task Assignment.

**Task prioritization** is an important step towards determining the execution sequence of tasks and the creation of the shop floor’s work schedule. It can be a challenging job for the supervisor due to the large number of tasks that usually have to be performed and the existence of various parameters that affect the priority level of a task, such as its criticality, the required work, the required equipment and other. Thus, automated task prioritization is a functionality that can prove valuable for determining the execution order of tasks when the work schedule needs to be changed. Furthermore, the supervisor can conveniently focus on the more important tasks based on the automated computed priority level of each task.

The creation of a **feasible and efficient work schedule** at the start of each shift or day is a complex process which consists of several steps (set the execution order of tasks, assign the tasks to machines, assign the tasks to workers). The system shall be able to assist the manager in the creation of the shop floor’s work schedule by evaluating different possible task assignments and selecting the ones with the highest ranking. A list of tasks and a set of available resources (human resources and/or machine resources) have to be passed to the decision support system as input so that the initial work schedule can be created.

In addition to the creation of an initial work schedule, **automated scheduling of a new task** is another important feature. These tasks are usually critical, and in that case, their execution has to be started as soon as possible. Scheduling these tasks manually may be a stressful job for the supervisor as he/she needs to make a decision quickly. The decision support system will be able to set the starting time of the new task and assign the appropriate resources to it, based on the characteristics and requirements of that task. To this end, the status of scheduled/running tasks and the status of each resource (worker, machine) are considered in order to schedule the new task. The adaptation algorithm must take into account the suitability of the workers and the machines. Furthermore, the impact of the addition of the new task on the shop floor’s work schedule should be as minimal as possible. Overwhelming alternations in the work schedule during the day is usually not desirable especially for the workers. When inserting a task to the work schedule, there may be the need to reschedule an already scheduled task of lower priority, for example by setting it to start at a later time. The adaptation algorithm shall automatically adapt the work schedule and export those changes as well. During the working hours, one or more tasks may have to be rescheduled or reassigned to another resource due to unexpected events, such as when a worker’s well-being condition does not allow him/her to continue the work, or in case of machine failure. The decision support system should be able to receive or deduce these events in real-time from the values that are monitored and logged by the sensorial network installed at the shop floor.

An additional adaptation concept is the **reassignment of a task** to another resource, worker or machine, in order to improve workload balancing among similar resources. The engine can evaluate the assigned workload per each resource, after a request initiated by the supervisor, and perform task reassignments in order to lighten an overloaded resource.

Optimization methods, such as genetic algorithms and constraint optimization, will be explored and evaluated in order to schedule new tasks that arrive in real-time as well as assign tasks to the most
suitable workers and the most suitable machines. The main objective in all these cases is to discover and apply the best-fit solution by taking into account the parameters of the involved entities (tasks, workers, machines) and the defined metrics of interest. The best-fit solution is the one with the maximum score with regard to the multiple metrics defined, which are the objectives (multi-objective optimization). Examples of metrics include the appropriateness of a worker to perform a task, the already assigned workload, current status etc.

Static and dynamic input data about the main entities involved (tasks, workers, machines, tools) need to be available to the Decision Support System in order to support the aforementioned adaptation concepts. A task or a set of tasks with defined execution order describes a manufacturing, or any other type of process that is taking place in the factory. The requirements of a task such as the due date, type of required equipment, type of required worker etc., are taken into account by the Decision Support System during the matching process. The characteristics of the resources, such as the machines and tools are also considered, as well as the characteristics of each worker. In this way the system can first find the candidate resources and the candidate workers for a task, and then select the most appropriate ones. For example, in order to assign a task to a worker, various criteria can be considered such as the type of task, the skills and the preferences of the workers, the workers’ workload, the physical location of workers in the factory etc. Proper assignment of tasks to workers and machines can be a very complex process due to the fact that industrial shop floors involve a significant number of tasks, employees and assets of different characteristics. Therefore, an automated matching process can be applied beforehand in order to eliminate workers or resources which cannot perform a particular task. Subsequently, the remaining candidate workers and resources can be evaluated in order to select the most appropriate.

User model data are utilized by the Decision Support System for selecting the most suitable workers for new tasks, and performing task reassignments in real-time when required in order to improve productivity. The feature rich user model developed in the context of Factory2Fit is going to be exploited by the engines of the Decision Support System, such as the Automation Level Adaptation Engine and the Task Distribution Engine. It will enable the engines to perform multi-criteria optimization operations, as performance-related metrics, cognitive state, well-being status, and preferences on different aspects will be considered. The same applies for the tasks and the machines, which are also described by a high number of attributes. Regarding the user requirements, workers need to have access to certain parts of the user model in order to enter data and update it. Such data are their preferences on various aspects, such as their preferences on tasks they like to work on and preferred working times and locations. Furthermore, other personal information such as the emotional status can be entered as well. Due to the nature of these attributes, they are kept private in order to protect privacy and not raise concerns, therefore they are not available to the supervisors or other workers. For the sake of usability, a worker should be able to update his/her preferences on-the-fly by selecting a current task in the work schedule and add it to the preferred ones.

The Decision Support System has to be configurable in order to be able to comply with the specific shop floor’s characteristics and operations. Moreover, initial configuration according to policies and preferences that are applied at the shop floor is required, in order for the system to produce acceptable output when making decisions. Reasoning output in the form of user-friendly notifications about the selection of a worker to perform a task should be considered. Notifications to the managers...
give insight to the manager into the way the DSS operates. On the contrary, the notifications intended for the user (worker) are simpler, as they inform the worker why he/she was selected to perform a new task.

3.4.3 Continental use case

3.4.3.1 Context of use
For Continental there is the potential to adapt the process of measurements and analysis within the laboratories. These measurements are done to ensure the high quality level during every step of production. To support this, various equipment is in use, such as coordinate measurement machines, form testers or devices for hardness analysis. The available measurement capacity always has to be in line with the needs from production side. Capacity contains always both, equipment and human resources. To provide fast measurement results on one side and to utilise the equipment well on the other side, a dynamic balancing has to be performed – the adaptation of the measurement process. This can be done for instance in terms of priorities, sequence, or assignment of the measurement tasks.

3.4.3.2 Goals
With the implementation of the Factory2Fit solutions the plan is to support the setting and controlling of priorities for measurement tasks in the measurement lab. This will cause a preferred processing of measurements for bottle neck production process steps. The identification of bottle necks demands information about the online status of production lines and progress of production orders in relation to the production volume/timing targets.

The system controls the priorities and considers the measuring machine abilities and it’s status as well as the worker’s role and profile (skills, preferences, etc.). By conducting this, the team management for matching staff to tasks can be supported.

