MANTIS

Cyber Physical System based Proactive Collaborative Maintenance

D1.2 Consolidated State-of-the-Art of Sensor-based Proactive Maintenance

Appendix 17:

Existing scenarios of maintenance related Human Machine Interaction (HMI)

Work Package	WP1 - Service platform architecture requirement definition. Scenarios and use cases descriptions
Version	1.0
Contractual Date of Delivery	30/04/2016
Actual Date of Delivery	03/06/2016
Dissemination Level	Public
Responsible	Erkki Jantunen
Contributors	Franc Novak (JSI), Gregor Papa (JSI), Arja Kotkansalo (LUAS), Ville Rauhala (LUAS), Antti Niemel□ (LUAS), Lidia Godoy (ACCIONA), Rafael Socorro (ACCIONA), Daniel Vladu□ič (XLAB), □pela Poklukar (JSI), Quinten Marcelis (ILIAS)

The MANTIS consortium consists of:

Num.	Short Name	Legal Name	Role	Country
1	MGEP	Mondragon Goi Eskola Politeknikoa J.M.A. S.Coop.	CO	ES
2	MONDRAGON	Mondragon Corporacion Cooperativa S.Coop.	BEN	ES
3	IKERLAN	Ikerlan S.Coop.	BEN	ES
4	TEKNIKER	Fundacion Tekniker	BEN	ES
5	FARR	Fagor Arrasate S.Coop.	BEN	ES
5.1	KONIKER	Koniker S.Coop.	TP	ES
6	GOIZPER	Goizper S.Coop.	BEN	ES
7	ACCIONA	Acciona Infraestructuras S.A.	BEN	ES
8	MSI	Mondragon Sistemas De Informacion S.Coop.	BEN	ES
9	VTT	Teknologian Tutkimuskeskus VTT Oy	BEN	FI
10	LUAS	Lapin Ammattikorkeakoulu Oy	BEN	FI
11	NOME	Nome Oy	BEN	FI
12	FORTUM	Fortum Power And Heat Oy	BEN	FI
13	SQ	Solteq Oyj	BEN	FI
14	WAPICE	Wapice Oy	BEN	FI
15	AAU	Aalborg Universitet	BEN	DK
16	DANFOSS	Danfoss A/S	BEN	DK
17	UNIV	Universal Foundation A/S	BEN	DK
18	HGE	Hg Electric A/S	BEN	DK
19	VESTAS	Vestas Wind Systems A/S	BEN	DK
20	SIRRIS	Sirris Het Collectief Centrum Van De Technologische Industrie	BEN	BE
21	ILIAS	Ilias Solutions Nv	BEN	BE
22	ATLAS	Atlas Copco Airpower Nv	BEN	BE
23	3E	3e Nv	BEN	BE
24	PCL	Philips Consumer Lifestyle B.V.	BEN	NL
25	PHC	Philips Medical Systems Nederland B.V.	BEN	NL
26	PHILIPS	Philips Electronics Nederland B.V.	BEN	NL
27	S&T	Science and Technology B.V.	BEN	NL
28	TU/E	Technische Universiteit Eindhoven	BEN	NL
29	RUG	Rijksuniversiteit Groningen	BEN	NL
30	UNINOVA	UNINOVA - Instituto de Desenvolvimento de Novas Tecnologias	BEN	PT
31	ISEP	Instituto Superior de Engenharia do Porto	BEN	PT
32	INESC	Instituto de Engenharia de Sistemas e Computadores do Porto	BEN	PT
33	ADIRA	ADIRA - Metal Forming Solutions S.A.	BEN	PT
34	ASTS	Ansaldo STS S.p.A.	BEN	IT
35	CINI	Consorzio Interuniversitario Nazionale per l'Informatica	BEN	IT
36	AIT	Austrial Institute of Technology GmbH	BEN	AT
37	HBM	Hottinger Baldwni Messtechnik GmbH	BEN	AT
38	INNOTEC	Innovative Technology and Science Limited	BEN	UK
39	AITIA	AITIA International Inc.	BEN	HU
40	BME	Budaperst University of Technology and Economics	BEN	HU
41	JSI	Josef Stefan Institute	BEN	SI
42	XLAB	XLAB d.o.o.	BEN	SI
43	FHG	Fraunhofer Institute for Experimental Software Engineering IESE	BEN	DE
44	M2X	M2Xpert GmbH & Co KG	BEN	DE
45	STILL	STILL GMBH	BEN	DE
46	BOSCH	Robert Bosch GMbH	BEN	DE
47	LIEBHERR	Liebherr-Hydraulikbagger GmbH	BEN	DE

Document Revisions & Quality Assurance

Revisions:

Version	Date	By	Overview
0.1	10.8.2015	Arja Kotkansalo (LUAS)	First draft
0.2	24.8.2015	Arja Kotkansalo (LUAS)	First draft
0.3	27.8.2015	Arja Kotkansalo (LUAS)	First draft
0.4	2.9.2015	Arja Kotkansalo, Ville Rauhala	First draft
0.4.1	31/08/2015	Franc Novak, Gregor Papa	Contribution from Novak and Papa added
0.5	16.9.2015	Arja Kotkansalo, Ville Rauhala and Antti Niemel□	Review and abstract
0.6	25.9.2015	Gregor Papa	Review
0.7	06.10.2015	Riku Salokangas	Added contractual date of delivery etc.
0.8	21.01.2016	Gregor Papa	Combined chapters from appendix 18 to this document
0.9	24.03.2016	Arja Kotkansalo	Added relevant standards and updates to references and contributors
0.10	18.4.2016	□pela Poklukar	Added some additional standards
0.11	26.04.2016	Quinten Marcelis (ILIAS)	Context review
1.0	02/06/2016	Mikel Muxika (MGEP)	Format correction Deliverable info update

Abstract

This appendix contains a description of existing scenarios of maintenance related Human Machine Interaction (HMI). The objectives are to describe the basics of the HMI design and especially to describe the approach for scenario based and context aware HMI design. The goal is also to give a practical examples of different scenarios that maintenance people are conducting during their everyday work. In each scenario is also a description of commonly used devices that maintenance people are using when communicating with the machine or system. The idea is to give an overall picture of when and how maintenance people are interacting with the machines and systems and through which kind of interfaces.

As a result and conclusion can be said that technology today offers multiple choices and solutions for different kind of devices that can be used to support everyday maintenance work. There are many different devices and types for interfaces available that maintenance people can use to interact with the machine and systems. There are also a portable devices that make it possible to connect with the machine or system directly from the field. However, often the most common way to interact between human and machine is through PC or laptop in the office or in the control room. Interfaces are often machine or system specific.

The results are largely based on previous research projects and experiences from the Finnish process industry. Certain industrial sectors are more advanced in using new technology concerning devices or interfaces between human and machines or system. However, the process or manufacturing industry seems to be more conservative when it comes to embracing new technologies.

Table of Contents

1 Introduction

As stated in [1], human machine interaction (HMI), attempts to rationalize relevant attributes and categories that emerge from the use of (computerized) machines. Four main principles, that is, safety, performance, comfort and aesthetics, drive this rationalization along four human factors lines of current investigation: physical (that is, physiological and bio-mechanical), cognitive, social or emotional. Guidelines and solutions from all the above area being applied in MANTIS, however due to space limitation we focus on selected issues, which we consider as essential in initial steps towards individual MANTIS project goals.

Industrial processes are constantly changing and more demanding. Therefore, the machines need to have more functionality. Their operators therefore have access to process information in order to make the right decisions in the right places. This demands effective user interfaces.

