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# E-Learning and Context Aware e-Support Software for Maintenance

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**Abstract.** Industrial Maintenance is seeking to enhance the efficiency of asset usage according to multiple criteria and constraints. Its implementation is facilitated by the application of a range of enabling technologies, termed in this context as e-Maintenance. Integrated e-Maintenance solutions can support a multitude of industrial maintenance procedures, from top-level management to low-level machinery technical issues. The level of complexity in these procedures varies greatly and requires a multidisciplinary level of skills from the involved personnel. Therefore, e-Maintenance applications can benefit from incorporating e-Learning and e-Support solutions. E-Learning can be an effective training method for maintenance, by providing cost effective, location-independent and easily updated training content. E-Support can be employed to provide technical staff with contextualized information and services in order to aid them with their assigned tasks. The WelCOM e-Maintenance architecture offers a framework that combines a networked infrastructure of intelligent wireless sensors, and a toolset of maintenance support services, linked to a CMMS. In this setting, one of the objectives is to integrate e-Learning in the form of web-based training modules and e-Support, by providing ubiquitous help through mobile devices to technical staff. The web-based learning is tailored to condition monitoring tasks, whereas the e-Support is planned to include instructions, videos, manuals or technical reports, all specially formatted to be delivered by a mobile device (tablet), exploiting its graphic, storage and networking capabilities. In this way, we aim for a smooth acceptance of the new e-Maintenance system, by providing easily accessible and context-dependend support for maintenance personnel.

## 1. Introduction

The ubiquity of e-Maintenance services facilitated by the extensive usage of mobile and wireless technologies constitutes a significant upgrade in modern industrial asset and maintenance management practice [5]. Through this upgrade, maintenance information and services can become seamlessly available across the maintenance operations chain. The potential impact is significant, as organizations are empowered to design, plan and execute their maintenance policies and programs based on the evidence of the most relevant and up to date information and knowledge. With increasing global pressure for achieving more rational and energy-efficient resources usage, while meeting safety and quality requirements, e-Maintenance constitutes an important enabling framework.

Importantly, e-Maintenance offers the opportunity for smooth, low risk and low cost integration of enabling technologies in maintenance processes and activities. Its implementation is facilitated by the application of a range of enabling technologies, such as web services, wireless networks, portable

devices, wired and wireless sensors and MEMS (Micro-Electro-Mechanical Systems), as well as auto-identification means, such as RFIDs (Radio-Frequency Identification). Coupled with intelligent computing, such enabling technologies directly upgrade the ability of an organization to oversee the implementation of a condition-based maintenance strategy [10].

Furthermore, maintenance staff is empowered to become mobile actors, operating in a dynamic environment and directly interacting with other involved personnel, while interacting with software offered through portable devices, in order to receive data for maintenance work orders and technical support. At higher enterprise layers, staff is also able to handle data from distributed shop floors, while having a direct insight into the assets and production state, as well as on resources availability and logistics. This integrated context offers to the organization the opportunity for e-maintenance activities (e-monitoring, e-diagnosis, e-prognosis) which enables the personnel to proactively engage to deliver the execution of maintenance services.

The increasing complexity and immediacy of the shop floor maintenance function, places a far greater emphasis on the ability to make informed decisions on the spot, whether these are related to diagnostics or to planning and execution of work orders and repairs. Success can be achieved insofar as personnel have the right skills but also the information needed to perform their intended function. Therefore, an e-Maintenance framework needs to be enriched with the right tools that upgrade the ability of maintenance personnel to meet these challenges. To this end, the opportunities offered by the introduction of e-Training and e-Support services are still relatively unexplored. This paper discusses prospects for e-Training and e-Support in the context of the WelCOM project, which introduces an integrated e-Maintenance architecture to support condition-based maintenance [14].

