An integrated approach for open e-Maintenance: Opportunities and challenges

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ABSTRACT

The present day e-maintenance space is evolving with isolated legacy sub-systems or packages that span heterogeneous and domain specific industry verticals. Developing a unified platform for e-maintenance catering to the varied domains shall hence pose a major challenge. An open systems based platform for e-maintenance can overcome some of these hurdles by defining the otherwise disparate systems as abstract entities with well defined public interfaces. The interfaces can be broadly classified based on the technology types, thus allowing individual vertical e-maintenance applications to align with their respective business interests. In all, this shall greatly help in reducing the overall operating costs and at the same time provide increased flexibility, reusability and reliability. The underlying standard protocol, defined through a group consensus, shall be responsible for transport of the e-maintenance data between the distributed subsystems via the TCP/IP standard within multiple administrative domains of e-maintenance across wired and wireless networks. This paper also looks at e-maintenance from a systems integration perspective and illustrates how open systems based approach can help achieve integration better.

Keywords

O&M, OMC, OMS, CMMS, PLC, HMI, PdM, PM.

1. INTRODUCTION

1.1 The Concept of Open e-maintenance

E-maintenance, considered strictly a complementary discipline to e-manufacturing, is defined based on multifarious views and perspectives. (Muller et al., 2008) propose the following definition for e-maintenance:

Maintenance support which includes the resources, services and management necessary to enable proactive decision process execution. This support includes e-technologies (i.e. ICT, Web-based, tether-free, wireless, infotronics technologies) but also, e-maintenance activities (operations or processes) such as e-monitoring, e-diagnosis, e-prognosis, etc." The e-maintenance enables four main different maintenance strategies such as:

- Remote maintenance
- Predictive maintenance
- Real-time maintenance
- Collaborative maintenance

This definition of e-maintenance is a precursor to the next generation of e-maintenance workflow wherein tether free Infocomm technologies are pushing a paradigm shift to drive complete business automation rather than just factory automation. The new paradigm would have intelligence instilled in the equipments in question, making them capable of transmitting real -time data such as alarms and events based on their current condition. These alarms/events, as a part of the e-maintenance solution can then be employed for PM (Preventive Maintenance) and/or for condition based maintenance (CBM).

For example, may companies still use their EAM (Enterprise Asset Management) or Computerized Maintenance Management System (CMMS) solutions are just another static data and reporting system. But real-time data management, alarming through powerful and advanced software features, which when integrated into the existing ERP package, can help transform the existing EAM/CMMS into a real-time and dynamic knowledge-driven solution. Another major aspect of e-maintenance would undoubtedly be to be able to manage the voluminous maintenance information ubiquitously over the internet and across heterogeneous domains. Trends indicate that the traditional fail and fix (FAF) practice has been replaced by the new "predict and prevent (PAP) paradigm" (Arab et al., 2009). Predictive maintenance (PdM) is being sought after because of its cost-effectiveness. The eventual aim of PdM is to perform maintenance at a scheduled point in time when the maintenance activity is most cost-effective and before the equipment loses performance within a threshold. As per the "Reliability engineering" online magzine (RE, 2007) the major reason why most of the PdM' programs fail is because the goals of the program are not well defined or understood well. Moreover, the goals need to be aligned to the exact needs for performing PdM in the organization. If the goals are set to comply with specifications based on "open" standards, it would help PdM succeed to a larger extent.

Going by the presence of numerous vendors in the marketplace for PdM, the market seems to be evolving into a highly fragmented market. The direct consequence of this is that multiple vendors are rolling out customized solutions for interfacing with the existing EAM systems. Without the existence of a formal alliance, the average e-maintenance customer runs the risk of breaking interoperability interfaces when they upgrade their EAM. One of the objectives of this paper is to focus on such

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limitations with the current legacy systems and introduce an integration procedure based on open, de-facto standards.

2. OPENNESS IN E-MAINTENANCE

2.1 Motivation & Benefits

Studies at Observatoire de la maintenance industrielle(OMI) have revealed that the total manpower and materials costs in the maintenance domain amount to about €22.7 million/year (ITEA, 2005), representing:

• Around 50% of general industrial services expenses;
• 12% of the average added value (up to 35% in some industrial areas);
• 300.000 people (7% of the total industrial workforce).

