

# A High Level E-Maintenance Architecture to Support on-site Teams

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## Abstract

Emergent architectures and paradigms targeting reconfigurable manufacturing systems increasingly rely on intelligent modules to maximize the robustness and responsiveness of modern installations. Although intelligent behaviour significantly minimizes the occurrence of faults and breakdowns it does not exclude them nor can prevent equipment's normal wear. Adequate maintenance is fundamental to extend equipments' life cycle. It is of major importance the ability of each intelligent device to take an active role in maintenance support. Further this paradigm shift towards "embedded intelligence", supported by cross platform technologies, induces relevant organizational and functional changes on local maintenance teams. On the one hand, the possibility of outsourcing maintenance activities, with the warranty of a timely response, through the use of pervasive networking technologies and, on the other hand, the optimization of local maintenance staff are some examples of how IT is changing the scenario in maintenance. The concept of e-maintenance is, in this context, emerging as a new discipline with defined socio-economic challenges.

This paper proposes a high level maintenance architecture supporting maintenance teams' management and offering contextualized operational support. All the functionalities hosted by the architecture are offered to the remaining system as network services. Any intelligent module, implementing the services' interface, can report diagnostic, prognostic and maintenance recommendations that enable the core of the platform to decide on the best course of action.

**Keywords:** manufacturing systems; platform technologies; maintenance

**JEL codes:** L23; L60; M54

## Introduction

Modern control approaches have set the theoretical background and foresee modular and distributed architectures where local intelligence and interaction play a significant role.

Local intelligence is fundamental to ensure that the system exhibits a coherent and desirable behaviour. However it does not exclude, although it minimizes, occurrence of faults and breakdowns. In (Barata et al. 2007b; Ribeiro 2007) the rationale for adopting self-diagnosis and, under controlled conditions, self-healing in the context of EAS/EPS has been detailed. The potential profit emerging from these mechanisms can be further extended if their input positively influences equipment's maintenance cycles.

The drivers for increased performance requirements in maintenance are identified as (Tsang 2002): emerging trends of operational strategies, toughening societal expectations, technological changes, changes in the people and organizational systems.

E-maintenance is consolidating as a reference paradigm. The research agenda has, however, been set on the development of diagnostic and prognostic techniques and methods and the integration of their results with business logic tools. An architecture that provides local maintenance operational support is advocated focusing in the organization of the best possible maintenance teams and in assisting them during the maintenance process. All the functionalities are offered as Web services to foster integration and pluggability.

### **From simple repairs to E-Maintenance**

#### ***Maintenance Strategies and Approaches***

Traditionally maintenance has been understood as repair activities. In this sense, primitive maintenance management methods were based in run-to-failure policies. These approaches fully rely in breakdown maintenance (BM) where assets are only subject of maintenance upon a failure occurrence. This approach was hardly ever fully implemented since routine tasks including lubrication and adjustments are often applied.

Nevertheless, this remains the most expensive method of maintenance (Mobley 2002) since it requires a considerable investment in spare parts inventory, high overtime labour costs, high machine downtime, low production availability, etc.

To cope with the severe drawbacks in run-to-failure methods the concept of preventive maintenance emerged in the 1950s. In this context, a time-based maintenance (TBM) was advocated to maximize uptime. TBM is based in the "bath-tub" curve that relates the failure tendency of products with the number of operations performed over time. It is however difficult to tune TBM since typical data such as mean-time-to failure (MTTF) or mean-time-between failures (MTBF) heavily depend on the operating conditions and environment. For this reason TBM may result either in unnecessary repairs or in catastrophic failures due to under-maintenance.

In the 1970s advances in machine diagnostics led to the concept of condition based maintenance (CBM). CBM relies in the frequent monitoring and evaluation of devices' status planning maintenance actions accordingly. When the concept emerged the existing technology was still too expensive to allow effective CBM implementation. To balance the costs of maintenance the concept of reliability centred maintenance (RCM) was introduced in 1978 by Matteson, Stanley and Heap. Although in its essence the principle that all the machines fail and have a finite useful life is wrong, RCM is currently correctly defined by the technical standard SAE JA1011 (Evaluation Criteria for RCM Processes) and is understood by many as one of the most significant tools in

ensuring that the risks of equipment failure are reduced to a tolerable level.