At the same time an online tracking of the task status is facilitated as well as the review and analysis of historical data.

In a final vision the system will allow a prediction of the work load and can itself request tasks at the production in case of low utilisation in the measurement lab.

Furthermore the possibility of immediate information transfer to the production can improve the profitability through reduced machine down times and scrap avoidance.

3.4.4 UTC use case

3.4.4.1 Context of use
UTC pilot studies are being handled in HVAC-Europe factory in Culoz, France. Air Handling Unit (AHU) assembly stations are particularly hosting Factory2Fit activities which consist of mainly manual tasks and limited automation due to complexity of the assembly process and highly customised product design.
Complex manual assembly process requires a certain level of expertise regarding to type of the AHU being produced. Henceforth, training a new assembly worker and equipping him with skills to make him/her able to have autonomous decisions and assemblies is the primary concern for HVAC-Culoz both for manufacturing productivity and worker engagement/satisfaction. In line with this, matching worker skill levels and preferences with weekly production plans of AHU’s is another important factor that HVAC-Culoz is facing in operational level. In addition, since all assembly operations are manual and most of them require special tools to be changed between different operations, sequencing of the assembly operations in a way that the operator fatigue is minimized (total traveling distance/time between tool magazine and AHU unit etc.) is another operational concern need to be considered. Finally, improving in-house material supply system and communication between material/subassembly suppliers and the assembly workers need to be improved to avoid missing part/supply delay problems and eventually to reduce worker stress level caused by pressure on meeting customer deadlines.

3.4.4.2 Goals
In this section, we are providing conceptual formulations of the three use cases mentioned in the context.

*Use case 1: Lot sizing and scheduling*
Problem: Assigning and scheduling AHU orders to stations
Maximize worker capability and preference matching while minimizing customer order completion time.
Subject to
- Due dates
- Competence level of workers
- Weekly schedule of workers
- Tool availability for stations

*Use case 2: Optimizing assembly process plan*
Problem: Sequencing of assembly operations in each station
Minimize fatigue due to assembly order complexity and total walking distance between AHU and tool magazine. Minimize total tool changeover time - walking from assembly unit to tool magazine.
Subject to
- Precedence between operations
- Sequence dependent changeover/incremental times

*Use case 3: Optimizing component supply*
Problem: Reducing work stress due to waiting/looking for missing components and causing pressure on workers for meeting deadlines
Minimize component supply delays and occurrence of missing/wrong part supply

The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 723277.
D1.3 – Adaptation Concepts

Subject to

- Milk-run train capacity and speed
- Demand and production rates of subassembly stations

Solutions for above formulated uses cases will be based on optimisation methods and will be evaluated with discrete event simulation techniques before deploying in the actual system.

3.4.5 Prima Power use case

3.4.5.1 Context of use

This case is focused on Prima Power customers having multiple machines in their factory. Prima Power machines run production orders, which contain information of the required materials, tools, etc. to be able to make the parts. Depending on the order it might require punching, laser cutting or bending a part. Orders can be part-by-part orders or product structure orders. The former includes individual parts to be manufactured while the latter includes several parts to be manufactured and to be assembled together.

3.4.5.2 Goals

Selecting dynamically correct machines for the production orders.

Use case 1: Production order distribution to machines

In this case orders are distributed to similar machines for punching and bending, taking into account machine capabilities, operators, the current task list of each machine as well as estimated run time for each step of the production.

Use case 2: Part routing

In this use case Product structure orders are routed through all production phases (nesting, cutting/punching, bending), and also assembly phases (welding, grinding, coating and assembly). The adaptation takes into account machine capabilities, operators, work phases, the current task list of each machine as well as estimated run time for each step of the production.
4 Concepts to engage the work community

4.1 Introduction

With the concepts to engage the work community, we aim to encourage and activate workers to motivate participation at the workplace. The workers are the best experts of their own work, and they have a lot of tacit knowledge and development ideas that may benefit the whole work community. Participation also supports ownership and community building, thus contributing to work well-being.

Participatory design can improve the commitment of workers and utilise their expertise to achieve better results. In our user studies (Deliverable D1.2) the workers would have liked to be more involved in the workplace and production design, and they thought that participation would decrease the problems that they face in their work. However, there were also doubts whether they really could possibly impact their work. It is important to identify the potential areas where the participatory design could be applied.

In the pilot sites, some solutions were already in use for informal knowledge sharing but the need for more developed systems was identified. An easily accessible platform for knowledge sharing could evolve to a place where good work practices and ways to solve problems are shared within the work community but also with work machine providers and other stakeholders.

The virtual factory would facilitate training problem solving skills in realistic problem situations. Virtual factory based training can be utilised well before the actual production line is in use and the training environment can be updated with actual problem situations and suggested solutions as they are faced. Another approach to training was identified as well: plug and learn concept where workers can themselves produce video-based qualification modules to be shared with peers. This is also related to knowledge-sharing and extending the role of the workers to active contributors in training. Module-based training approach would facilitate learning at the worker’s own pace, thus supporting the workers to take responsibility of their own competence development.

4.2 Participatory design

Factory2Fit scenario #6: Developing work practices together

Alec and Niles have just started as factory operators. Owen, who has long-time work experience, introduces them with the work practices and explains how to produce the order with the available machines. Alec is ok with the instructing and starts to work accordingly. However, Niles begins to question the working methods, since the technological advances he has been taught at school are readily in his mind and he is aware of the tools in use in his new workplace. He is very eager to take the tools into productive use. With enthusiasm, Niles provides suggestions to Owen how the opportunities of the tools could be better utilized in the everyday work. Owen tells Niles about the new virtual factory platform that the management has introduced for participatory design activities but Owen has not had time to familiarize himself with.

Niles shares his development ideas on the Virtual Factory platform and guides Owen to access the model also, to give his feedback. Based on his work experience, Owen identifies some safety concerns with Niles’s ideas and together they work the ideas further. The virtual factory platform facilitates testing the ideas in realistic production environment, seeing the production process running and assessing how the ideas work. Now also
Alec joins the ideation and provides some good solutions to the problems identified in testing the ideas in the virtual factory. Soon the whole operator team gets involved in the discussion, and other workers complement the ideas based on their own background. Also some designers contribute and comment how the new ideas could be supported by manufacturing design solutions. When the supervisor gets involved in the discussion, he can see the whole discussion, which helps him in assessing the idea. In the next weekly planning meeting, the whole operator team discusses the ideas and the supervisor tells that the team can test the ideas in practice to see how it works. The operators report their experiences and development ideas further onto the virtual factory. After the test, the new practices seem indeed to improve productivity and quality and they are adopted as part of the official practices. Niles and Owen get awarded as the initiators of the new practices.