Traditionally, maintenance cost(s) primarily involve:

- The cost of labour.
- Cost of parts for repairs
- The costs associated to downtime.

Another major potential cost incurred in the E-maintenance is costs associated to integration of legacy systems to enhance functionality or introduce automation in existing e-maintenance systems. Open systems help to a large extent in curbing the costs involved in "system integration".

The benefits reaped from the proposed "open" integration model shall be numerous including the following:

2.1.1 Increased OEE

The primary intention of an open integrated approach would be to automate each of the tedious processes involved in e-maintenance, which would translate to improvements in overall equipment effectiveness (OEE) for productivity enhancement.

2.1.2 Choice of maintenance strategy based on a more mature knowledge base:

Take for example; Company A has been using a proprietary solution and has been using CBM as the maintenance strategy for quite some time based on a management decision. However, they realized CBM was not the best method suiting them, especially from the perspective of cost effectiveness.
When failures of machines or components are not critical, we can allow corrective maintenance (CM), in which actions are taken after failures are detected. When the lives of machines or components can be estimated precisely, TBM is the most effective means of maintenance.
With the use of open standards such as MIMOSA-OSA which helps you assess your system based on industry wide knowledge pool and expertise, the chance of running into a risk of choosing a "wrong" type of maintenance strategy gets lower (MIMOSA, 2006).

2.1.3 Software Reusability

Design wise, the integrated OMC shall comply to the Open closed principle (Martin, 1996) in the world of object oriented design. The open architecture shall define multiple layers of abstract interfaces. The system (hardware/software) design shall be reused when extending functionality. This allows maximum reuse of existing interfaces/interface agents for the system designers/developers.

2.1.4 Low Interoperability concerns

A full fledged e-maintenance requires the new platform to support support the semantic and technical interoperability required for the right interconnection of all the previous technologies to make operating the platform as a whole.

2.1.5 Openness

Making an e-maintenance system whose components are interchangeable requires software architecture(s) which are flexible in nature and allow tools and algorithms which are flexible in nature. Designing systems with a specific application will cause the application be limited in scope, The flexibility required can be achieved through an open systems approach instead of building custom solutions.

2.2 Requirements

The Software Engineering Institute (SEI) defines an open system as a collection of interacting software, hardware, and human components with interface specifications of its components that are fully defined, available to the public, and maintained according to group consensus (Meyers et al., 1996). When applied to the realm of e-maintenance, it would mean an open consortium which works in a collaborative and a cooperative manner to generate cross-platform and multi-vendor solutions. The unified approach realizes improved preventive and condition based e-maintenance, thus reducing O&M costs and increasing equipment availability. A holistic approach will also help alleviate the otherwise obvious disconnect between the "Operation" and "Maintenance" departments in a typical manufacturing environment.

An open system would require integration of operational and manufacturing processes, systems and people to minimize the overall vertical and horizontal information gap created by islands of e-maintenance data spread across the various functions in a manufacturing ecosystem. An open e-maintenance infrastructure would greatly reduce integration costs, and the total cost of ownership (TCO), and at the same time provide a generic plug and play interface for interaction between the existing proprietary and rather isolated e-maintenance frameworks.

This paper aims to present architecture in an attempt to establish a holistic approach towards e-maintenance using open, standardized systems.

2.3 Challenges in building a business solution using open system methodology

Open e-maintenance solutions will have their own share of challenges. More and more innovative techniques and methods driven by latest e-technologies have to be developed in order to perform asset maintenance in a seamless way. These methods have to be abstracted in order to the user remaining transparent to the overall process. For example, consider a manufacturing facility where Wi-Fi shall be used instead of Bluetooth. To the Human machine Interface(HMI) user, it might not mean anything except a performance improvement, but to the designer and the developer of the e-maintenance tool, it will boil down to re-implementation of the lower abstraction layers which represent the connection to the equipments in the facility.