Currently the widespread networking technologies and the decrease in the cost of electronics are bringing up again CBM (Jardine et al. 2006) as a relevant and cost effective paradigm. A similar concept the one of predictive maintenance (PM) (Mobley 2002) is also emerging. In the literature, however, there are no fundamental differences between CBM and PM.

A review on the advantages and disadvantages of these maintenance strategies can be found in (Waeyenbergh and Pintelon 2004).

### ***E-maintenance***

The concept of E-Maintenance was introduced in recent literature (since 2000) and despite the lack of consensus in a common definition (Iung et al. 2007) most of the works cover the following issues, insisting on the relevance of the underlying IT infrastructure: multilevel network integration of maintenance activities and related applications and attaining near zero device downtime.

E-maintenance advocates the incorporation of maintenance in product life cycle. In (Takata et al. 2004) the concept of life cycle maintenance was introduced to stress the importance of maintaining the products in an acceptable functional level during their lifecycle while continuously improving them as well as maintenance techniques so that existing products can adapt to changes in the operational environment.

The concept of E-Maintenance has been driving several projects worldwide.

One of the most active research centres in maintenance is the intelligent maintenance systems (IMS 2007) (IMS) group that seek the achievement of near-zero breakdown performance. The IMS developed the Watchdog Agent™ (Lee et al. 2006) to implement CBM. This system collects data from sensors monitoring critical processes and matches it against known sensor signatures to detect process degradation.

Prognosis is supported by applying trending and statistical modeling over the process signatures while diagnosis is based in the memorization of relevant signature patterns of past events. Additionally the Watchdog Agent™ is integrated with the IMS Device-to-Business (D2B™) (Huang et al. 2005) platform that provides a link between the shop floor and e-business.

In (Han and Yang 2006) a maintenance framework, based in the concept of maintenance centre, is presented. Each maintenance centre is divided in:

- Fundamental research group – research in recent technologies and simulation analysis
- Enterprise group – provide information flow between associated enterprises.

- Expert group – grant support to maintenance system research and improve and optimize the research results.
- Industry case history collection group – collect knowledge from the industrial environment to feed a case database to be used later in case based reasoning for diagnosis, risk assessment, help desk, decision support and maintenance strategy.

Moreover the framework relies in local maintenance centres at plant level that coordinate the following activities: continuous assessment of equipment health, maintenance and repair operation process management and comprehensive data representation and synthesis. In this context the local maintenance system works as a test platform for the results derived from the maintenance centre.

The problem-oriented multi-agent-based E-service system (POMAES) proposed in (Yu et al. 2003) explores co-ordination, co-operation and negotiation in multiagent systems to solve problems in the industrial context. This raises the notion of collaborative maintenance. In this context a prototype implementation was applied to control a water valve. In this setup three experts were considered:

- Production management expert: controls the water volume.
- Maintenance expert: optimizes the valve and the platform availability by minimizing direct and indirect costs related to maintenance.
- Control expert: ensures the behaviour of the installation is in accordance to the production strategy.

Through interaction a balanced compromise is achieved that maximizes availability keeping maintenance costs controlled.

Other maintenance platforms include PROTEUS (Bangemann et al. 2006) that focus on the integration platform rather than on the development of dedicated maintenance tools. From an architectural point of view PROTEUS denotes a star like shape being the central point occupied by the central service application (CSA) that provides integration oriented services. Additionally the platform relies in intelligent core adapters (ICA) to provide standardized interface transformers for the peripheral applications and functional core applications (FCA) to implement supplementary functions needed by the global service requirements and not provided by the platform tools.

A complete review on the concept of e-maintenance, major achievements and current research is provided in (Muller et al. 2007).

## **An E-Maintenance Architecture to Support on-site Teams**

### ***Architecture***

So far research in IT based maintenance systems has focused in providing complete and vertical solutions ranging from low level diagnosis and prognosis to the establishment of collaborative maintenance sessions. In the architecture hereby proposed a somehow different approach is considered.