## **2. e-Maintenance Architecture**

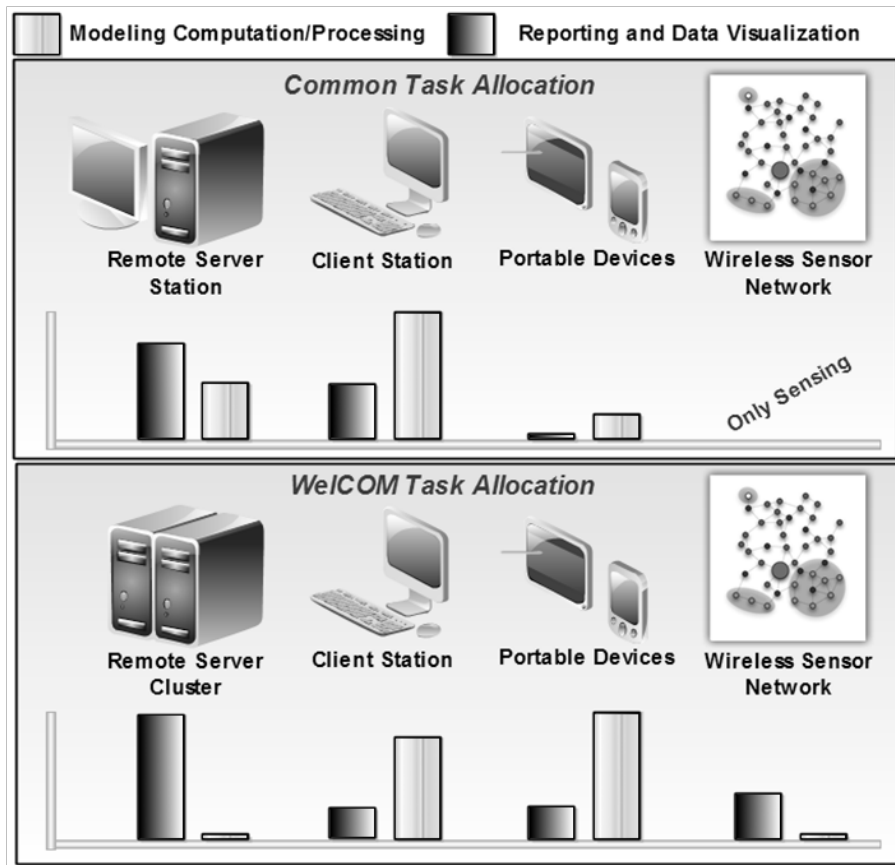
The WelCOM platform constitutes an initiative to vertically integrate different organizational layers of the maintenance function by introducing a number of functional components for monitoring, diagnostics, prognostics, maintenance planning and e-support. While the requirements definition is driven by an industrial testbed, WelCOM invests in independent modular components, capable of extensive customization and configurability. As a system, it is designed to employ software mechanisms and services that bring functionality in three major hosting domains of its infrastructure: (i) server back end logic, (ii) sensor embedded logic and (iii) portable device applications.

Each of these three domains features device-native advantages that can leverage the efficiency and extend the applicability of certain maintenance-related tasks. Following the recent design patterns in middleware architectures, the aim is to exploit the computational capacity of embedded and mobile operating systems. WelCOM aims to move a balanced part of its modeling mechanisms and client interfaces down to the level of embedded routines and mobile applications respectively. Such a decentralization of the platforms logic and user access intents to achieve a two-fold result:

### *2.1. Independent focus of implementations.*

Having studied the input and output requirements of each monitoring task, along with assessing its user interaction level and its administrative nature, it is possible to allocate implementations to device domains. Each implementation can be driven by a development process that makes use of the latest domain-oriented frameworks, and at the same time provides the proper interfaces for cross-domain data exchange and process invocation (service calls). In this context, WelCOM is designed to port novelty detection down to sensors and platform control along with report compilation (data presentation and input) down to portable devices (Figure 1). Novelty detection is a data modeling task that plays a significant role in identifying abnormal behavior of machinery operation. The computational complexity of such a task is dictated by the number of monitored parameters and the processing needs of the modeling technique. Fine tuning such factors can enable the implementation of the corresponding components at sensor level logic. Sensor embedded novelty detection transforms the WelCOM sensing infrastructure into collective processing nodes, capable of producing added value in terms of information semantics at the early stage of data acquisition. Report compilation is an

interaction based process that designates the user's ability to receive and enter semantically enriched information to the system. Semantically enriched output information relates to highly descriptive representations of processed monitored parameters, such as detailed trends, outlier detection and pattern visualizations from all platform's backend detection mechanisms. Semantically enriched input information, relates to highly configurable reporting forms capable of effectively capturing the user's observations, empirical feedback and maintenance field knowledge.