HMI denotes real-time interaction and communication between human users and a machine via a human-machine interface. Hereby, the term “machine” indicates any kind of dynamic technical system and it relates to different tech
functionalities of HMI such as presentation and processing of information, advanced features include explanation and adaptability based on user and application models and knowledge-based systems for decision support. [2, p. 101]

Human role remains one of the important factors in system operation. The human role is twofold: controlling, which comprises continuous and discrete tasks of open- and closed-loop activities and problem solving which includes the higher cognitive tasks of fault management and planning. The increased degree of automation in control of dynamic technical systems does not replace the human users but rather modifies the interface [2, p.
102]

The interaction and the study of human-computer called HCI (human-computer interaction). It is one of the research direction in computer science. HCI is a discipline that studies the design of interactive computer systems, evaluation, and implementation of the use of human as well as related phenomena [3]. HCI is a multidisciplinary research area where human and computer activities from different angles are involved, e.g. cognitive psychology, computer science, user interfaces, usability and software. [4]

2 Scenario-based design

MANTIS HMI approach includes scenario-based design. Scenario-based design is a family of techniques in which the use of a future system is concretely described at an early point in the development process. Narrative descriptions of envisioned usage episodes□user interaction scenarios□are then employed in a variety of ways to guide the development of the system that will enable these use experiences. Like other user-centred approaches, scenario-based design changes the focus of design work from defining system operations (e.g., functional specification) to describing how people will use a system to accomplish work tasks and other activities [5].

As stated in [6], scenarios highlight goals suggested by the appearance and behaviour of the system; what people try to do with the system; what procedures are adopted, not adopted, carried out successfully or erroneously; and what interpretations people make of what happens to them. Scenarios have a plot; they include sequences of actions and events, things that actors do, things that happen to them, changes in the circumstances of the setting, and so forth. Scenario representations can be elaborated as prototypes, through the use of storyboard, video, and rapid prototyping tools. They are the minimal contexts for developing use-oriented design rationale: a given design decision can be evaluated and documented in terms of its specific consequences within particular scenarios.

User interaction scenarios serve as the basic inputs for group brainstorming, developing further alternatives, or raising questions about the assumptions behind the scenarios. They can be used to analyse software requirements, as a partial specification of functionality, and to guide the design of user interface layouts and controls. They can also be used to identify and plan evaluation tasks for usability tests [5]. The basic argument behind scenario-based methods is that descriptions of people using technology are essential in discussing and analysing how the technology is (or could be) reshaping their activities. A secondary advantage is that scenario descriptions can be created before a system is built and its impacts felt [7].

Figure 1 shows an overview of the scenario-based usability engineering framework proposed in [7]. This issue is likely to be considered in different implementations within MANTIS project therefore it is prudent to review the concept in more details. The framework encompasses a task flow from problem analysis to design and then to evaluation. Scenarios are used to analyse requirements, envision new designs, guide prototyping and implementation, and organize evaluation.

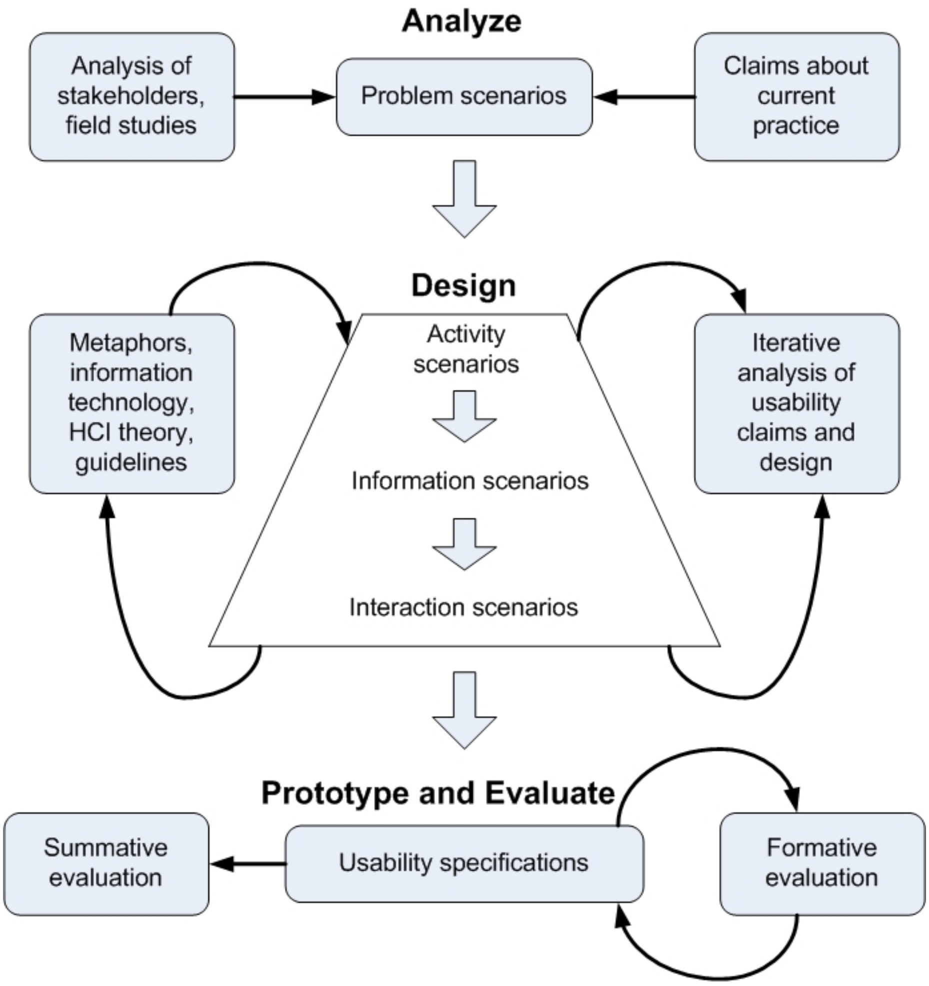

Figure 1. Scenario-based usability engineering framework

In requirements analysis, the problem situation is studied in different ways, such as interviews with clients, field studies or brainstorming among users and developers. This input is used to formulate problem scenarios in which characteristics of the users and typical user tasks are manifested. The main contribution of these scenarios is that they evoke reflection and discussion. Furthermore, the analysis of scenarios is stimulated by claims that expose important features and their impact on users experiences. The analysis of claims presents an important issue when considering and prioritizing alternatives. The design phase is organized in three sub-stages. The first sub-stage includes activity scenarios that focuses on pure functionality and represent typical or critical services that people will seek from the system. The second sub-stage deals with information scenarios that provide details about the information that the system will provide to users. The third sub-stage involves the design of interaction scenarios. These scenarios describe the details of user action and feedback. Each interaction scenario is a fully specified design vision: the users and task(s) being supported, the information needed to carry out the task, the actions the users take to interact with the task information, and the responses the system provides to users' actions. Each set of scenarios is complemented by claims that analyse the possible positive and negative consequences of key design features. The design ideas are evaluated via a prototype that demonstrates solutions proposed in a scenario. In the proposed framework, two evaluation approaches are provided: formative and summative. Formative evaluation is carried out to guide redesign, while summative evaluation serves for system verification. Scenarios guide evaluation through usability specifications, like user tasks with specified usability outcomes that are evaluated repeatedly to guide redesign work. Comprehensive discussion on the use of scenarios in requirements analysis, information design, interaction design, prototyping, and usability evaluation is given in [7].