No predefined arrangement of the devices is assumed from the control point of view so that the present architecture behaves indifferently of the underlying control network topology.

This architecture targets state-of-the-art control approaches where systems are envisioned as dynamic compositions of intelligent and autonomous modules. Emerging approaches following this paradigm include: Reconfigurable Manufacturing Systems (Bi et al. 2007), Evolvable Production Systems (Barata et al. 2007a), Holonic Manufacturing Systems (Babiceanu and Chen 2006), etc. This architecture is developed under the framework of Evolvable Production Systems where some essential characteristics of the autonomous modules have been demonstrated namely: self-monitoring/self-healing (Ribeiro 2007). The ability of each module to assess its own state and report it under abnormal conditions is therefore assumed and has been subject of several prototype implementations using modern distributed computed paradigms namely Multiagent Systems (Ribeiro et al. 2008b) and Service Oriented Architectures (Ribeiro et al. 2008a).

Each module performs self-monitoring/diagnosis being able to use that information to issue predictive maintenance alarms in addition to time-based (according to the manufacturer's recommendation) preventive maintenance alarms. Furthermore all its related documentation (technical manuals, blueprints, repair/maintenance procedures, etc) is stored locally.

It is assumed that the diagnosis/prognosis and maintenance functions are according to the computational power available in the module. In this context the present architecture does not induce any constraint in that matter relying in Web Services' interfaces to harmonize all the incoming and outgoing information.

The Maintenance Team Configurator (MTC) is one of the core components of the architecture and maintains a pool of the available maintenance technicians, their skills and the pending maintenance/repair tasks (Figure 1).

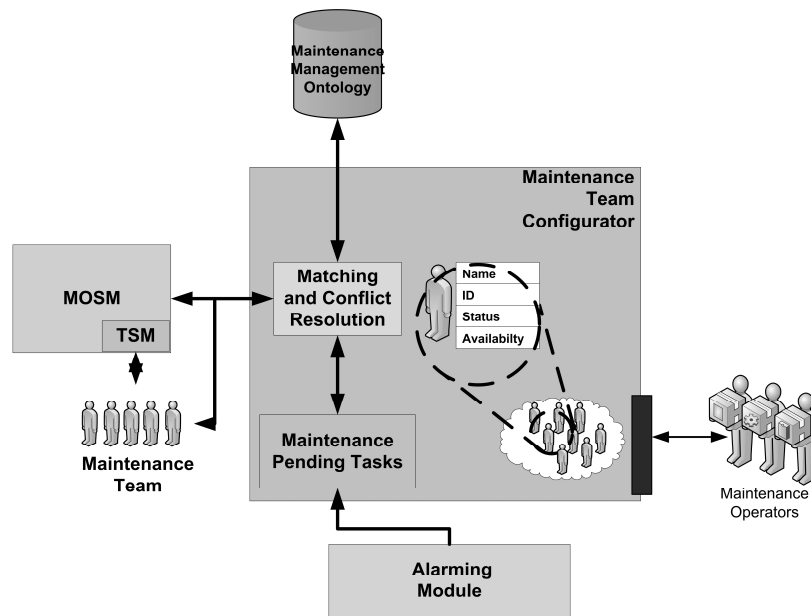


Figure 1. Maintenance Team Configurator

All maintenance operations are stored in a history database along with other relevant variables including:

- The nature of the operation: routine, critical, schedule, unscheduled...
- The success rate of the operation: as a measurement of the performance of the technicians and the guidance provided by the platform;
- The technicians involved: each technician has a score that grants him credit to perform more complex operations.