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2.4 Evaluation of Open Systems

2.4.1 Discussion of some existing open platforms

With the advent of various e-technologies responsible for data acquisition and to aid decision making, it becomes imperative to establish some sort of openness for enabling interoperability and addressing integration concerns. The recurring operating costs of any type of maintenance are mainly driven by the cost to manage the prognostic “decision-making” information in an efficient and accurate manner. To begin with, any web based technology for e-maintenance provides an open platform to publish and transport maintenance data. A service oriented protocol which treats individual pieces of maintenance data as objects would help in enabling an end to end mechanism for transporting maintenance data across heterogeneous systems.

MIMOSA (Machinery Information Management Open System Alliance)is an association dedicated to developing the adoption of open information model in manufacturing, fleet, and facility environments with information standards which enable collaborative asset lifecycle management. DYNAWeb develops a CBM system based on OSA-CBM standard over MIMOSA comprising broad of capabilities like sensing and data acquisition, signal processing, health assessment, prognosis etc. This platform ensures the integration of all the components (software and hardware) using different technologies (sensor technologies, wireless communication technology) and providing them with agents and (Semantic) Web Services to allow the integration and the reuse among different applications.(Gilabert et al., 2007). Another example of a generic platform is the European PROTEUS project (Bangemann et al., 2006) (ITEA, 2010) which aims at the integration of these various sub-systems, thanks to a unique and coherent description of the equipment (through an ontology description), a generic architecture (based on the “Web Services” technology) and coherent models of heterogeneous components

2.4.2 Opportunities and criteria influencing consumer decisions

The major influencing factor in choosing an e-maintenance application is cost of its implementation, integration and maintenance of the software/hardware platforms. An open platform will help attain affordable design(s), and can more easily accommodate rapidly changing technology to achieve system *cost*, schedule, and performance benefits by promoting multiple competitive sources of supply within the commercial marketplace (Larson et al., 2000).

3. OPEN MAINTENANCE CONTROLLER

Traditionally, e-maintenance has been performed through point to point solutions; thus every time there is a new integration scenario, a custom solution is built to address the concern. Enterprise Bus-based solutions are now preferred, whereby all systems communicate via an intermediary system through adapters, which convert data between the system’s native format to the bus’ format and back again. The enterprise service bus (ESB) is the result of this paradigm, with many of the larger IT vendors now offering competing products in this space (Mathew, et al., 2009).It also leads to a greater reliance on contract-based services as systems only know of the ESB and the services or interfaces it makes visible to a particular system. For example, consider some sensor based condition monitoring data could be treated as a class or a category of information which would aid CBM (condition based maintenance) method. Traditionally this data shall be gathered through a network actor system which shall interact with the dumb sensor to distribute the information to standard TCP/IP networks. A client which is interested in the sensor data shall subscribe to the object and hence shall automatically receive the required information in configurable intervals of time. If the client is no more interested in the information, it shall unsubscribe to the object’s service. So the system shall be provisioned with the required information. If this object is standardized based on a open protocol, it would only require the client to subscribe to that object type and the unique identifier tied to that sensor in a production environment.

The future factory scenario shall be dominated by Service Oritnted Architecture (SOA) (Cannata et al.,2007), which empowers us with new capabilities and enables the realization of sophisticated approaches based on the collaboration of devices, network services within the single enterprise and among enterprises. Integration of data as condition monitoring data with maintenance systems has been the stumbling block for many companies in the past. The key is to integrate to existing computerized maintenance management software systems such as; Maximo, Datastream etc. to automatically create work requests directly from real-time events occurring with plant assets.