While in the above framework emphasis is given to usability engineering issues, model-based design is successfully applied in other problem domains. Scenarios are, for example, incorporated in a strategy to provide flexible solutions that allow future system changes to be accommodated with minimal alterations to the existing system [8].

Scenario planning is also a widely accepted management process for decision support activities [9]. Scenarios are defined as a management tool for identifying a plausible future and a process for forward-looking analysis. The above work addresses the problem of process and support of knowledge-based scenario management in decision making. A generic, knowledge-based, life cycle based approach for scenario management is proposed that supports a range of activities from idea generation to final use of the scenarios. Key phases of the life cycle are idea generation, scenario planning, organization, development, execution, analysis, evaluation, and decision support.

In contrast to behaviour modelling, which has not had a widespread impact on practitioners because model construction remains a difficult task, scenario-based specifications have a wide acceptance in industry and are well suited for developing first approximations of intended system behaviour. In [10], the authors propose a process for elaborating system behaviour that exploits the potential benefits of behaviour modelling and scenario-based specifications yet ameliorates their shortcomings. The concept that drives the elaboration process is that of implied scenarios. Implied scenarios identify gaps in scenario-based specifications that arise from specifying the global behaviour of a system that will be implemented component-wise. They are the result of a mismatch between the behavioural and architectural aspects of scenario-based specifications. Due to the partial nature of scenario-based specifications, implied scenarios need to be validated as desired or undesired behaviour. The scenario specifications are then updated accordingly with new positive or negative scenarios. By iteratively detecting and validating implied scenarios, it is possible to incrementally elaborate the behaviour described both in the scenario-based specification and models.

Scenarios can be abstracted and categorized and thus support model-based generation of user interfaces. Task models such as models using the Concur Task Tree (CTT) notation can be applied. A review of task models can be found in [11] and a taxonomy for the comparison of task models in [12], respectively. Alternatively, more recent OO-Method and associated Conceptual Model [13] has been tailored for the creation of information system applications.

HMI includes human factors, machine factors and interaction factors. Human-centred design and engineering are nowadays a widely accepted and practiced approach in HMI. Both human body-related and physiological factors have been intensively studied during the last five decades. Since HMI in system maintenance is dynamic and thus put operator in a control loop, cognitive factors such as workload assessment, situation awareness and human error need to be considered in developed solutions [14]. While automation can assist human operators with task execution, many current designs may actually add to workload and increase user errors. Understanding human sensory data, the cognitive demands and the task context, as well as their interactions in a specific system, represents the first step toward effective human-centred design of interfaces that optimize operator workload. Modelling the interrelationships between mental workload optimization, situation awareness and decision-making can represent an important help to system designers when creating interfaces for specific mission and task domains [1]. Human performance models that reliably predict human capabilities and limitations could assist in the design of novel system interfaces [15]. For the purpose of effective user interface design in MANTIS, the general concept where task workload and workload associated with acquiring situation awareness interact and associated guidelines presented in [1] are worth following. Human error problem is widely recognized and will remain a significant concern for the development of complex systems. The problem has been approached from various viewpoints. Human error is often associated with the loss of situation awareness that occurs when users fail to identify the consequences of changes in their environment. A number of conceptual models that help us to understand the ways in which a loss of situation awareness can contribute to team-based errors has been developed in [16]. Besides, a great deal of attention has recently been devoted to the topic of resilience engineering [17]. This assumes that we should focus less on the causes of human error and more on the promotion of recovery actions.

3 Proactivity

Another important issue in MANTIS HMI design is proactivity. Proactive system is change-oriented and has self-initiated behaviour. Proactive HMI connected to context-aware system predicts next feasible action based on context change or user action.

The design of multi-modal, adaptive and pro-active interfaces for complex real-time applications requires a specific approach in order to guarantee that the interaction between human and computer remains natural. In [18] a formal framework to organize and annotate the existing HMI design solutions (patterns) is proposed. These patterns enable designers to optimize the interaction between human operators and systems that reason about and proactively react on information captured e.g. via sensors.

4 Devices

There are various HMI related devices used by maintenance staff or mechanics. Operation and maintenance staff currently encounter these devices in their everyday tasks and the devices role in maintenance related activities are becoming more important and more common. Commonly used HMI related devises used in different maintenance tasks are smart phones, tablets, operator interface terminals, PC-based HMIs, data loggers, transducer and analyser displays. [19]

5 Baseline descriptions of the existing scenarios

Enterprise Resource Planning (ERP) systems are one of the main management tools. The ERP system is the enterprise information system of the company, the purpose of which is to integrate the different functions of the company among themselves. Some of these functions are for example the production, the distribution, the warehouse control, the billing and the accounting. Enterprise resource planning system can include operation control, different items as a payroll computation, bookkeeping, personal ledger, warehouse control and production control. ERP systems often have their own special section to the control of materials, projects, maintenance, resources and asset management. Modern ERP systems in different partitions are usually separate modules, which companies can buy according to their needs. [20, pp. 25, 26]

In today's business operations almost all have some kind of information system for enterprise resource planning. ERP Systems have been created to replace the manual accounting and operations and to accelerate that way and to facilitate everyday working. When the computers and software will develop in more and more companies, nearly all the functions will be to link to a database. Extensive ERP systems include several modules are complex wholeness□s which implementation and maintenance require plenty of expertise. Due to this the companies have begun to use commercial systems intended for enterprise resource planning, rather than the company itself produced and maintained by the system. [20, p. 26]

Information systems of the maintenance refer to the systems that have been meant for the operation control of the maintenance and for control of material flow. Maintenance of information systems has built the necessary links with other production systems. The own operators and maintenance staff and possibly outsider of the production plant usually establish the users of the system, the company which offers maintenance service. The workers are a user in an important role from the municipality and they are responsible for the production of the new information to the system. [20, p. 27]

Condition based maintenance aims to predict the negative events and in case of the failure, set the production back up as economically as possible. Typically, the prediction is based on the observations from the condition monitoring, which is an important tool for that. However, collecting and analysing data from the process automation into information that benefits maintenance is done quite seldom. Still, there are a lot of different sensors and automation systems that are collecting useful data from the maintenance point of view. [21]

Production control is based strongly on the data received from the external factors, which mainly means from the customers. Based on these external demands, the production is trying to adapt, so that the changes would be as small as possible and the load in the production would be as steady as possible. The effects caused by these external demands, can be usually controlled quite well, partly because of strong development of process control and automation technology.

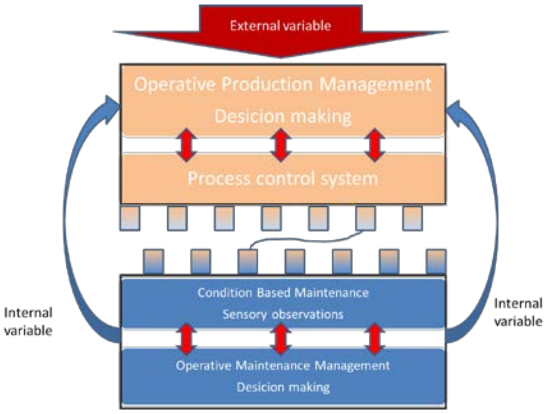

Figure 2. Separate production control and maintenance

Internal variables, planned and unplanned shutdowns are recorded into maintenance information systems and seldom into production systems. Also disruptions in production are seldom recorded automatically into maintenance information systems. Figure 2 presents the separate functioning of these different systems. [21]

In this section it is intended to describe which situations the maintenance staff or the mechanic is in contact with the information processing systems or with the devices.