**Figure 1.** Decentralization of Maintenance System Tasks.

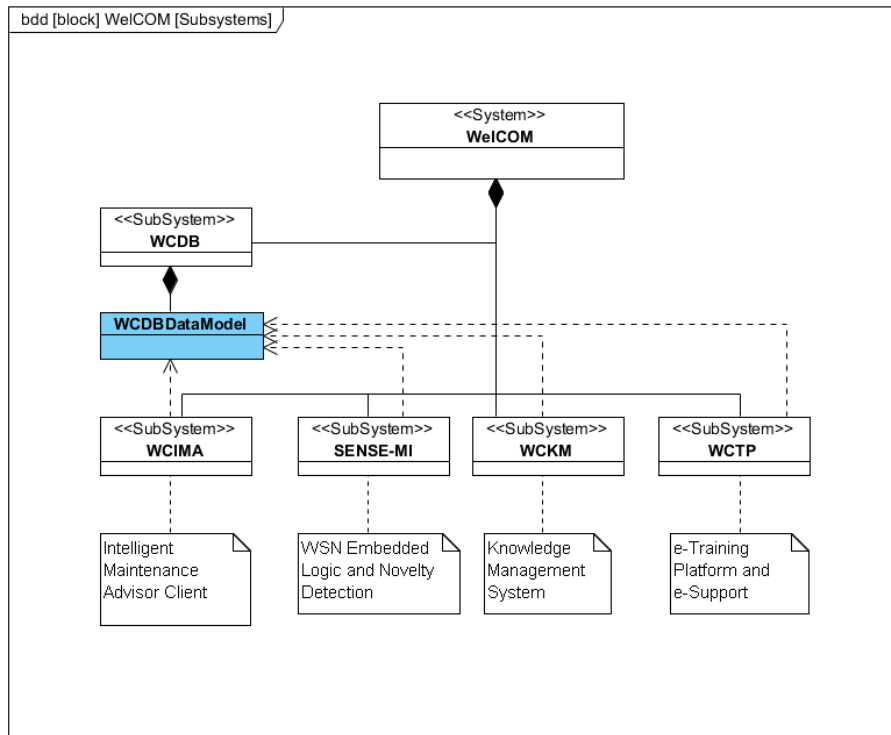
### 2.2. Maximizing the efficiency of domain feature integration.

The development of maintenance tools has shifted from the limited concept of computer-based solutions, to a collaborative set of software modules hosted by largely diverse small devices. Such devices exhibit unique functionality solely due to their novel hardware features and scaled size (portability).

- In the WelCOM platform, programming a condition monitoring profile into a sensor node directly elevates the platform's data quality and semantics, since such components integrate pre-processing filters to the data acquisition level. Furthermore, each sensor node acts as a gateway for an increasing number of parameters, since its routines can significantly reduce data transmissions to the "novelty-assessed" and thus effectively (energy) manage more streams. Thus, the extended utilization of these nodes provides the means to unlock new roles for them and scale their performance.
- Developing maintenance tools for a portable device allows WelCOM to exploit the range of benefits associated with mobile/remote system access and user/actor positioning. Mobility ensures that WelCOM users (technician/manager/engineer) will be constantly updated and, when required, instantly respond. Positioning can power context-aware mechanisms to

optimally compose updates/reports, while also semantically annotate (geotags) user input or interaction in general.

Acting as design specifications, the above target goals lead to a WelCOM system e-Maintenance architecture composed of five (5) subsystems (blocks) as shown in Figure 2:



**Figure 2.** WelCOM System Architecture and Components.

The **WCDB** (WelCOM Data Base) subsystem acts as a unified data model for WelCOM's processes. Its implementation is comprised by relational and embedded databases, along with properly scaled services that can effectively manage the backend data repository, the sensor-embedded parameter history, and the portable device cached information. The design principles for this model derived from semantics drawn from the widely adopted MIMOSA schema and process specifications of the project's industrial testbed, as specified by industrial requirements from Lifts Manufacturing Industry (KLEEMAN Lifts – [www.kleemanlifts.com](http://www.kleemanlifts.com)).

The **SENSE-MI** (Sensor Embedded Maintenance Intelligence) Subsystem is populated by components responsible for handling, accessing and computationally utilizing the WelCOM's sensor nodes and a prototype Wireless Optical Sensor (WOS) [2]. These components operate to serve the node's smart behavior through a range of modeling tasks (sample pre-processing, novelty detection). A set of drivers and interfaces facilitate the interoperability between sensor and remote services.

The **WCKM** (WelCOM Knowledge Management) block is the platforms means to capture, store and handle maintenance knowledge in the systems context. Employing data analytics and reasoning techniques, this subsystem's components work on the semantic enrichment of WelCOM's data model. The end these data processing processes are structured to form the system's diagnostics, prognostics and decision support.