The key to better e-maintenance is gathering comprehensive maintenance data. MIMOSA‘s integration technology is based on a mature open standard, the MIMOSA XML-based standard for maintenance integration, and the OPC standard for device communication. Together these standards reduce the cost and risk of integration greatly. MIMOSA open standards will help create a protocol translation layer for the individual heterogeneous e-maintenance modules. The proposed model (Figure 1) depicts the integrated platform (Open maintenance controller) which contains the following subsystem objects:

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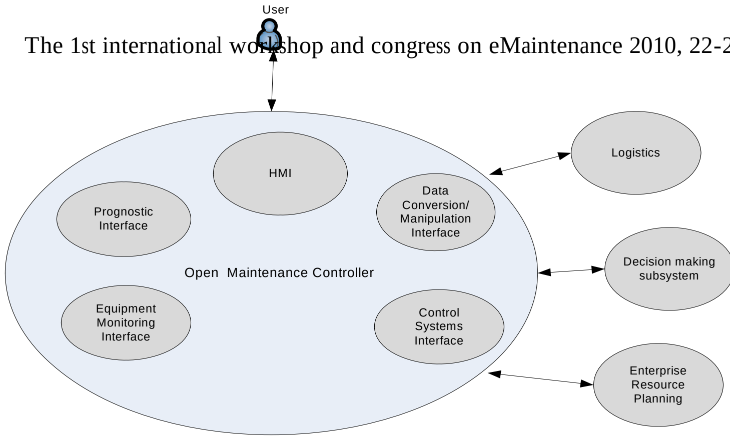

Figure 1 High-level interfaces of the Open maintenance controller

3.1 Interface(s) to other e-maintenance subsystems

The proposed integrated "Open Mainainence Controller" shall expose the following e-Maintenance service(s) as public interfaces for tying it to the external subsystems in a manufacturing environment:

3.1.1.1 Control System(s) Interface

Control System(s) interface allow the OMC (Open maintenance controller to talk to the PLC (Programmable logic controllers) associated to the equipments for multiple I/Os. This would translate the data transmitted over the TCP/IP networks to a specific set of commands/logic to be operated over hardware. The PLC logic shall be responsible control of hardware operation

3.1.1.2 Prognostic Interface

The Prognostic interface provides a facility for doing e-prognosis and the related algorithms based on the current performance input from data acquisition systems. The prognostic database gathered over time aids in the decision making process.

3.1.1.3 Human Machine Interface

The HMI shall enable interaction with human operators; or by using common process automation Supervisory Control and Data Acquisition (SCADA) software.

3.1.1.4 Data Manipulation Interface

The Data manipulation interface shall deal connecting to the real time database for CBM, extracting the required information from external databases, perform data analysis and pre-processing using graphical and statistical analysis

3.1.1.5 Equipment Monitoring Interface

The Equipment monitoring subsystem shall also be a part of the "core service" tied to the OMC (Operation maintenance controller). It shall consist of the following software components (Figure 2):

- Equipment Monitor points: The equipment monitor points are data pointers to which the client, for example the conditioning monitoring subsystem could hook on to receive sensor data "asynchronously".
- Sensor Interface: Helps gather the condition monitoring data through a wired/wireless network interface over TCP/IP.

The concept is the open maintenance controller acts as a service to different open maintenance controllers in different zones (geographically distributed). "Zones" could be intra-organization or inter-organization. These zones could comprise individual subsystems like a Data acquisition system, equipment monitoring subsystem or a legacy system for that matter.

The open maintenance controllers (OMC's) (Fig 2) talk to each other via a de-facto open protocol based on open standards such as XML over TCP/IP.

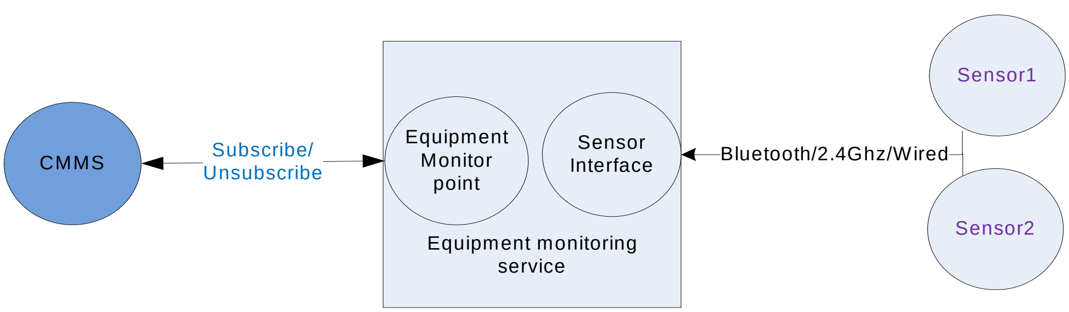

Figure 2 Event oriented Equipment condition monitoring mechanism

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3.2 Auto Discovery of OMC service