The increasing significance of innovations (Franke et al., 2016) results either from the rising market demands (Reguia, 2014) or the need to improve products and processes by consideration of new technologies and digital approaches (Radziwon et al., 2014; Lasi et al., 2014). Innovations are only successful when the provided products and services sate the needs of the end users by providing an additional value (Cavaye, 1995). Hence, user-integrated innovation by dint of participatory design is a key competitive factor for the design of innovative products, services and processes (Reguia, 2014) supporting the implementation of new technologies in a working factory and their consideration in the planning process. All these approaches help to deal with shorter product life cycles and to achieve user satisfaction while having a stronger competitive market situation (Cavaye, 1995).

A factory demands for optimization of its product portfolio and production program, its processes or its layouts while increasing of its modularity and flexibility. Hence, methods of open innovation – especially of participatory design – are investigated to identify their application fields in the context of factory planning and management. A method cube is developed supporting the preselection of suitable methods including their combination and order to tap their full potentials. These methods will, where feasible and beneficial, include the usage of the Virtual Factory Platform of Factory2Fit as a tool for participation, sharing knowledge and concepts and involving the workers.

4.2.1 Literature Review

Every new idea, new technology or new method results in innovations which are qualitative unprecedented products or procedures differentiating appreciable against the state-of-the-art. Innovations drive national economics (Bauer, 2013) by generating new ideas as basis for the creation of new products, processes and services.

To strengthen the Factory2Fit approach suitable methods for participatory design in a (virtual) factory environment need to be provided and developed, thus the focus is on guiding and enabling process and work place innovations within a factory by means of the Virtual Factory Platform. Process innovations increase the economic efficiency of the production by improving business and production processes and provides the setting for designing improved and/or adaptive work places to increase worker satisfaction. Additionally, innovations build the basis to react on slumps in economic activities as well as on problems during production. Procedures to develop innovative processes as well as innovative factory structures and layouts are distinguished in designing completely new or redesigning by modification of existing characteristics or by adding further characteristics (Nurturenergy, 2017). The general procedure to deal with innovations is represented by the innovation circle as shown in Figure 10.
Innovations in factory planning and factory management belong especially to process innovations improving business competitiveness, worker conditions and satisfaction, process stability while optimization of material, information and energy flow and reducing profusion.

New ideas for innovations result either from user or customer needs or from newly available production procedures and technologies (Gakkai, 1988). Hence, it is necessary to study demands across the enterprise with open innovation approaches (Gassmann and Enkel, 2006). Open Innovation describes the innovation process with open enterprise borders to consider internal and external ideas during the development of new products, services and business models. The open-minded characteristic supports open knowledge transfer and networking as well as the optimization of process flows (Gassmann and Enkel, 2006; Innolytics, 2017).

Hence, open innovation is the main topic covering different disciplines: user innovation (Rayna et al., 2015; Mackrill et al., 2017), design thinking (Hasso Plattner, 2017; Geissdoerfer et al., 2016; Plattner et al., 2009), computer-supported cooperative work (Hasenkamp and Syring, 1994), crowdsourcing (innolytics, 2017; Rayna et al., 2015) and participatory design (= co-creation) (Colin et al., 2015). These disciplines provide different types of methods to be applied for process innovations which will be reviewed and evaluated regarding their feasibility to be combined with the Factory2Fit Virtual Factory Platform, the existing interdependencies between these disciplines are represented in Figure 11.

**Participatory design** itself is a discipline of open innovation during the ideation phase of the innovation process and describes the involvement of different stakeholders in the design process to increase the degree of satisfying the end users’ needs (Colin et al., 2015). The main principles of participatory design are shown in Figure 12.
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 723277

The approaches of participatory design enable the integration of different interest groups into the innovation cycle. Especially, workers contribute their experiences and know-how to capture ideas for improvements more efficiently which increases quality and practicability of the resulting innovative designs. Additionally, involved workers' behaviour is characterized by a higher degree of trust, loyalty and engagement. Decisions are born by the integrated employees improving the support by workers based on better transparency of the decision-making process.

The design procedures aim at the improvement of software systems, integration of new technology to current systems as well as at solving failures on shop floor and increasing worker satisfaction.

### 4.2.2 Methodological Approach

#### Participants of Participatory Design

The approaches of participatory design relate to the composition of the participants for tapping their full potential because there aren't any hierarchical or educational limitations (see Figure 13). Hence, the participants have to be determined and reviewed in a prior step. Three main criteria were developed describing the knowledge base of each participant:

- Affiliation with the company: internal vs. external
- (general) knowledge distribution in the group: homogeneous vs. heterogeneous
- (specific) knowledge related to the Design context: uninitiated vs. mixed vs. expert

The affiliation with the company describes the position of each single participant related to the enterprise. An internal participant has advanced knowledge concerning processes, hierarchy, business culture and other special characteristics of the enterprise. An external participant has mostly only general knowledge.
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The general knowledge distribution describes the fields of expertise and their range in the group of participants. The perspective – like methodological, professional, interface, hierarchical or role knowledge – has to be chosen case-by-case based on the use case for the participatory design approach.

The specific knowledge relates to the context of the participatory design approach containing a reference to the need of prior knowledge building for generating a common understanding of the topic.

Figure 13. Exemplary participant composition for solving factory planning tasks with participatory design.
Fields of Applications

Participatory design approaches aim at different results which allows the application in different fields (shown in Figure 14) based on their degree of methodological complexity. These fields of application depend on the use case to be addressed, the tools being involved and the goals to be reached by the team. The Factory2Fit Virtual Factory Platform can be used as supportive tool for e.g. knowledge sharing and layout designing during the participatory design process.

Figure 14. Application Fields related to the innovation cycle

Application Field 1: Acquisition of Knowledge

The "Acquisition of Knowledge" takes place during the “ideate” and “define” phase of the innovation cycle to raise the participants’ awareness for new technologies.

Field(s) for method combination: Method for Acquisition of Knowledge

Application Field 2: Improvement / Adaption

The application "Improvement / Adaption" of a current system is based on the first application field extended with the innovation cycle’s “explore” and “validate” phases. Hence, the knowledge according to the new technology exists from either approaches of participatory design to acquire the knowledge (Application Field 1) or as prerequisites for the design process. A prototypical realization of results can be included optionally.

Field(s) for method combination: Method for Acquisition of Knowledge + Method for Improvement (+ Prototyping Approach)
Application Field 3: Realization

The “Realization” has the highest degree of methodological complexity covering all steps of the innovation cycle. A complete new technology is in the focus of this application. Hence, this application field is based on the prior application fields.