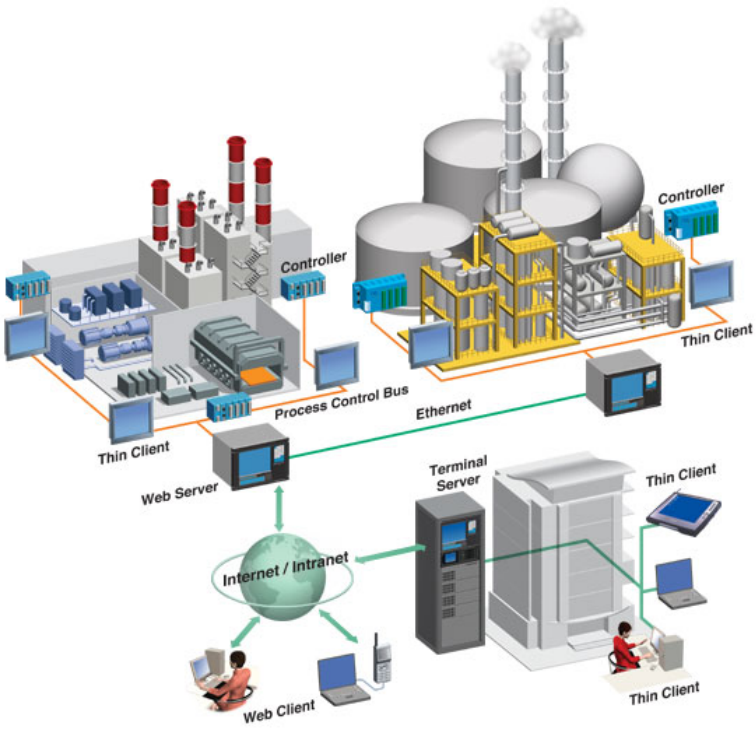

Figure 3. An example of process and automation systems attached to production process [22]

In the Figure 3 above is depicted an example of plant architecture. The system supplier has aligned its hardware. Client solution benefits customers from a shared multi-user architecture. If offer security for critical data and field maintenance results. Usually software let the system integrator easily harmonize hardware with industrial applications for environmental monitoring and transportation systems. [22] Modern digital field automation processes provide accurate diagnostic information. Therefore, these advanced field management tools are essential tools in the maintenance for ensure accurate and undisturbed process. [23] Many factories have around the clock operation control room and process control system must be easily attached to the maintenance system. [24]

Today's manufacturers are faced with the challenge of integrating information from the manufacturing process with other business processes. The automation system (Figure 4) may be a system or a single programmable logic device for controlling operation of the whole plant. One of the factory production activities in controlling the automation system to the central unit acts as a monitoring station, which builds on the connected PC's hardware and hardware discrete I/O units, according to the industry standard. Factory go to control the fairways, which are also referred to as fieldbus, connect the pitch control units, as well as the individual actuators and sensors to the control room computers. [25, p. 20]

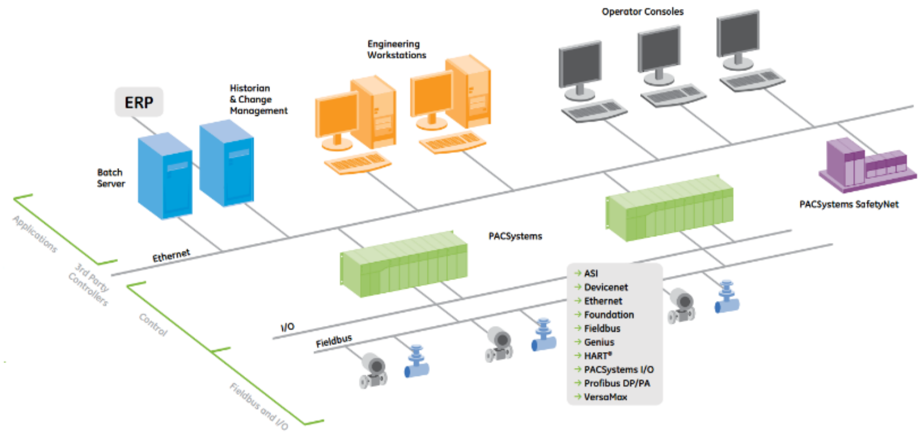

Figure 4. The Process Systems architecture. The system consists of several layers. [26]

Fieldbus System hierarchical division is as follows:

Top level, Applications Layer: The control room computers, separate control terminals and alarm printers are located at this level. From this level may also be associated with a local area network and possibly the Internet [27] p.27. It contains the software that powers the information capabilities of process systems, featuring an Engineering Workstation, Operator Console, Historian, Change Management, Batch Execution and ERP connectivity. [26]

The middle level, Control Layer includes the control units, controllers and actuators controls control logic units [27, p. 27].

The lowest level, Fieldbus and I/O Layer: the individual control units, transmitters, sensors, instrumentation, and process control actuators [27, p. 27]. It is based on an Open Field bus approach and offers a comprehensive portfolio of I/O, so you can choose the right strategy for your needs [26].

Maintenance at the moment

The maintenance work is increasingly mobile, and the same maintenance staff have to deal with a growing number of production facilities. In addition, outsourcing of maintenance services and the purchase of services is growing. Changing the job description sets new requirements for the information management. The maintenance work has become more and more mobile. Because the work itself has become mobile, the information management of maintenance tools also have to become mobile. [28]

In common we know that in factories maintenance there are several computers / telephone system but they are rarely modified. (smartphones, tablets and other mobile devices). Most of the systems used in industrial automation and condition monitoring systems are closed to third party access. The inherent result of the industrial internet all systems would be opened to third party access. [29]

5.1 Work orders receive and sign in maintenance

Maintenance with PC, Smartphone or Tablet

CMMS was mainly used for information transfer and communication between people of different positions and organizations, e.g., sending and receiving work orders or accessing information from the system [30]. Preventive maintenance work orders are generated on a schedule rather than by request. Individual work orders are assigned to the maintenance supervisor or foreman.

Often the documentation of maintenance based on the fact that when the day of work is done, operator go to the (table) computer to report his/her work end of the day. Such problems usually appear in the fact that the maintenance system is not used or the registrations to be done and based by a few active users. The utilisation rate of the system this way will remain weak [20]. This contributed to the fact that IT solutions are not available on the work site. The most common situation was that maintenance and operative staff used the IT-solutions through the office PC. Although the most significant part of the data was collected from the jobsite while maintenance was execution [30]. In pre-planning maintenance, there are applications that enable planned maintenance automatically created electronic work orders supervisors or installers.

5.2 Preventive Maintenance and Condition Monitoring measurement

According to Finnish PSK-6201, 3rd edition (Maintenance. Terms and definitions) □Condition based maintenance means planned repair of faulty items detected by condition monitoring or inspections. Condition monitoring activities include inspections and monitoring performed either by sensing or by measuring devices, and analysis of measurement results.□ [31]

Related to the maintenance organization's data collection method for condition monitoring measurements are usually a variety of portable or permanently installed measuring devices. However, portable instruments for the measurement data collected through the production process or the conclusions drawn from them are reported to IT systems often only the end of the working day. [20, p. 48]

The data collected portable measuring instruments, to the maintenance information system are reported in the information equipment to be used, for example, making preventive maintenance rotations as a reference. These include, for example, work orders acknowledgments, which are often automatically transferred to the maintenance of the information system when the instrument is connected to the docking station. An example of this, SKF Marlin (system) logger [32]. The measurement results referred to in portable condition monitoring measurement equipment is usually not transferred to the maintenance of the information system. However, the conclusions drawn from the measurement results are reported to the maintenance information system, for example in the form of fault indication or work orders. [20, p. 48]

Condition Monitoring

Using HMIs, the machine or process skid operating data can be read and saved in real time.