**WCIMA** (WelCOM Intelligent Maintenance Advisor) acts as a collection of client interfaces and coordinating components, capable of retrieving the users' input and translating it into a well-defined and properly profiled workflow of tasks. Focusing primarily on user interaction and feedback, WCIMA recruits the dynamics of mobile and voice interfaces for data visualization and intuitive

reporting respectively. Users input and task submission are encapsulated into remote calls/requests/invocations to services, residing in the system's core modeling subsystems.

The **WCTP** (WelCOM Training Portal) subsystem provides an e-Training platform that aims to familiarize maintenance personnel with the WelCOM's tools and their features. e-Support is a platform service, capable of streaming technical documentation and instructional digital resources and videos related to context-specific maintenance tasks. WCTP is further analysed in the following sections.

### **3. Advanced learning in Maintenance**

In the last decade e-learning has gained popularity and ubiquity, with related research carried out towards a wide spectrum of directions. Human – computer interaction, content adaptation, learner profiling, learning personalization, e-learning standards, groupware and social learning have emerged as relevant active areas of targeted research.

The learner interaction with the learning material has been improved and moved towards more engaging environments, by employing Augmented Reality (AR) learning implementations. These technology-mediated environments have been often used in the last two decades in the areas of simulation, games and research. However, lately there are attempts to apply this technology into ubiquitous learning, by introducing new platforms for easy creation of Virtual or Augmented scenes without advanced programming knowledge [8]. Usage of games to enrich education was also put forward [21], with augmented and virtual reality applied unobtrusively on traditional games like poker or go and artistic activities like calligraphy, to provide engaging learning experiences for the learners and thus enhance situation awareness. In such a setting, interaction is treated as a positive factor towards increased learner attention.

Learning Theories, such as behaviorism, social cognitive theory, information processing theory and constructivism [16] and learning styles identification [6] can be used to evaluate the impact of different teaching approaches. For example, teacher-centered, student-centered and blended learning are compared in an engineering student setting, concluding that blended learning could be the most effective method between them [1]. Another example is the development of 3D multimedia courseware that materializes known learning theories [13]. Cognitive Load Theory (CLT) and methods are also proposed to evaluate performance across different learning settings [19]. CLT in particular is defined as the sum of intrinsic, extraneous and germane load that are required in a learning procedure. They proceed with a list of guidelines to e-learning designers to enhance cognitive capacity, such as the use of complementary and not redundant information, the employment of different media to load different sub-systems of working memory and the use of multiple examples together with the provision of fading instructional support.

Another highly sought goal is personalisation, i.e. the adaptation of learning content according to a trainee's profile [15]. This profile reflects user knowledge, history and characteristics. A recommendation system that uses semantic web ontologies to achieve content filtering according to learner profiles is presented as one approach that can be adopted [17]. Learner profiling can be done fuzzy ontologies that can better describe ambiguous information in specific knowledge domains [7], which in turn can be exploited by a fuzzy profiles-based recommendation engine. With the recent emergence of mobile and ubiquitous learning, through the use of mobile devices, learner personalization becomes a powerful means to provide contextualized support for mobile user actors. This level of personalisation implies a series of additional challenges and features, including context modeling & identification, location-awareness and collaborative and social computing support [9].

In the area of Industrial Maintenance, a common accreditation framework is highly sought, as it can enhance workers mobility, as well as enterprise recruitment and staff development. Learner satisfaction, market orientation of the offered courses and usability aspects are of crucial importance for the adoption of e-learning in Maintenance. E-Learning standards have been developed with the intention to promote content reusability, discoverability and interoperability. Nevertheless, a major issue in standards is that they are not able yet to support modern complex learner – system

interactions, like multimedia or educational games. One way to alleviate this problem is through repurposing of Learning Objects (LO) and usage of Model-Driven Architectures, XML technology and XSL transformations [12]. To promote collaboration in learning, a system that employs and combines many different social software tools, while at the same time managing Digital Rights (DRM), has been proposed [4]. Social learning may yet suffer from a poor assessment of users' credibility, which can be taken into account by different means, such as citation analysis [20]. Nonetheless, such an approach may be of limited use in such a practice-oriented discipline, such as Maintenance and alternatively Social Network Analysis and Ontologies can be employed to increase the efficiency of the credibility estimation [22]. However, reliability and quality assessment in e-Learning is an issue of active research [18] and learning style matching is one way to improve enhance the personalization efficiency of the process [11]. Furthermore, cloud computing, Software as a Service (SaaS) and Platform as a Service, are emerging enabling implementation frameworks, wherein the performance of the supporting infrastructure for virtual world and mobile learning has to be assessed [3].