Field(s) for method combination: Method for Acquisition of Knowledge + Method for Improvement + Prototyping Approach

Methods of Participatory Design

In the field of factory planning, it is necessary to integrate stakeholders directly to perceive and communicate their actual needs of functional and design features. Hence, the methods of participatory design have to be investigated in detail. Muller and Kuhn (1993) provide an overview of methodological approaches of participatory design related to their time of use along the product life cycle and their stakeholder participation (shown in Figure 155).

![Figure 15. Overview on methodological approaches of participatory design (related to Muller and Kuhn, 1993)](image)

The diversity of methods in participatory design can be divided in five categories: gamification, prototyping, creativity techniques, dynagrams and image schemes.

Gamification is used to understand a context playfully (Riedel et al., 2014). Examples of methods are LEGO® SERIOUS PLAY® or scenario analysis. LEGO® SERIOUS PLAY® is an innovative hands-on and minds-on method based on metaphorical thinking to improve the understanding of processes. This is achieved by interpretation of alternatives and significances, and discussions in a group (Carpenter, 2008). Scenario Analysis describes the investigation of future developments based either on varying ways to reach desired situations or on varying expectations of progressing (Hassani, 2016). LEGO® MINDSTORMS® rebuilds the production structure in a scaled Lego model representing processes with the aid of programming, and technical components (Biermann, 2013).

Prototyping describes the creation of the first of its manner with reduced demands related to design, function and quality compared with the end product / process to identify weaknesses. Prototypes are physical or virtual models of products or processes. Physical product prototypes are realized by rough prototyping or rapid prototyping, while virtual product prototypes are created by CAD modelling and sketching (Geuer, 1996; Trossin, 1999).
A process prototype represents the main activities of a process considering their interdependencies. The level of detail is geared to the original process. Hence, the complexity increases (DIN, 1981). Process prototypes can be implemented physically by using LEGO® MINDSTORMS® or Cardboard Engineering for example (Biermann, 2013) and virtually by simulation models. Simulation is the key method of systems dynamics used to investigate the characteristics of a social, economic, biological and ecological system. Such a system is defined by dynamic and temporary interdependencies between system entities and their environment (Forrester, 1968).

Creativity techniques are well-known methodological approaches to gather ideas by open-minded and unlimited thinking. Typical methods are Mind Mapping, Morphological Box and Brainwriting (Mesquite, 2011).

Dynagrams are defined as interactive visualizations based on a diagram. They allow users to create, change and extend products or processes collaboratively. The analysis and investigation of scenarios, the yield of conclusions, the preparation of experiences as well as the evaluation and decision-making are enabled. Common dynagrams are the Roger Dynagram, the Sankey Diagram and the Confluence Diagram (Eppler and Kernbach, 2016).

Image schemes are abstract representations of recurring dynamic patterns of interactions to structure people’s awareness. The means are abstractions being more tangible than symbols but less realistic than pictures. They represent sensorimotor contours consisting of information which can be visual, haptic, kinesthetic or acoustical. Hence, image schemes are a metaphorical approach originating from linguistic contexts that is now extended into non-linguistic fields like cognitive psychology (Hurtienne and Blessing, 2007).

Methods of these categories can be utilized to support and strengthen the user oriented innovation process while and by integrating the stakeholders at the same time (shown in Figure 16).

![Figure 16. Participatory design methods supporting and strengthening the innovation process](image-url)

The realization of participatory design methods requires different levels of creativity from the participants. The degree of creativity has to be selected according to targeted results of the
participatory design procedure and the existing knowledge of the technology. Hence, a relation between creativity and technological novelty is identified, as shown in Table 44.

<table>
<thead>
<tr>
<th>Demands resulting from Objectives</th>
<th>Degree of Technological Novelty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Creativity</td>
<td>abstract, innovative approach, break-out the well-known processes</td>
</tr>
<tr>
<td>low</td>
<td>collection of user opinions</td>
</tr>
</tbody>
</table>

Table 4. Relation between Creativity and Degree of Technological Novelty

The kind of suitable method can be selected by analysing the general initial situation. If well-known processes have to be optimized by using existing technology, the demand for creative procedures will be high due to breaking-out of common structures being necessary. The mind of the participants has to be opened by a creative and abstract thinking. Whereas, new technologies like digitalization approaches, being unknown for the participants, are shared concerning their facts. Such a knowledge acquisition requires a low degree of creativity during a high degree of technological novelty.

Preselecting methodologies related to the innovation context

The literature review shows the variety of participatory design methods. Hence, a target-oriented preselection of methodologies is necessary supporting the choice of a suitable method for a specific context with low expenditure (Tawalbech et al., 2017). Therefore, the methodological cube was created (shown in Figure 17).
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 723277

Figure 17. Methodology Cube

The level of objectives represents suitable methods related to the team prerequisites and the intended results. In general, the level of objectives results from the methodological overview of Muller and Kuhn (1993) which is shown in Figure 16. The axis “Position in Innovation Cycle” and “Team Composition” are defined and completed with the prior knowledge of the participants related to the focused technologies of the design process. The “Level of Team” describes the participants and their knowledge base. The “Level of Competence” expresses the dealings with the prior knowledge related to the innovation cycle.

These three dimensions represent the entire complexity of criteria for the selection of suitable methods.

The methodology cube can be divided in 27 sub-cubes. Figure 17 shows an example of such a sub-cube. Every sub-cube has a defined position during the innovation cycle and is characterized by the team composition and the existing prior knowledge. Hence, these input data are used to describe the initial situation where influence factors can be derived. Suitable methods of Participatory Design including their order and combination are determined under consideration of these input data. Ultimately, a guidance for the efficient application of the user-integrated design procedures is issued which describes the process flows connected with their required inputs and outputs, conditions and special demands on participants.

Use Cases for Participatory Design Approaches

Virtual factory simulation enables workers to understand the whole manufacturing process and their role in it. Workers’ motivation and well-being will be enhanced by improving their understanding on how their work affects the whole process and ultimately the customer satisfaction. The participatory design model will involve all the relevant stakeholders in the process. It will support both horizontal peer collaboration inside and between the teams, and furthermore vertical collaboration between
different hierarchical levels. Recognising and combining effectively the ideas, needs and goals from shop floor to managerial level forms the basis for all other development in the factory. The virtual factory model will be used as an engaging platform that enables individual workers and work teams to contribute to the design of manufacturing operations and task distribution. With close cooperation with actual end users, this task will innovate ways to utilise the virtual factory model in participatory design activities. The methods of participatory design will be selected for each case study by using the methodological cube. Target-oriented method selection and methodological guidance support the innovation process by combining different procedures around the key tool - the Virtual Factory Platform.