Figure 5. Both the PC-based HMI on the left and the embedded HMI on the right can be used to measure and monitor energy use

HMIs, whether PC-based or embedded, can connect to a variety of machine controllers, and these connections are required to measure and monitor e.g. energy use. Inputs to the controllers□whether a current sensor or other discrete and analogue signals□give important machine status and measurement data that can be used to improve efficiency. Components such as power metering devices can often be connected directly to the HMI, simplifying the network architecture. [33]

5.3 Analysing the results of condition monitoring

Condition monitoring systems create connections from the production level to the control level. For instance combining condition monitoring solutions with control unit data can provide combined process data and condition monitoring data. This combination can yield better basis for condition analysis. Combining the machine data and condition data makes it easier to rule out anomalies in condition monitoring that are a direct result of changes in process parameters and are not an indication of condition deterioration. With condition monitoring solutions in conjunction with the control unit, it is possible to develop a comprehensive solution for assessing the condition of a machine or system. The data can be sent via Ethernet (e.g. Ethernet TCP/IP protocols or web services) to other data receivers, such as the automation control units of other manufacturers or database supported receivers, such as SCADA or MES systems. [34]

Measurements relating to condition monitoring systems are often instrument-specific, in which case there may be several in a single organization. The data collected from the measurement devices are analysed within the condition monitoring systems, but the results of the analyses are then stored in maintenance information systems. Additional analysis tools may be used such as FMEA, FMECA and simulations, these are again separate systems. [33, p. 49] Figure 6 describes the overall concept of condition monitoring.

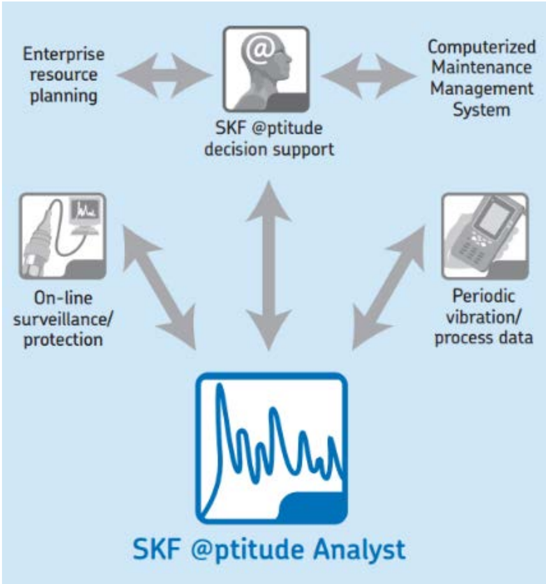

Figure 6. One integrated platform for condition monitoring hardware and software

5.4 Storage and spare parts management

Maintenance often needs materials. [31] Some of these materials are available in-stock in the factory storage. In case the material needed are not in stock they need to be ordered. This can be done via desktop PC or mobile application. [22] If a communication interface e.g. maintenance information system - ERP information system compatibility is lacking, spare parts ordering process in several different sources of information could not functioning. The lack of storage elements, finding spare parts for the system is difficult and the accuracy of the data, as well as spare parts inventory is not up dated.

5.5 Maintenance work planning

Generally, maintenance, materials management, purchase and sale of information systems are linked with each other via the communication interfaces. Although in some cases, the maintenance information system may be stand alone, without other interfaces for communication. The most used functions of CMMS are related to device information, fault reports, work orders and job design. Materials management systems tend to focus on the management of spare parts and a storage position. The purchase and sale systems are used to acquire equipment and spare parts as well as possibly sold in maintenance service.

Information flows between operation and maintenance e.g. supervisor and/or maintenance management system as fault reports or work orders. In some cases in this process is confirmed using telephone. Maintenance work planning is done by saving all information needed for work completion in work order. Work planning usually includes e.g. spare parts, resource allocation, planned work load, scheduling, tools, work instructions, drawings and work safety instructions. In maintenance work orders the most important information is the target of the work because all the other information are targeted on devise level and attached to devise position [35].

One commonly used effective method is the use of templates, or instructional "example work" saved into the CMMS. These example works are ones well planned work orders saved in the system, which are easy to use again in similar work. [36]

5.6 Technical documentation

Certain information regarding technical documentation and drawings are stored both in the maintenance system and in other media (i.e. computer hard drives, CD-ROMs, paper). However, the stored information was not regularly updated or maintained and, thus, making it difficult to know if it can be trusted. Sometimes, the information sources contained conflicting information, which made it difficult to trust. [30]

At the moment common situation is that the technical documents are saved in various locations e.g. in CMMS, document management system, hard drives, Intranet and internet (equipment manufactures web pages). [20]

5.7 Fault tracing and diagnostic

Whether fault tracking is done on location or in a more distributed manner, somewhere in the process the fault log ends up in some sort of control room where there is the full access to the process automation system. Through process automation the maintenance person have access to failure logs, alarm history and all the trend curves from the process measurements. These are important information when finding the target and the reason for failures.

Also all the intelligent machines like frequency changer and machines equipped with operation panels and displays have inbuilt functions to support fault tracing and diagnostic. E.g. maintenance person can also access into machines control settings by connecting his/her laptop into PLC.

Support for failure tracing and diagnostic are often searched from CMMS□s maintenance history and from operators logbooks and failure history. Important information are also equipment manufacturers□ instructions and other technical documentation.

6 Visualization

First, we turn to the way we perceive data visualizations. Stephen Few [37] writes: One of the earliest contributions to the science of perception was made by the Gestalt School of Psychology. The original intent of this effort when it began in 1912 was to uncover how we perceive pattern, form, and organization in what we see. The founders observed that we organize what we see in particular ways in an effort to make sense of it. The result of the effort was a series of Gestalt principles of perception, which are still respected today as accurate descriptions of visual behaviour. Here are a few of the principles that can inform our data visualization efforts:

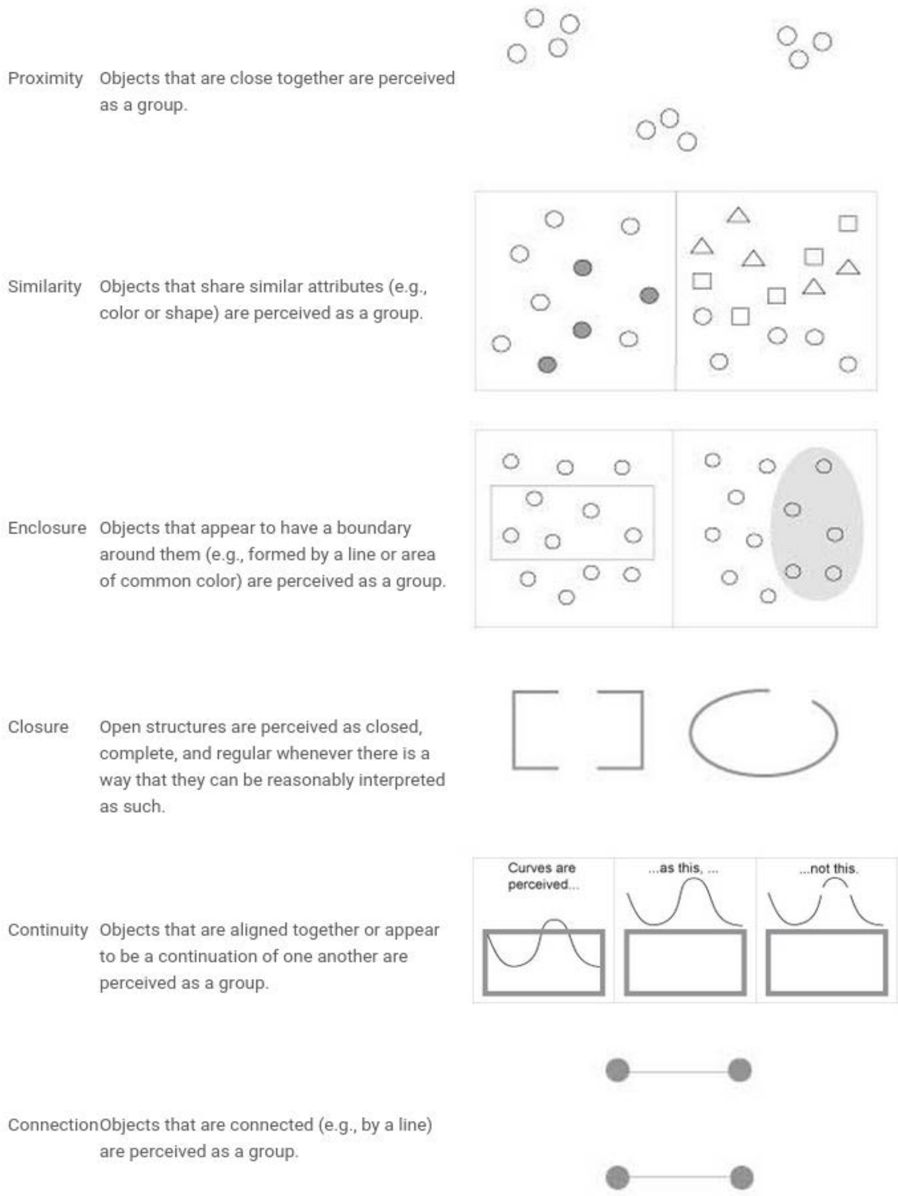

Figure 7: Gestalt principles of perception

These are the building blocks for any kind of visualization □ be it scientific visualization or visualization of the user interface. When moving to the actual visualization of the user interface, we need to consider these four dimensions, which, according to Paterno [38], contribute to the context:

- user-related aspects: preferences, goals and tasks, physical state (e.g. position), emotional state, etc.;

- technology-related aspects: screen resolution, connectivity, browser, battery, etc.;
- environment-related aspects: location, light, noise, etc.;
- social aspects: privacy rules, collaboration, etc.

According to changes in those aspects of the context of use any aspect characterizing a user interface can be modified. This means the user interface can be adapted according to the context □ the perceivable aspects, including media and interaction techniques, layout, graphical attributes; dynamic behaviour, including navigation structure, dynamic activation, and deactivation of interaction techniques; and content, including texts, labels, and images.

The reason for this adaptation lies in the fact the user interface has to adapt to its own context (the device on which it is being presented) and the task to be done (some tasks are not feasible given certain devices). The examples of this adaptation are most easily seen when using personal computer or mobile device (smartphone, tablet) to perform the same task. The visualization of the UI usually changes between devices, while also some of the actions can, while other cannot be done. The adaptation of the visualization is usually tackled with an appropriate model based design, targeting multi-device contexts.

7 Conclusions

Here are the conclusions of this Deliverable. (Speci fication of and defi fferent inte scenarios) In table below the most common everyday scenarios related to maintenance tasks are described in the left column and in the next column devices commonly used in each scenario.

A summary table existing scenarios of maintenance related Human Machine Interaction (HMI) example:

Scenarios	Devices	Description
Work orders receive and sign in maintenance	Smartphones	In the mobile maintenance, work orders are widely received using mobile phone. Commonly used in mobile maintenance like real state.
	Tablets	Enabled in the field, i.e., operator could look drawings, PI diagrams or manuals. Commonly used in mobile maintenance. These already exist but are used a limited extent.
	Laptop/PC	Traditional desk computer where operators works. In the factory.
Preventive Maintenance and Condition Monitoring measurement	Vibration measurement device	Conducting condition measurement on the field. Used in the process.
	temperature measurement device	Conducting condition measurement on the field. Used in the process.
	Infra red/non contact version	Conducting condition measurement on the field. Used in the process.
Analysing the results of condition monitoring	Condition monitoring measurement device	Analysing results directly on the field.
	Laptop/PC	Analysing the collected measurement results later in the office.
Storage and spare parts management	Laptop/PC	Checking spare parts availability, quantity and location. Purchase request if needed. Signing out collected spare parts.
	smartphone	Checking spare parts availability, quantity and location.
Maintenance work planning	Laptop/PC	Work planning usually includes e.g. spare parts, resource allocation, planned work load, scheduling, tools, work instructions, drawings and work safety instructions

Technical documentation	Laptop/PC	different documentation systems (e.g. DoHa)
Fault tracing and diagnostic	Process automation Control room	Full access into the process automation system. The maintenance person have access to failure logs, alarm history and all the trend curves from the process measurements
	operation panels and displays	These have inbuilt functions to support fault tracing and diagnostic. E.g. maintenance person can also access into machines control settings by connecting his/her laptop into PLC.
	CMMS□s maintenance history	Support for failure tracing and diagnostic are often searched from CMMS□s maintenance history and from operators logbooks and failure history. Important information are also equipment manufacturers□ instructions and other technical documentation.
	Industrial laptop / tablet	Laptop on the field More flexible than tablet but not as mobile nor as easy to use. Allows connection to various devises and monitoring systems on the field. Used in the process.
	intelligent machines like frequency changer	These devices often allow users to view trends of data, alarms and events.

References

[1] G. A. Boy, The handbook of human-machine interaction: a human-centered approach, Ashgate, 2011.

[2] "MANTIS Full Project Proposal," 2014.

[3] A. Oulasvirta, Ed., Ihmisen ja tietokoneen vuorovaikutus, Gaudeamus, 2011, p. 320.

[4] L. Parkkila, "Ihminen-ihminen ja ihminen-tietokone vuorovaikutus," 2013.

[5] A. Sears and J. A. Jacko, The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications, (Human Factors and Ergonomics), 2nd ed., 2006.

[6] J. M. Carroll, Making Use - Scenario-Based Design of Human-Computer Interactions, Massachusetts Institute of Technology, 2000.

[7] M. B. Rosson and J. M. Carroll, Usability Engineering. Scenario-Based Development of Human-Computer Interaction, Morgan Kaufmann Publishers, 2002.

[8] I. Bate and P. Emberson, "Incorporating Scenarios And Heuristics To Improve Flexibility In Real-Time Embedded Systems," in *Proceedings of the Twelfth IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS□06)*, 2006.

[9] D. M. Ahmed, D. Sundaram and S. Piramuthu, "Knowledge-based scenario management □ Process and support," in *Decision Support Systems, Volume 49, Issue 4, November 2010, pp 507-520*.

[10] S. Uchitel, J. Kramer and J. Magee, "Incremental elaboration of scenario-based specifications and behavior models using implied scenarios," in *ACM Transactions on Software Engineering and Methodology, Volume 13, Issue 1, January 2004, pp 37□85.*.

[11] Q. Limbourg and J. Vanderdonckt, "Comparing task models for user interface design, in D. Diaper & N. Stanton (eds)," in *The Handbook of Task Analysis for Human-Computer Interaction*, Lawrence Erlbaum Associates, Mahwah, NJ, USA, 2003, p. chapter 6.