Whenever a recommendation or a repair alarm is received the MTC suggests a team, after computing these variables based on the maintenance history of the failing modules. The MTC will match this information against the knowledge in the Maintenance Management Ontology (MMO) and the availability of the technicians. Conflicts in the matching are solved by the rules of the MMO where team composition rules are mapped. Team formation comprises:

1. Evaluating the urgency of the pending maintenance tasks.
2. Assigning and negotiating each participant's roles.
3. Notifying the participants of the nature and location of task.
4. Handing over the control to the Maintenance Operational Support Module (MOSM) that through a technical support interface (TSM) guides the maintenance teams during operation. The operations supported by the MOSM include the establishment of remote sessions with the manufacturer's

technical support to direct local less specialized teams in more complex operations.

As the MTC manages, plans and schedules the totality of the maintenance actions and teams, it can alternatively postpone the execution of maintenance by acknowledging that a best team will be available within a reasonable time interval.

## **Pervasive Network Technologies and Work re-Organization**

The general acceptance and importance of web based technologies in industrial scenarios is changing the way technicians interact with the shop floor components.

The industrial sector, traditional reluctant to dramatic paradigm shifts, has acknowledged the potential of these emerging concepts and paradigms and is preparing the next generation of industrial equipment to be Web ready.

The Devices Profile for Web services (DPWS) implemented by Schneider Electric (SE) (<http://www.soda-itea.org/Downloads/SoftwareComponents/1176900642.3.html>) is a clear example of the different mindset of industrialist towards web enabled components. The toolkit implements the stack represented in Figure 2 as described in (Chan et al. 2006). The rational that led SE to adopt DPWS is documented in (Jammes et al. 2007; Jammes and Smit 2005).

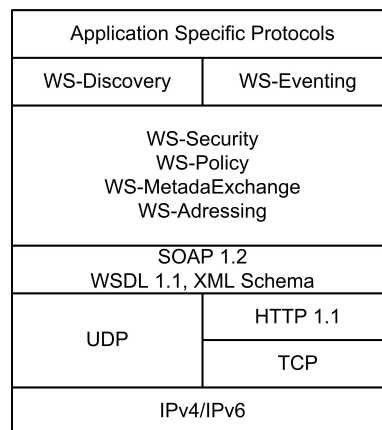


Figure 2 – DPWS stack adapted from (Jammes and Smit 2005)

From a technician point of view the interaction with the industrial equipment can be profoundly different. In the present architecture it is envisioned that maintenance personnel can be informed of occurrences by SMS or e-mail on personal handheld devices. Further the technician can subscribe to periodically receive relevant data from

devices under observation. Both modules and technicians are integrated in the IT infrastructure and collaborate in the maintenance process and shop floor becomes an interconnected intelligent environment.

Creating a sustainable production environment requires, among other things, the elimination of breakdowns and other sources of energy waste. This has been one of the decisive drivers for changing the perception that people normally have maintenance from "fail and fix" practices to a "prevent and maintain" mindset.

Emerging e-maintenance architectures are a fundamental step in this process taking advantage of the embedded computing power on modern industrial devices to trigger maintenance before breakdowns. Additionally they present new business opportunities.

Maintenance is frequently an outsourced activity the proposed architecture allows a maintenance company to timely respond to problems in an optimized way. On the one hand, the size and skills of local maintenance teams can be optimized in time according to the envisioned maintenance/repair tasks. Through the analysis of device's fault history and fault reporting a technician is able to reach a faster diagnosis or even have the intelligent module doing that autonomously. In this context highly specialized technicians can be re-allocated and manage several installations geographically disperse. Also repair operations using specific resources are known in advance saving time in assessing the tools required.

## **Conclusions**

E-Maintenance is increasingly a strategic pillar of enterprise competitiveness and sustainability. Supported by pervasive networking technologies, the concept opens new business opportunities.

A high architecture in the framework of EAS has been presented that explores the notion of e-maintenance focusing in the optimization of teams.

In short, the best possible teams are selected to react to events triggered by intelligent devices in the shop floor that autonomously interact with the technicians through the platform. Contextual support is provided during an operation which allows human and material resources optimization. New knowledge is extracted supporting the evolution of the platform in forming teams according to the technician's skills and credit.

All the intervenient in the process are integrated and managed by the platform towards the establishment of a collaborative intelligent environment that seamlessly supports the interaction between humans and shop floor objects.

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