4.2.3 Prima Power use case: Participatory Design of new production equipment

The Virtual Factory Platform is used to jointly define production equipment modules and their positioning based on assigned tasks to be performed as well as existing and predetermined environmental parameters. The participatory design involves equipment supplier(s), process owner(s), setters, operators and maintenance staff. Based on the 3D simulation model, further optimization can be performed with respect to worker’s needs and preferences in order to optimize the workflow and reduce stress and other negative effects by incorporating worker’s knowledge in the design process. The 3D model being generated in this design phase virtually represents the production equipment to be operated in the future, and can also be used for virtual commissioning and operator pre-training.

4.2.4 UTC use case: Participatory Design for defining new layouts for manufacturing or assembly departments and processes

The Virtual Factory Platform is used to jointly define needed production equipment, area assignment and transfer points as well as their positioning based on existing layouts and predetermined environmental parameters or dimensioning parameters for new processes. Based on the 3D simulation model, further optimization can be performed with respect to worker’s needs and preferences in order to optimize the workflow and reduce stress and other negative effects by incorporating worker’s knowledge in the optimization or design process. The 3D model being generated virtually represents the workflow to be implemented in the future, and can also be used for virtual commissioning and worker pre-training. Furthermore the 3D model and simulation is usable to enhance workers’ understanding and acceptance and to determine needs for improvement or adaptation.

4.2.5 Continental use case: Participatory Evaluation of new technologies and levels of automation

The Virtual Factory Platform is used to jointly evaluate new or potentially applicable production equipment, process technology or equipment and process modifications. Based on the 3D simulation model, alternatives can be simulated and compared with respect to worker’s needs and preferences in order to minimize negative impacts on workflow and work satisfaction by incorporating worker’s knowledge and preferences in the evaluation process. The 3D model being generated virtually represents the potentially used workflow and processes and can also be used for building a knowledge base for technically feasible Levels
of Automation. Furthermore, the 3D model and simulation are usable to enhance workers’ acceptance.

4.3 Knowledge sharing

Factory2Fit scenario #7: Support in problem-solving

Jill, 40 years, has been working in the factory for 6 years. Previously she has worked in similar factories. Jill sees work only as a way to earn a living and appreciates her current job, which is not too challenging. A new machine-system was implemented onto the factory floor one month ago. Jill took part to the training because she has not used this kind of system before. Now she has worked with the system one month: one week with the trainer from the manufacturing company and three weeks by herself. She thinks that the basic use of the system is easy. The next order has come and it requires a change of tools in the tooling system. As Jill does not yet feel very confident with tool changing, she is using an augment reality (AR) based application that provides stepwise guidance. Her AR device gives advice that ensures that she proceeds correctly with the steps when changing the tools. After finishing the tool change, she steps outside of the systems’ safety zone and tries to start the manufacturing system. She gets an error message in the machine’s user interface regarding the tooling system. She wonders what went wrong even though she followed all the steps instructed by the AR application. She remembers that a couple of days ago during a shift change her colleague said that he had some problems with the tooling system. Jill takes her smartphone and opens the knowledge sharing software. She takes a picture of the tooling system and makes a search with it to find information regarding problems related to it. She finds that her colleague has recently solved a similar problem and he has shared a video of it. Jill checks the video that illustrates how her colleague solved the problem. She uses the same problem solving style and is soon ready to start the system. She presses thumbs up icon in the smartphone’s knowledge sharing application to tell that the problem solving video was useful. In addition, she makes a remark that there may be an error in the tool change guidelines.

4.3.1 Motivation and expected impacts

Knowledge sharing among workers is an important activity for a factory’s shop floor. Workers frequently face new problems that they do not know how to deal with. Novice workers may need help in order to perform infrequent operations and more experienced workers are not always available to provide the necessary guidance to the novice worker. The occurrence of a complex and critical task can also force (even) an experienced worker to consult technical diagrams and user guides. However, existing documentation may not provide support to all situations, and support can be found in other workers, if the worker knows whom to ask. For all these reasons, innovative tools that support knowledge sharing in an industrial environment have the potential to improve the collaboration among workers and the productivity as well.

Guidance provided by an experienced worker may not be available when a problem occurs. Using knowledge sharing tools, a worker can quickly receive guidance to solve problems, without the need to ask for help. A database which is fed with information about the steps of a task and solutions to commonly found problems can be utilized by an application which presents the information to the worker on request. The retrieved information can be in different forms, depending on the context, such as text, schematic diagrams, images or videos. The workers, who possess the tacit knowledge, should have motivating tools to share the knowledge to get it to the database to be shared.
Another advantage when using knowledge sharing tools, is the capability of recognizing the most critical phases and tasks. This can be achieved by logging the workers' guidance requests and extracting statistics in order to determine the most frequent requests. Moreover, the use of a web-based platform which supports direct communication between employees in real-time can allow remote assistance sessions between novice workers and experienced workers or supervisors. Training is another activity that can benefit from the use of knowledge sharing tools. Training sessions can be time consuming and usually require an expert worker to be present at the training location. Through the use of knowledge sharing tools, a trainee worker can be self-trained in simple tasks by watching appropriately created training videos.

There is a considerable number of expected impacts on the operation of the shop floor when knowledge sharing tools are employed, which are listed below.

- Tacit knowledge of the more experienced workers is made visible and taken into use
- Collaboration between workers is enhanced and becomes more convenient.
- Workers can solve problems independently, resulting in the reduction of response times and use of additional human resources.
- Workers can provide suggestions on various issues to stakeholders. The worker is an expert of his/her own work and therefore the suggestions may lead to the improvement of work procedures resulting in re-adaptation of the current practices.
- Knowledge sharing output can be used to redesign existing practices or to adopt new ones.

The training processes and training planning can be improved by using the data produced by the knowledge sharing tools to identify frequent problems and suggested solutions.

### 4.3.2 Methodological Approach

Knowledge sharing among peers may include both tacit as well as explicit knowledge. Explicit knowledge is easily transmissible using formal language as it is more visible. Tacit knowledge on the other hand is instead rooted in action in a specific context (Nonaka, 1994). The use of Augmented Reality (AR) can thus greatly assist in the exchange of knowledge, as it links digital or virtual information to objects or places in the physical world, thus making it contextual. Adding social media features to support peer-to-peer knowledge sharing has recently been examined (Aromaa et al., 2017) indicating positive user experience. Together, AR and social media features showed a great potential for knowledge sharing in industrial maintenance. Factory2Fit aims to introduce these concepts to the area of manufacturing.