It is in this backdrop that the WelCOM e-Learning components are designed to deal mainly with on the spot e-Support for field personnel and to offer an integrated e-Learning platform, within an industrial maintenance management setting.

#### **4. e-Learning and e-Maintenance**

To facilitate the adoption of e-Maintenance in practice, e-Learning has a crucial potential impact. By providing context-depended training and support, maintenance staff is better positioned to take full advantage of the offered technological solutions. The proposed e-Learning system is built around a central 'knowledge repository', management by a typical Learning Management System (LMS) platform, namely Moodle. Training content is described with the use of meta-tags, in order to facilitate content discovery by the trainees.

Usage of an established and well-known e-Learning platform like Moodle has distinct benefits:

- Easy and intuitive user and access control management, having a full set of functions incorporated into the LMS core to support them.
- Simplifies the procedure of frequent updates that are considered crucial as in the context of Industrial Maintenance, relevant machinery information and techniques are upgraded, expanded or enhanced on frequent basis. Using a web-based LMS enables direct updates of the learning content from any user that has the appropriate rights, from everywhere.
- Provides a central point of installation, allowing for easy system backups, updates, failure recovery and security routines.
- Open source system allows for customization and development of training modules, tailored to serve industrial requirements, with the support of a module that communicates directly with the mobile devices and handles user credentials and mobile content delivery.

However, in most typical LMSs, such as WebCT, Sakai and Moodle, content delivery is oriented for wide computer screens through the web and not for mobile devices, such as smartphones or tablets. This project utilizes mobile devices to support workers during their job on the shop-floor. Access through a mobile browser to the LMS is not always adequately functional as it implies a series of actions not optimized for mobile devices, like typing credentials, selecting menus and hyperlinks in a page that is cramped with extraneous information. Furthermore, learning content in general is not considered useful to workers during their job, as they do not desire to spend time searching through training content or answering test questions. While comprehension questions are considered beneficial in an e-Learning environment, as it has been proved that they actively help the user to assimilate the new material, they are an obstruction to a technician that needs immediate support information on how to perform a specific task.

In order to mitigate the above problems, in our proposed solution we separate WelCOM e-Training into e-Learning intended for computers and e-Support that will be delivered to mobile devices as shown in Figure 3. E-Learning can use all the functionality provided by the LMS to enhance learning,

such as comprehension questions, quizzes and links to relevant web resources. Content formats can exploit the latest web technology advances to provide an engaging learning environment, graphic effects, videos, sounds and three dimensional graphics. This content is addressed to trainees that will use computers with full sized monitors to access it. These may be department managers or new technical staff that needs quick familiarization with the e-Maintenance system.