[12] G. Meixner and M. Seissler, "Selecting the Right Task Model for Model-based User Interface Development," in *ACHI 2011 : The Fourth International Conference on Advances in Computer-Human Interactions, pp. 5-11*, 2011.

[13] O. Pastor, S. Espa□a, J. I. Panach and N. Aquino, "Model-driven development," in *Informatik Spektrum 31(5): pp. 394□407*, 2008.

[14] K.-F. Kraiss, Ed., Advanced Man-Machine Interaction, Springer, 2006.

[15] M. J. Doyle, "Modeling the interaction between workload and situation awareness: An overview and future course," in *Symposium conducted at the Human Interaction with Complex Systems and 2nd Sensemaking of Complex Information Annual Conference, Norfolk, VA*, 2008.

[16] M. Endsley, "Situation awareness: Progress and directions.," in *In S. Banbury and S. Tremblay, A cognitive approach to situation awareness: Theory, measurement and application*, Aldershot, UK , 2004.

[17] E. Hollnagel, D. D. Woods and N. Leveson, Resilience Engineering: Concepts and Precepts. Aldershot, Ashgate, Aldershot: Ashgate, 2006.

[18] N. Ferreira and et al, "Patterns for HMI design of multi-modal, real-time, proactive systems," in *IUI 2013 Workshop: Interacting with Smart Objects*, 2013.

[19] Advantech, □IoT and Big Data Combine Forces,□ 2015.

[20] V. Rauhala, "K□ynniss□pidon tiedonkeruun tehostaminen, K¨YNTI □ K□ynniss□pidon tiedonhallinta," 2013.

[21] A. Siimes, V. Rauhala and A. Kotkansalo, "Information Management of Production Assets," in *EuroMaintenance 2014, Congress proceedings May 5-7, Helsinki Finland*.

[22] "Human Machine Interfaces," Advantech, 2015. [Online]. Available: http://www2.advantech.com.tw/eAutomation/Human-Machine-Interfaces/includes/image˙HMI.htm.

[23] Promaint, "Kentt□- automaation hallinta tehtaan toiminnan apuna," 30 10 2013. [Online]. Available: http://www.promaintlehti.fi/Kunnonvalvonta-ja-kayttovarmuus/Kentta-automaation-hallinta-tehtaan-toiminnan-apuna. [Accessed 20 08 2015].

[24] Promaint, "Tietojohtaminen nousemassa kunnossapidon avaintekij□ksi," 21 11 2013. [Online]. Available: http://www.promaintlehti.fi/Tuotantotehokkuuden-kehittaminen/Tietojohtaminen-nousemassa-kunnossapidon-avaintekijaksi. [Accessed 19 08 2015].

[25] K. Stouffer , J. Falco and K. Kent, □Guide to Supervisory Control and Data Acquisition (SCADA) and Industrial Control Systems Security,□ 2006.

[26] G. F. I. Platforms, "Proficy Process Systems," 2009.

[27] J. Tarvainen, □Tiedon jalostaminen k□ynniss□pidon tarpeisiin K¨YNTI - k□ynniss□pidon tiedonhallinta,□ 2013.

[28] "Toiminnanohjaus taskussa," M-Technology Oy, 2014. [Online]. Available: https://toiminnanohjaustaskussa.wordpress.com/. [Accessed 12 8 2015].

[29] H. Manninen, Writer, *Teollisuuden Internet:Lis□□ tehoa koneista.* [Performance]. Control Express Finland Oy, 2014.

[30] M. Al-Jumaili, V. Rauhala, P. Tretten and R. Karim, "Data Quality in eMaintenance: A Call for Research," in *Proceedings of MPMM*, 2011.

[31] P. S. Association, *PSK 6201 (Maintenance. Terms and definitions),* 3rd edition ed., 2011.

[32] SKF, "SKF Microlog Inspector/SKF MARLIN Systems/Accessories Catalog," 2015.

[33] R. Clark, "System Integration: Using HMIs to improve energy efficiency," *InTech Magazine,* vol. 2015, no. Jul-Aug .

[34] Schaeffler, □The FAG SmartCheck on the path towards Industrie 4.0,□ 21 8 2014. [Online]. Available: http://www.schaeffler.de/content.schaeffler.de/en/press/press-releases/press-details.jsp?id=68270337. [Accessed 28 8 2015].

[35] L. Parkkila, □K□yt□n ja kunnossapidon yhdist□minen k□ynniss□pidoksi,□ Lapland University of Applied Sciences, Kemi, 2015.

[36] E. Sorvisto, "K□ynniss□pitoon liittyv□n tiedonhallinnan tehostaminen Kemin kaivoksella," 2011.

[37] S. Few, "Data Visualization for Human Perception," in *The Encyclopedia of Human-Computer Interaction, 2nd Ed*, M. Soegaard and R. Friis Dam, Eds., Aarhus, The Interaction Design Foundation.

[38] F. Paterno, "User Interface Design Adaptation," in *The Encyclopedia of Human-Computer Interaction, 2nd Ed*, M. Soegaard and R. Friis Dam , Eds., Aarhus, The Interaction Design Foundation.

[39] R. L. Boring, J. Hugo, C. M. Richard and D. D. Dudenhoeffer, □SIG□The Role of Human-Computer Interaction in Next-Generation Control Rooms,□ Idaho National Laboratory, 2005.

[40] "Plant Information - Proficy Mobile," Novotek, 2015. [Online]. Available: https://www.novotek.com/en/products/plant-information/proficy-mobile. [Accessed 10 08 2015].

[41] A. Philips, "5 Disruptive Technologies; Facing ERP," *Manufacturing Global,* p. 17, July 2015.

[42] "Control systems connectivity and modernization," ABB, 2014. [Online]. Available: http://new.abb.com/control-systems/system-800xa/control-systems-connectivity-control-room-consolidation-modernization. [Accessed 10 08 2015].

[43] "Mobiilisovellus k□ynniss□pidon tarpeisiin," Lapland University of Applied Sienceses, 2014.

[44] Panasonic, "Realising the gift of time -Enterprise and goverment tablet solutions," 2014.

[45] Metso, "Results automation," 2014.

[46] Siemens, "Operator Control and Monitoring Systems," 2015.

[47] SKF, "Basic condition monitoring products," [Online]. Available: http://www.skf.com/pk/products/condition-monitoring/basic-condition-monitoring-products/index.html. [Accessed 1 9 2015].

[48] C. Maras, "Thermal Imaging Cameras a Great Tool for Predictive Maintenance Inspections," *Maintworld,* no. 2, 2013.

[49] FLIR, "Thermal imaging guidebook for industrial applications," FLIR Systems AB, 2011.

[50] SKF, "Vibration measurement tools," [Online]. Available: http://www.skf.com/pk/products/condition-monitoring/basic-condition-monitoring-products/vibration-measurement-tools/index.html. [Accessed 1 9 2015].

[51] Schaeffler, "FAG SmartCheck, Machinery monitoring for every machine".

[52] O. Off-Highway, "Fluid power systems & components," 2015. [Online]. Available: http://www.oemoffhighway.com/product/11293138/enm-co-series-t39-lcd-hour-meter-and-up-counter. [Accessed 29 8 2015].

List of annexes

Annex A1. The relevant standards related to appendix 17: Existing scenarios of maintenance related Human Machine Interaction (HMI) and appendix 18; Existing visualization techniques

Concerning WP5, HMI design and development

Task 5.1 - Interaction scenarios identification (app 17)

Task 5.3 - Context-awareness approaches

Task 5.4 - Intelligent Human-Machine Interface design (app 17)

Task 5.6 □ Advanced visualization approaches (app18)

Annex A1.