Knowledge sharing solutions within F2F will be primarily built to harness the advantages of AR platforms and contemporary smart devices. The aim is to attach augmented information onto different parts of a machine configuration, assembly station, part or product, using real world 3D geolocalized data as templates for augmentation. Knowledge can be connected to an actual physical location or its presentation in virtual factory model. Even if it is often useful to connect knowledge to a certain location, knowledge can alternatively be linked to a certain time, production situation or alarm/error. For easy access to knowledge, it should be tagged to support efficient search.
The augmented reality solutions will make contextual guidance available in a given situation. Technology platforms identified for the use of augmentation include standard PCs, smart devices equipped with cameras and Microsoft HoloLens. Potential uses for these technologies include:

- Viewing and interacting with 3D models,
- Video chat,
- Watching live or pre-recorded content,
- Receiving and consulting remote instructions.

Furthermore, utilizing 3D Object Scanner technology (e.g. Vuforia) can assist in the creation of augmentation targets, e.g. elements on which augmented interfaces can “snap on to” upon detection and provide outlets to access the requested knowledge upon request (Figure 18).

![Figure 18. An example use of augmented reality headsets in the augmentation of workstation. A pop-up interface can be "snapped" upon the component/station, providing outlets towards knowledge sharing relevant to the current location.](image)

Augmentation via 3D scanning and object recognitions alone will not suffice, or may not be practical for all cases. However, cases in which 3D Object Feature detection and extraction is limited, due to the materials and textures (e.g. metal sheets) and environmental conditions (e.g. lighting), knowledge sharing is bound to take place. Therefore within F2F, video analytics will play an important part in cases where a video database is to be utilized. Towards this end, algorithms in computer vision, machine learning, object detection and localization estimation will be combined.

To improve productivity through collaboration and social interaction approaches, a social web platform will also be designed. Companies are already using existing messaging systems such as Whatsapp and Messenger for knowledge sharing (Deliverable D1.2). They are good for messaging but they do not support information search for knowledge sharing. The Factory2Fit knowledge sharing platform will provide features such as:

- activity feeds,
- role/position assignment,
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- administrative interfaces,
- easy access to multimedia content sharing,
- profile and connections (groups, teams, direct relations) management,
- best practices,
- multimedia content,
- suggestions section,
- social notifications and powerful search tools for activities,
- videos and other users for one-on-one direct interactions.

The social web platform will be linked to the aforementioned AR rendering solutions to support internal communication in a geo-located (e.g. component- or stationary-based) manner based on the previously mentioned techniques for 3D object recognition and augmentation through 3D Object scanning or video analytics. Gamification practices would be beneficial to be included in social web platform, in order to increase worker’s motivation and efficiency.

The knowledge sharing solutions have to be designed effectively in order to be able to comply and satisfy the user’s and the shop floor’s needs and requirements. The most important requirement that has to be satisfied is the information sharing. During shift change, training, sharing good work practices or even in cases of problem solving, information sharing is the most crucial part. A user should have access to stored knowledge during his/hers whole shift, in order to accomplish a task, ask for advice or even resolve an error situation if needed. Information needed for each task should be updated and connected with good practice advice and also training lessons. Knowledge gathering should be proactive and effortless to the worker. Knowledge should automatically be connected to a certain context or user. Worker-generated guidance may need to be moderated to check e.g. safety risks before sharing the advice.

4.3.3 Prima Power use case

The workers have several knowledge needs. These are mostly related to guidance on how to deal with error situations, e.g.:

- How to deal with an alarm, and what are the recommended solutions
- Stepwise instructions to problem solving (when there is no ready solution)
- How to deal with an error situation without an alarm, then by describing the error, the worker should get guidance
- What is the estimated time to recover from a certain error situation
- How to prevent errors, based on experience from previous errors
- How to start production after a stop situation, stepwise instructions are needed
- Who knows about what – who to ask for support

There are also knowledge sharing needs about production related issues with programmers and production management.

Access to knowledge should be proactively provided, before the worker asks. This is important especially in preventing errors. The guidance should be situationally relevant and the timing of giving the guidance should be right.
Sharing knowledge should be made easy and motivating for the workers. Ideally the worker could just speak out the advice - rather than filling in forms. Still the gathered knowledge needs to be well indexed for re-use. Context data should be captured automatically to support indexing. In addition to sharing knowledge within the factory, knowledge could be shared with the machine supplier (Prima Power) and perhaps also with other factories.

Knowledge shared locally should annotate the official guidance and eventually become part of official guidance. Actual problems and problem solving knowledge could also be utilised in training.

Possible knowledge sharing platforms include:

- Prima Power machines and system
- Add-on system interface on a tablet
- Virtual Factory – a static 3D model might be sufficient
- Augmented reality solutions
  - Perhaps not practical for contextual information presentation as would require operator to move to the point of information
  - Could suit well for stepwise instructions

### 4.3.4 Continental use case

The basic task related knowledge and information can be displayed to the worker depending on his skill level, role and current task, for example: work instructions. Beyond that the workers are producing content for more detailed instructions in several medial formats (text, video clips, etc.) or complement the available instructions with additional advices and hints. This can be of avail, especially for problem solving in case of errors by proposing contextual knowledge from database through the system.

### 4.4 Training and learning at work

**Factory2Fit scenario #8: Online preparation course**

Aziz has just been hired by a manufacturing company. He does not know much about the forthcoming work tasks, but he is supposed to become a production line operator in the factory. Aziz is a young man and not an experienced factory floor worker. He is currently participating in an orientation period in his new workplace, but it is not yet training for the actual operator work. The company that will build the production line will also provide training for the operators. Aziz is excited.

The first part of the actual training is an online preparation course. The supervisor explains that Aziz has to complete this preparation course before the actual training starts. The course includes an online exam as well and Aziz is a bit nervous: He has never been a bookworm and his experiences from school exams are not so motivating. Furthermore, the course content will be in English, which he does not understand very well.

When Aziz logs in to the preparation course site for the first time, he is positively surprised. The course is built on the Virtual Factory platform and includes illustrative pictures, 3D visualisations and videos explaining the basic elements of operating the production line. He learns about user interfaces: how do they look like and what kind of functionalities they provide. The pictures of the user interfaces include interactive buttons that shows the action when they are pressed. Through videos, he also learns about the basic tasks of the operator, safe operation of the machine and even solving the basic problem: how to remove the metal sheet that is stuck in...
Aziz can freely decide when to take the online exam, as long as it’s taken before the given deadline. The exam questions are written in Aziz’s native language. The questions are partly problem-based, meaning that Aziz must choose the right answers to certain problems. The exam includes familiar pictures from the course material. When Aziz makes a mistake, the exam instantly gives feedback and tells the right answer. Finally, when Aziz has completed the course, the trainers will receive a notification. After the exam Aziz still has the access to the course content, so that he can refresh his knowledge whenever needed.