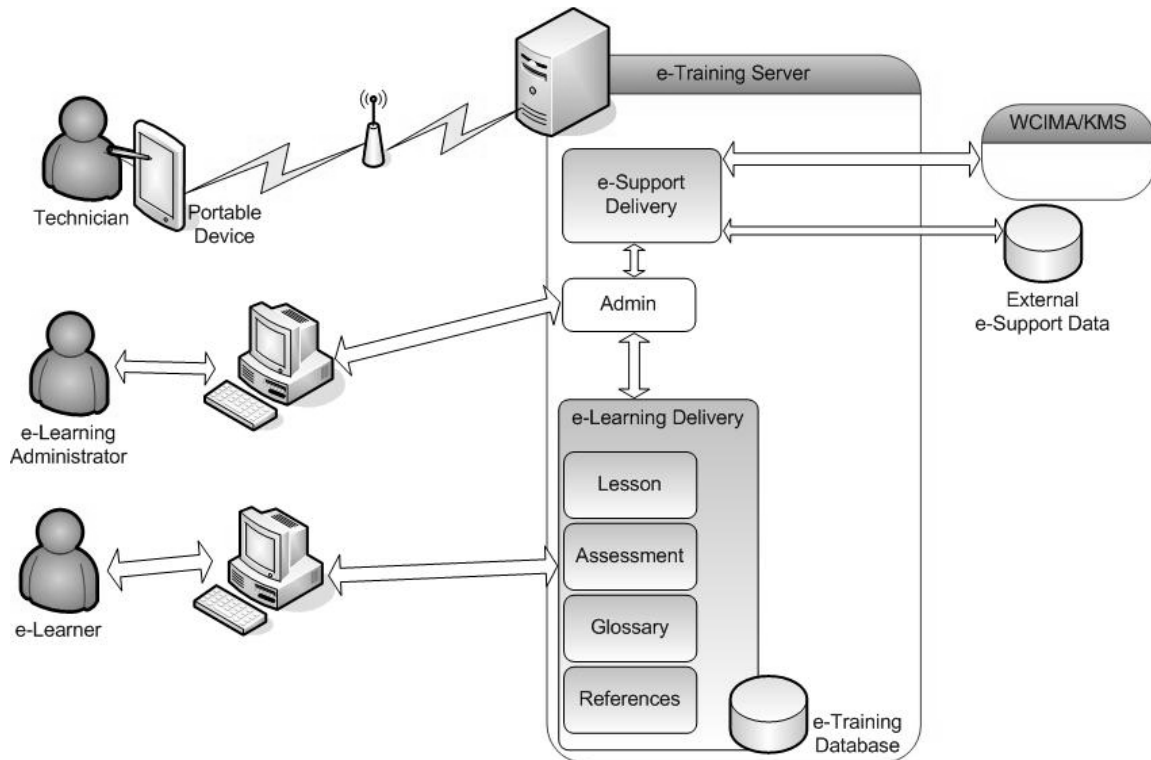


Figure 3. WelCOM e-Training architecture.

On the other hand, mobile content, customized for tablets and portable devices, able to exploit the offered graphic, storage and networking capabilities, follow different specifications from traditional web-content. Thus, the learning material does not have to be delivered to the mobile device as a web page but instead in a purposefully built native mobile application. This mobile learning application typically features a simple and intuitive user interface. The e-Support mobile application is planned to be integrated in the main support software that will be executed on the mobile device.

Having as goal to facilitate maintenance staff to locate the support content they need, while interacting with as few menus as possible, we separate the content into fine grained learning objects. These learning objects are specific and clearly defined, such as certain machine maintenance tasks or guidelines for replacement of problematic parts. Meta tags are to be added to every learning object, so the learning system will locate and deliver to the mobile device all the existing information about the problem that the worker is dealing with. This service is delivered by a dedicated module to reside inside the LMS, while managing most of the communication with the mobile device.

E-Learning standards, such as IEEE LOM are followed by the Learning Objects with the intention of simplifying the creation and definition of new objects. Learning standards have thorough meta-tags definitions in their core that will be used to describe the learning objects, their interrelations, the relevant tasks and any other information that is deemed useful to our project.

To conclude, the usage scenario of the proposed solution is the following:



- While the technician interacts with the support application in the mobile device, he/she asks for e-Support by clicking a button on the screen.
- E-Maintenance application notifies e-Support in the mobile device, providing technician, machine and failure identification codes.
- The mobile e-Support application sends the data to the corresponding module in the LMS platform, identifying user credentials and searching for relevant material based on internal tables and meta-tags.
- E-Support content is delivered to the mobile device. The technician can select which of the provided information is useful for his current task.
- Users can request at any point specific parts of the e-Support content by providing manually machine identification codes or problem descriptions.
- Managers can frequently update e-Support material with new manuals, technical videos and blueprints.
- All the interactions are automatically recorded by the e-Training system. This information can help in the future in the pinpointing of problematic tasks that require more supportive material.

## 5. Conclusion

Lately e-Maintenance is increasingly used as an indispensable part in Industrial Asset Lifecycle Management. The likely adoption prospects of an integrated e-Maintenance solution are increased if effective e-Training and e-Support is offered to aid maintenance staff interaction with such a system. Following the main system's trend of delegating tasks to peripheral nodes, the e-Support is designed in a way that is inherently oriented towards the mobile staff. The exploitation of mobile capabilities through a specifically built native application enhances usability. The usage of a web-based e-Learning system, designed to aid the use of the whole e-Maintenance platform is also part of the identified industrial requirements. Its main added value lies with the offered help and familiarization with the e-Maintenance platform and associated technologies and tools.

The main innovative points of our approach are based on the efficient use of enabling technologies in the WelCOM platform, offering features such as:

- on the spot e-Support which offers information disambiguation and context-dependent data delivery,
- accurate, fast and clear work order assignment,
- on the job and context-dependent training support,
- expandable e-Support structure and capabilities,
- low-cost integration with e-Maintenance systems.

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