Each of the OMC's shall be capable of discovering each other using a dynamic service discovery protocol. The protocol shall also allow any client for e.g. a User interface/HMI to discover the various OMC's in the same administrative domain. The underlying protocol used in discovery shall leverage on the standard TCP/IP network to interoperate. Basically an open e-maintenance controller (OMC) involved in e-maintenance shall discover each the other OMC's services and then can subscribe to different e-maintenance services hosted by it. Each of the services is associated to an individual subsystem outputs for e.g. HMI subsystem, the Data monitoring subsystem etc.

4. TRADITIONAL CMMS AND PROPOSED EXTENSION BASED ON AN OPEN FRAMEWORK

CMMS is a tool which performs asset management, predictive & maintenance tracking Software systems are now required to manage and control assets, plant and equipment maintenance in today's manufacturing, facilities and service industries.

In this paper, we present a model for e-maintenance based on an existing system (DataStream 7i) and the extensibility of the system using open system technologies. The major challenge in establishing a holistic approach for predictive maintenance is the heterogeneous models offered by different designers of the e-maintenance systems. Even the source of data could be from different departments, but it is different in all respects.

4.1 Performance indicators

Maintenance performance indicators (MPI) are linked to the reduction of down-time, costs and wastes, and the enhancement of capacity utilization, productivity, quality, health and safety. Therefore, MPIs compare the actual conditions with a specific set of reference conditions (requirements/targets).

Overall equipment effectiveness (OEE) is used as a key performance indicator for the manufacturing industry in its continuous search for new ways to reduce downtime, costs and waste, to operate more efficiently, and to achieve greater capacity. The three elements of OEE, availability, performance speed and quality, help to determine the impact of the performance of an individual piece of equipment, and the concept of OEE can be applied to railway infrastructure. (Parida and Chattopadhyay, 2007). Some typical key performance indicators (KPI) for manufacturing include operating cost; asset availability, lost time injuries, number of environmental incidents, OEE and asset utilization.

4.2 Existing CMMS- the7i

DataStream 7i has helped improve the production efficiency of Trane, a leading HVAC supplier in USA. The 7i facilitates asset management and systems management based on individual equipments and accounts the costs/events and various Preventive Maintenance schedules associated to each of the equipments. When failures of machines or components are not critical, we can allow corrective maintenance (CM), in which actions are taken after failures are detected. A CMMS can also provide historical information which is then used to adjust PM system setup over time to minimize repairs that are unnecessary, while still avoiding run-to-failure repair. With the usage of 7i platform, the process at the HVAC gave them the ability to schedule preventive maintenance, thus reducing overall downtime and reduce the cost of expensive repairs.

4.3 Existing third party tool for PdM

The very best PdM systems are expert systems that can perform expert system analysis like puts maintenance procedures on hold until absolutely necessary, thus extracting maximum equipment up-time. In addition, the best expert systems offer diagnostic fault trending where individual machine fault severity can be observed over time.

A typical report generated by a third party condition monitoring tool called XL in the HVAC company gives an idea of how OEE is calculated and how reports are generated to aid decision making currently.

```
Shift Report-<Sheet MetalX>
Shift Information
--------------------------------------------
--------------------------
Shift Start:      2/16/2010   7:00:00    Ideal
Cycle:           9.000000000
Shift End:         2/16/2010 15:30:00    Takt
Time:              9.000000000
Shift ID:                    Shift 1   Average
Cycle:         9.400000000
Counts                                  OEE
---------------------------------   -------
---------------------------
Good Count:              543     Availability:
16.49%
Reject Count:                               21
Performance:                  86.83%
Total Count:                               564
Quality:                      96.27%
Average RPH:                        74    OEE:
13.78%
Production Times                       Targets
and Goals
---------------------------------   -------
--------------------------
             HH:MM:SS                  Percent
Efficiency:                   28.95%
Run:           1:15:12         14.74%   Target
Count:                1,948
Down:            3:36:58         42.54%    Goal
Count:                  2,840
Setup:         2:43:48        32.12%
Standby:       0:54:00        10.58%
Total:         8:29:59       100.00%
```