4.4.1 Literature review - State of the Art

A lot of research has recently focused on the concept of Learning Factories. Learning Factories pursue an action-oriented approach with participants acquiring competencies through structured self-learning processes in a production-technological learning environment. Learning Factories thereby integrate different teaching methods with the objective of moving the teaching/learning processes closer to real industrial problems (Tisch et al., 2013). Rentzos et al. (2015) point out that manufacturing education should support the transition from manual work to the future knowledge work. Their teaching factory concept integrates the learning and working environments and thus creates realistic and relevant learning experiences.

Interactive involvement and the participants’ own actions facilitate competence development through structured self-learning processes (Tisch et al., 2016). The training should support solving real production-related problems in two kinds of solution processes: an algorithmic approach where a known problem is solved by a specified decision-making process and a heuristic approach where a new, initially not defined problem is solved by open, analytical and reflective iterations (Tisch et al., 2016). Marvikios et al. (2013) propose role game based industrial learning with interactive simulation environments. They claim that fast and cost-efficient digital training can reduce the need for real hands-on practice and facilitate integrating a broader range of realistic training scenarios. Gonzalez-Franco et al. (2017) showed that training using head mounted devices can replace person-to-person training. Their setup allowed for real-time interactions to simulate conventional forms of training. They tested the system implementing a manufacturing procedure of an aircraft maintenance door. Results indicate that the training using augmented reality device produce similar results as person-to-person training.

4.4.2 Methodological Approach

Motivation for the concept

Learning at work is an important concept to keep the worker informed with the changing work environment and technologies at workplace. The learning is especially critical when a person newly joins a workplace and spends considerable time in training. Even after the initial training the learning at work is important to keep the worker updated with the latest technologies and changing work environment. In this module our aim is to develop novel concepts for learning at work, which allows them to keep themselves abreast with the adaptive work, providing easy and intuitive approach to training a new employee. A key idea for development of the learning at work concept is to capture the knowledge of the experts in an easy and efficient manner so it can be utilized and transferred to
the new and novice workers. The expert knowledge will be utilized not only by the novice worker but also the workers who are from different domains or are not familiar with certain aspects of the work.

A virtual factory platform can support training the operation of an automated production line well before the line is installed. The environment also facilitates training with realistic situations, including exceptional situations such as alarms and errors.

**Expected impacts**

The envisaged tool for learning at work is expected to have the following impacts on the work environment:

- *Reduce dependency on expert worker*: The tool is expected to reduce the dependency on the expert workers in the factory by capturing their knowledge and
- *Lower the training period for novice worker*: The novice worker spend considerable time in introductory training.
- *Improved knowledge transfer*: Traditional learning at work is mostly delivered through hardcopy documents. In the proposed approach we develop novel approaches where the augmented video-based tools will be developed which will utilize the advancement in the computer vision and machine learning technologies to device efficient search and interface which is easy and efficient for the novice work.
- *Adaptive learning for workers*: The tool will allow workers of different skill sets to utilize the knowledge of an expert worker. It will provide a dynamic solution where the worker would have an option to select appropriate training material based on his/her skill set.

**Description of the concept**

*Video based learning solution*: The video provides an intuitive and easy tool to transfer the knowledge. The example of video based learning can be found on video based learning portals such as Coursera ([https://www.coursera.org/](https://www.coursera.org/)) and Udacity ([https://www.udacity.com](https://www.udacity.com)). The idea behind the video based learning solution is to capture the expert knowledge of the factory workers in videos. Videos of expert worker while working in the factory will be recorded. A large number of videos with expert workers working in different scenarios will be stored in a database. These videos will be automatically annotated to index the contents present in them. The information about the content present in the video will also be stored as the metadata with each video. A tablet device will be used to display the videos of expert.

*Virtual factory solution*: With the virtual factory, the worker can practice with actual tasks and also train problem-solving in realistic situations. The training can take place well before the actual manufacturing environment gets to use.

**Enabling technologies**

- Virtual factory platform
- Image recognition algorithms
- Automatic indexing approach
User requirements

Based on the user interviews (Deliverable D1.2), Virtual factory based training is a well accepted idea. Realistic problems and solutions need to be gathered to be utilised in training. The idea of utilizing videos to capture complex assembly operations was well accepted in the interviews as well. After training, it is important to ensure that new skills are taken into use, so the worker is given more challenging tasks as (s)he learns.

4.4.3 UTC use case

The factory manufactures air-handling units (AHU). It has five main subassemblies. The air-handling units assembled at this plant are very different. The difference comes from the capacity of the AHU, therefore the assembly of a AHU with high capacity is different from the AHU with lower capacity. Currently for each AHU configuration the workers receive a document which has the details of the components to be configured. For most of these configurations the most of the basic steps stay the same. Depending on the scale of the AHU, the basic steps have to be repeated more times. For example, one of the sub-assemblies for the AHU is a panel. It is the lower base of the AHU. Depending on the capacity of the AHU, the size of the panel varies. However, the size of the panel varies in the incremental manner, as the panel is assembled by attaching a unit of metal sheet together. The metal sheet component comes in a specific size and the panel size can only be a multiple of the metal sheet component. Therefore, in order to train the worker to assemble the panel, the training should be done for the over-complete case so that it also allows the worker to assemble smaller panels too. Currently the information is transferred in form of paper in the factory for all the assembly processes.

Subassemblies:

Some important points to consider during the design of the training tool are listed below:

- The work done in sub-assemblies is independent from other sub-assemblies, provided all the parts are available for a specific sub-assembly.
- At each of these sub-assemblies a specific part of the AHU is assembled. The level of difficulty varies between different sub-assemblies. Some are more difficult than others. There is also redundancy in the work process in some sub-assemblies; therefore, the training for certain subassemblies can be shared. However, for most of the subassemblies the process is very different. They involve different components and also very different assembly process.
- The workers usually work in a specific sub-assembly. It takes worker up to six months to get comfortable with the tasks at some of these sub-assemblies. The time required for assembling the AHU part varies between different sub-assemblies. It can vary from a half an hour to few hours.
- The work involved in these sub-assemblies is highly repetitive and execution of some specific steps in a pre-defined sequence. The important point is the sequence of the steps stays the same during the process. If the subassembly sequence is: A=>B=>C=>D, then the sequence of the steps stay same, although depending on the scale the repetitiveness might change. For
example for the large AHU the sequence might be something like: A=>A=>A=>B=>C=>C=>C=>D.