Standard Organization	Number	Title	Publishing Year	Work Package	Task
ANSI/HFES	100	Human Factors Engineering of Computer Workstations	2007	WP5	Task 5.4
ANSI/ISA	101.01	Human Machine Interfaces for Process Automation Systems	2015	WP5	Task 5.4
EN	13460	Maintenance - Documents for maintenance	2009		
IEC	62550	Spare parts provisioning	2014		
IEC	62402	Application guide Obsolescence management	2007		
ISO	9241-1	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 1: General introduction	1997	WP5	Task 5.4
ISO	9241-11	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 11: Guidance on usability	1998	WP5	Task 5.4
ISO	9241-110	Ergonomics of human-system interaction -- Part 110: Dialogue principles	2006	WP5	Task 5.4
ISO	9241-12	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 12: Presentation of information	1998	WP5	Task 5.4
ISO	9241-13	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 13: User guidance	1998	WP5	Task 5.3
ISO	9241-14	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 14: Menu dialogues	1997	WP5	Task 5.4
ISO	9241-143	Ergonomics of human-system interaction -- Part 143: Forms	2012	WP5	Task 5.4
ISO	9241-15	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 15: Command dialogues	1997	WP5	Task 5.4
ISO	9241-16	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 16: Direct manipulation dialogues	1999	WP5	Task 5.4
ISO	9241-2	Ergonomic requirements for office work with visual display terminals	1992	WP5	Task 5.4

		(VDTs) -- Part 2: Guidance on task requirements			
ISO	9241-210	A Human-Centered Design Process	2010	WP5	Task 5.3
ISO	9241-210	Ergonomics of human-system interaction -- Part 210: Human-centred design for interactive systems	2010	WP5	Task 5.4
ISO	9241-302	Ergonomics of human-system interaction -- Part 302: Terminology for electronic visual displays	2008	WP5	Task 5.6
ISO	9241-303	Ergonomics of human-system interaction -- Part 303: Requirements for electronic visual displays	2011	WP5	Task 5.6
ISO	9241-305	Ergonomics of human-system interaction -- Part 305: Optical laboratory test methods for electronic visual displays	2008	WP5	Task 5.6
ISO	9241-307	Ergonomics of human-system interaction -- Part 307: Analysis and compliance test methods for electronic visual displays	2008	WP5	Task 5.6
ISO	9241-400	Ergonomics of human-system interaction -- Part 400: Principles and requirements for physical input devices	2007	WP5	Task 5.4
ISO	9241-5	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 5: Workstation layout and postural requirements	1998	WP5	Task 5.4
ISO	9241-6	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 6: Guidance on the work environment	1999	WP5	Task 5.4
ISO	9241-6	Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 6: Guidance on the work environment	1999	WP5	Task 5.4
PSK	6201	Maintenance. Terms and definitions 3rd edition ed	2011	WP5	Task 5.1
PSK	7502	Key performance indicators of logistics. Material function.	2002		
SFS EN	13306	Maintenance. Maintenance terminology	2010	WP5	Task 5.1
SFS EN	15341	Maintenance. Maintenance Key Performance Indicators	2007	WP5	Task 5.1
SFS-EN	62744	Representation of states of objects by graphical symbols Kohteen toimintatilan esitt□minen graafisilla tunnuksilla	2015		

SFS-EN	894-1	Safety of machinery. Ergonomics requirements for the design of displays and control actuators. Part 1: General principles for human interactions with displays and control actuators	2009	WP5	Task 5.4
SFS-EN	894-2	Safety of machinery. Ergonomics requirements for the design of displays and control actuators. Part 2: Displays	2009	WP5	Task 5.4
SFS-EN	894-3	Safety of machinery. Ergonomics requirements for the design of displays and control actuators. Part 3: Control actuators	2009	WP5	Task 5.4
SFS-EN	894-4	Safety of machinery. Ergonomics requirements for the design of displays and control actuators. Part 4: Location and arrangement of displays and control actuators	2010	WP5	Task 5.4
UNI	10584	Maintenance. Systems of information of maintenance	1997	WP5	Task 5.1
UNI	10652	Maintenance - Appraisal and evaluation of the goods condition	2009	WP5	Task 5.4
UNI	10147	Maintenance - Additional terms and definitions to.	2003		
UNI	11063	Maintenance - Definitions of ordinary and extraordinary maintenance	2003		
UNI	11082	Maintenance - Specific terminology for the group transportation field	2003		
UNI	10749-1	Maintenance - Guidelines for management of maintenance materials - General aspects and organizational problems	2003		
UNI	10749-2	Maintenance - Guidelines for management of maintenance materials - Criteria for classification, codification, standardization and support	2003		
UNI	10749-3	Maintenance - Guidelines for management of maintenance materials - Criteria for the choice of materials to be managed	2003		
UNI	10749-4	Maintenance - Guidelines for management of maintenance materials - Criteria for operational management	2003		

UNI	10749-5	Maintenance - Guidelines for management of maintenance materials - Criteria for purchasing, tests and final check	2003		
UNI	10749-6	Maintenance - Guidelines for management of maintenance materials - Administration criteria	2003		
UNI	10874	Maintenance of buildings - Criteria in order to write maintenance and use manuals	2000		
VDI	2892	Management of maintenance spare parts. (Ersatzteilwesen der Instandhaltung)			
CENELEC	50459-1	Railway applications - Communication, signalling and processing systems - European Rail Traffic Management System - Driver-Machine Interface - Part 1: General principles for the presentation of ERTMS/ETCS/GSM-R information	2005	WP5	T5.4
CENELEC	50459-2	Railway applications - Communication, signalling and processing systems - European Rail Traffic Management System - Driver-Machine Interface - Part 2: Ergonomic arrangements of ERTMS/ETCS information	2005	WP5	T5.4
CENELEC	50459-3	Railway applications - Communication, signalling and processing systems - European Rail Traffic Management System - Driver-Machine Interface - Part 3: Ergonomic arrangements of ERTMS/GSM-R information	2005	WP5	T5.4
CENELEC	50459-4	Railway applications - Communication, signalling and processing systems - European Rail Traffic Management System - Driver-Machine Interface - Part 4: Data entry for the ERTMS/ETCS/GSM-R systems	2005	WP5	T5.4
CENELEC	50459-5	Railway applications - Communication, signalling and processing systems - European Rail Traffic Management System - Driver-Machine Interface - Part 4: Symbols	2005	WP5	T5.4
CENELEC	50459-6	Railway applications - Communication, signalling and processing systems - European Rail Traffic Management System - Driver-Machine Interface - Part 4: Audible information	2005	WP5	T5.4

ETSI	EN 301 515	Global System for Mobile communication (GSM); Requirements for GSM operation on railways	2005	WP5	T5.4
ETSI	TR 102 281	Railways Telecommunications (RT); Global System for Mobile communications (GSM); Detailed requirements for GSM operation on Railways	2013	WP5	T5.4
IEEE	730	IEEE Standard for Software Quality Assurance Processes	2014	WP5	T5.1, T5.4
IEEE	830	IEEE Recommended Practice for Software Requirement Specifications	1998	WP5	T5.1, T5.4
IEEE	1016	IEEE Standard for Information Technology□Systems Design□ Software Design Descriptions	2009	WP5	T5.1, T5.4
IEEE	1063	IEEE Standard for Software User Documentation	1987	WP5	T5.4