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4.4 Advantages of CMMS and the need for linking to PdM

The Maintenance Excellence Institute and others validate that poor utilization of existing CMMS systems is a major improvement opportunity (Peters et al., 2002).
The major benefits drawn from CMMS systems by Trane, a leading HVAC manufacturer, are as follows:

- Improved Work control for e.g work order generation.
- Improved planning and scheduling
- Improved parts and Materials availability.
- 7i is a completely server based system which uses Java and XML which are inherently open in nature. It may be deployed in heterogeneous systems and at the same time be integrated with open standards.

Another major untapped feature of 7i is the availability of Application Program Interfaces (APIs) facilitates the input of data directly into the CMMS database. These APIs have been proven to be instrumental in the integration of PLC's, and other third party real-time data monitoring solutions.

However, in spite of the judicious use of 7i, the HVAC manufacturer still depends on the preventive maintenance schedules controlled by the 7i system. The calendar based preventive maintenance does not account for the condition of the machinery which eventually runs into failure, causing unscheduled maintenance. To prevent this scenario, a hypothetical model is presented where the PLC monitoring the equipment condition transfers the condition data to create an alert to the CMMS (7i) system, it would greatly help increase the Overall Equipment Effectiveness (OEE). OEE is a manufacturing process metric which takes into account the various sub components of the manufacturing process – Availability, Performance and Quality. Calculating availability manually through existing data collection for equipment condition can be erroneous. With introduction of the proposed OMC based system, the CMMS system would rely on the data collected from just a few discrete points called monitor points to provide a simplistic OEE calculation using only run-time, downtime and idle time information.

OEE = Availability X Performance Rate X Quality Rate %

Availability refers to the machine or cell being available for production when scheduled. By comparing the actual cycle times against ideal cycle times, OEE allows for a determination of how much production was lost by cycles that did not meet the ideal cycle time. Quality focuses on identifying time that was wasted by producing a product that does not meet quality standards. The XL system is used in the company for measuring OEE metrics for the current shift and job.
The OEE recorded for the past few months in Trane's production line has been showing a downward trend. The reason for deterioration in OEE is mainly due to the longer (material, new operators) setup times coupled with the lower availability of the machine(s). For e.g., the material may not run in one machine, so they will take it out and replace it with another roll and it will run.

The PdM information can greatly help improve the OEE by integrating it with the existing CMMS, so that it provides the means to relate the condition of a machine to work order and equipment history data related to types of repairs, frequencies and causes for failure based on past trends. This will certainly help towards achieving a well-automated overall e-maintenance system.

4.5 Passive Integration

The current approach for linking the PdM data to the CMMS is through a manual and an error-prone method through which the data gathered through the XL tool is manually fed to the CMMS.

A passive approach would be to somehow import relevant data to be exchanged including equipment identification, timestamps, and repair priority/recommendations into the CMMS database.

4.6 Proposed integrated approach

The proposed Integration of CMMS with PdM data and the other maintenance modules would essentially mean exchange of information using a common framework. For example, the Common Information Exchange Schema (CRIS) has been designed and MIMOSA has focussed efforts on defining the information model to enable seamless addition of data tables that should be communicated to an existing CMMS. An OMC gateway shall be required to translate the raw PdM data to the required common protocol format spoken by the participating subsystems.

The integration of 7i though the propsed OMC based model and MIMOSA's open XML standard will allow incorporation of "Condition Based Maintenance" into the HVAC Company's existing PM and work order system. The final integrated system based on MIMOSA's open specifications shall then be capable of automatically creating work orders directly based on real time events associated to the plants machinery and assets. The proposed architecture (Figure 3) shall reduce the operating cost(s) by a considerable margin and hence would bring an inherent improvement in the Return on Investment (ROI).