Training tool

Based on the process described above, we consider the following steps in the design of the training tool. The video based training tool is designed because the components of the sub-assemblies have complex shapes and the interaction between these components is quite complex to be modelled in a simulated environment. The overall design of the training tool is shown in Figure 19. The important points to be considered for the video based training tools are described as follows:

Modular: The assembly process can last anywhere between a half hour to a few hours, therefore capturing the video for the entire duration of 4 to 5 hours for a specific sub-assembly is not the right approach. With the training videos of this length, the novice worker will not be able to focus and also finding the right content in the video would be difficult. Based on the discussion with the training manager and the experienced workers in the factory we have decided to have a modular approach to the training videos. The main idea is to make videos of the key steps in a sub-assembly process. The key steps are the unique steps in the sub-assembly process. The length of the video will be kept to 1-2 minutes to help the viewers keep their attention to the videos.

Maintain Holistic sequence: An important aspect of the sub-assembly process is the linear sequence of the steps. However, if the training video is made modular by cutting it into segment of key steps, we lose the information about the relation between the different steps in the sub-assembly. In order to retain the information the training tool, in spite of being modular should keep the relation between the different steps at the sub-assembly. For each video in the assembly process we will store the...
information about which video comes before and after, so the worker can get a detailed information about the whole assembly process for a specific component.

**Tacit knowledge transfer:** At times, there is too much information in a video, which might make it difficult for a novice worker to focus on the most crucial point. We will provide an annotation tool which the expert worker can use to add more information in the video at specific sequence in form of text and marker to highlight certain aspects during the training. It will allow the expert worker to transfer the tacit knowledge, which might be difficult to capture, visually in videos.

**Efficient search interface:** With the large number of videos in the database, efficient search strategy for the relevant video becomes very important. The tool will provide the novice worker an option to search the video based on the image search and selection from the panel menu. An example use case is shown in Figure 20.

![Image based search for training video retrieval.](image)

**4.4.4 Prima Power use case**

**4.4.4.1 The context of use**

The customers often expect that production should start at a 100% capacity the next day after installation of the manufacturing line. For the new investment, often the customer has already sold out machine capacity in advance. If the line is a replacement investment, they may have sold out the previous machinery as there is no space for both existing and the new machinery at the customer plant. Customers tend to under-estimate the efforts needed in starting the production, as they may not be familiar with new automated manufacturing technology.
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement no 723277
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Figure 23. The virtual factory can be used with the actual user interfaces.

The aim of the preparation course is to illustrate the appearance of CAM (Computer-Aided Manufacturing) and user interface and to provide general understanding on how they work. At this stage, the focus will not yet be on problem solving, which will be focused more in the actual training.

Preliminary basic content of the preparation course, regardless of the machine type will include:

- Introduction to the CAM system for part programming and Tulus system for part flow designing and monitoring
- Core tasks of the machine operator: inserting the metal sheet, removing the sheet etc.
- Safe operation of the machine
- Solving the most common problem: What to do when the metal sheet is stuck in the machine
- Some basic rules ("philosophy") on how to operate the machine

There will be an online exam after the preparation course. The exam is based on the idea of self-evaluation and the correct answers will be shown instantly to the learner. Prima Power will be able to keep track of the people completing the exam.

In the implementation of the preparation course, the following issues will be considered:

- The course will be implemented as a distance learning course utilising the Virtual Factory tool.
- The course material must be mainly pictures and videos, there should not be too much text due to possible language problems.
- Existing learning tasks (Prima Power) can be utilized in the preparation course.

After the preparation course, issues to be studied for the actual training include:

- Problem solving: 10 most typical error situations; simulating these errors and learning how to solve them.
- With the help of the virtual factory model it can be teach how to operate with different interfaces / in different situations, and how certain problems show on the user interface.
- The virtual factory model should adapt to different customers (adaptation seen by Prima Power).
• Training should include role- and knowledge based parts. Training should adapt to worker roles and competencies.
• Augmented reality based on-the-job learning is also an interesting option

4.4.5 Continental use case

By digitalisation of work instructions, guidance in multimedia format can be shared. The workers can also contribute to the content (see Section 4.3) themselves. Also the mandatory training content will be provided depending on the educational level of the worker and could be combined with a verification of the acquired skills.

Ideas for the solution:

• Task specific instructions in video clip, slides and/or text format provided in the intranet
• Search engine for finding relevant content by keywords, metadata, tags
• Annotation of video content (indexing), for allowing quick search for specific sections
• Virtual factory could be used for making some of the videos
• Suggestions of training content based on skill level and when was the last time worker performed the task (reminder/refresh); some of the content can be mandatory
• Verifying the skills with a quiz or by a manager after going through the training content
5 Conclusions

In this deliverable we have introduced the adaptation concepts that Factory2Fit project is proposing based on a thorough analysis of industrial needs. The concepts have been developed in close collaboration between the industrial partners Continental, Prima Power and UTRC-I, who will provide the pilot environments for the forthcoming development of the concepts and all the other Factory2Fit project partners. The main principle is that the worker is an expert of his/her own job and thus (s)he shall have an active role in the adaptation. The adaptation solutions are divided into two main categories: solutions to empower the worker and solution to engage the work community.

Empowering the worker solutions are based on a worker model. This category includes three concepts: 1) Worker dashboard to give the worker motivating feedback of his/her well-being and performance; 2) Adaptive user-machine interaction for personally and situationally relevant support and functions; and 3) Adaptive task assignment for personally and situationally relevant and motivating tasks.

Engaging the work community solutions encourage and activate workers to active participation at the work place. This category also includes three concepts: 1) Participatory design with motivating tools to contribute to designing their own work environment and related tools and practices; 2) Knowledge sharing tools to make tacit knowledge visible and accessible; and 3) Training solutions that support efficient adoption of new machines and practices, engage workers to contribute to the training materials and support continuous competence development at the worker’s own pace.

We have described the theory and the central ideas related to each concept. We have illustrated the concepts with scenarios of future factories. The Worker Feedback Dashboard will be similar (except for the performance metrics) in each industrial case, that is why we have not described separately the industrial use cases for it. For all the other concepts we have described tentative use cases by the Factory2Fit industrial partners Continental, Prima Power and UTRC-I, in total 12 industrial use cases.

Parallel to the definition of the use cases, the development of the technical enablers for the solutions has been started in the technical work packages of Factory2Fit. The next phase will be to further define the industrial use cases and make sure that the technical enablers are supporting them. The target is to start piloting the best solutions in industrial pilots in autumn 2018.
D1.3 – Adaptation Concepts

References


D1.2 Industrial requirements described the Industrial requirements based on interviews and observations at the pilot sites. A public deliverable,

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