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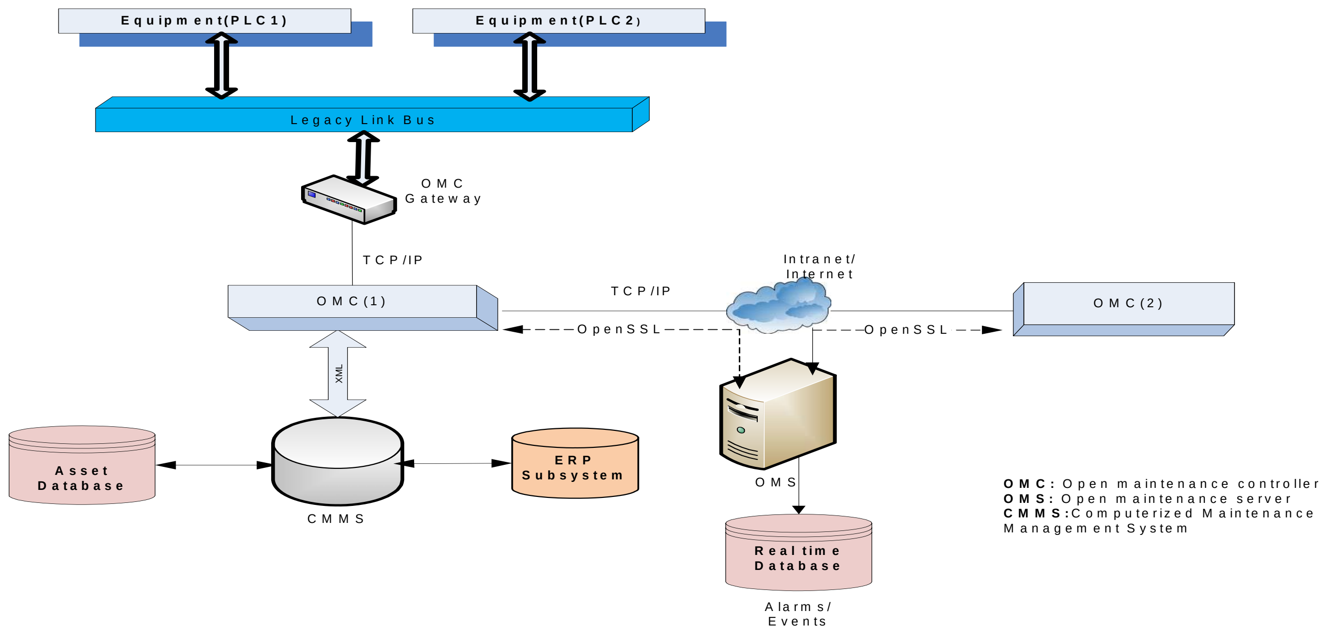

Figure 3 Proposed Extension of the CMMS system using open standards.

5. CONCLUSIONS AND FUTURE WORK

This paper gives an overview of an open systems approach to e-maintenance with a hypothetical example of how an existing

CMMS can be transformed to a fully automated e-maintenance solution. It identifies the weaknesses of the existing CMMS system and how can you leverage on the new system to optimize organizational profits. It also mentions the capabilities of the proposed architecture and addresses certain challenges faced in order to enable an open framework. The detailed cost benefit analysis for the framework is beyond the scope of this paper and will be discussed in a follow up paper.

The findings so far suggest that the different traditional practices used in preventive and condition based maintenance strategies require building customised solutions. An open system solution can tackle the associated problem in fairly cost-effective manner.

Ubiquitous and intelligent processing of maintenance data using standards "on demand" shall facilitate interoperability with existing legacy systems. This platform shall scale well to serve additional requirements of the user based on new information, historical analysis, and new measurements etc.

A prospect of this work will be to generate a virtual framework of the system to do performance benchmarking of the integrated system based on real data gathered through the real system. This shall further help in evaluating whether or not the solution supports the industry wide best practices and the total maintenance process.

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