

Maintenance Knowledge Management with Fusion of CMMS and CM

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Abstract- Maintenance can be considered as an information, knowledge processing and management system. The management of knowledge resources in maintenance is a relatively new issue compared to Computerized Maintenance Management Systems (CMMS) and Condition Monitoring (CM) approaches and systems. Information Communication technologies (ICT) systems including CMMS, CM and enterprise administrative systems amongst others are effective in supplying data and in some cases information. In order to be effective the availability of high-quality knowledge, skills and expertise are needed for effective analysis and decision-making based on the supplied information and data. Information and data are not by themselves enough, knowledge, experience and skills are the key factors when maximizing the usability of the collected data and information. Thus, effective knowledge management (KM) is growing in importance, especially in advanced processes and management of advanced and expensive assets. Therefore efforts to successfully integrate maintenance knowledge management processes with accurate information from CMMSs and CM systems will be vital due to the increasing complexities of the overall systems.

Low maintenance effectiveness costs money and resources since normal and stable production cannot be upheld and maintained over time, lowered maintenance effectiveness can have a substantial impact on the organizations ability to obtain stable flows of income and control costs in the overall process. Ineffective maintenance is often dependent on faulty decisions, mistakes due to lack of experience and lack of functional systems for effective information exchange [10]. Thus, access to knowledge, experience and skills resources in combination with functional collaboration structures can be regarded as vital components for a high maintenance effectiveness solution.

Maintenance effectiveness depends in part on the quality, timeliness, accuracy and completeness of information related to machine degradation state, based on which decisions are made. Maintenance effectiveness, to a large extent, also depends on the quality of the knowledge of the managers and maintenance operators and the effectiveness of the internal & external collaborative environments. With emergence of intelligent sensors to measure and monitor the health state of the component and gradual implementation of ICT) in organizations, the conceptualization and implementation of E-Maintenance is turning into a reality. Unfortunately, even though knowledge management aspects are important in maintenance, the integration of KM aspects has still to find its place in E-Maintenance and in the overall information flows of larger-scale maintenance solutions. Nowadays, two main systems are implemented in most maintenance departments: Firstly, Computer Maintenance Management Systems (CMMS), the core of traditional maintenance record-keeping practices that often facilitate the usage of textual descriptions of faults and actions performed on an asset. Secondly, condition monitoring systems (CMS).

Recently developed (CMS) are capable of directly monitoring asset components parameters; however, attempts to link observed CMMS events to CM sensor measurements have been limited in their approach and scalability. In this article we present one approach for addressing this challenge. We argue that understanding the requirements and constraints in conjunction - from maintenance, knowledge management and ICT perspectives - is necessary. We identify the issues that need to be addressed for achieving successful integration of such disparate data types and processes (also integrating knowledge management into the "data types" and processes).

Keywords: CMMS, CM, Maintenance Knowledge Management, Experience Management, I-Maintenance

I. INTRODUCTION

The production and process industry are passing through a continuous transformation and improvement for last couple of decades, due to the global competition coupled with advancement of information and communication technology (ICT). The business scenario is focusing more on e-business intelligence to perform transactions with a focus on customers' needs for enhanced value and improvement in asset management. Such prognostic business requirement compels the organizations to minimize the production and service downtime by reducing the machine performance degradation. The above organizational requirements necessitate developing proactive maintenance strategies to provide optimized and continuous process performance with minimized system breakdowns and maintenance. Implementing solutions from the business world concepts such as e-intelligence, e-factory, e-automation, E-Maintenance, e-marketing and e-service have emerged.

E-Maintenance provides the organization with intelligent tools to monitor and manage assets (machines, plants, products, etc.) proactively through ICT, focusing on health degradation monitoring and prognostics, instead of fault detection and diagnostics. Maintenance effectiveness depends on the quality, timeliness, accuracy and completeness of information, knowledge and earlier experiences related to machine degradation state and support processes, based on which decisions are made. This translates into a number of key requirements: preventing data and information overload, ability to differentiate and prioritize data and actions (during collection as well as reporting), to prevent, as far as possible, the occurrence of information islands and to effectively communicate status and vital information to relevant actors. Integration and inclusion of maintenance knowledge management (MKM) into the processes and

infrastructures of E-Maintenance creates the foundation for a more comprehensive approach to ICT-based maintenance solutions which one can call I-Maintenance (“Intelligence-based Maintenance”). The I-Maintenance approach not only aim at integrating maintenance knowledge management into the solutions but also offer integration of collaborative environments, remote computational services, ontology’s for effective tagging of resources, solutions etc. all designed to be effectively used across different levels of the organization and between organizations.

CMMS and CM are the most popular repositories of information in maintenance, where most of deployed technology is installed and unfortunately isolated information islands are usually created. While using CMMS and CM technology as isolated systems can bring the achievement of maintenance goals, combining the two into one seamless system can have exponentially more positive effects on maintenance group’s performance than either system alone might achieve. The combination of the strengths of an effective top-notch CMMS (preventive maintenance (PM) scheduling, automatic work order generation, maintenance inventory control, and data integrity) with the wizardry of a leading edge CM system (multiple-method condition monitoring, trend tracking, and expert system diagnoses) allows work orders to be generated automatically based on information provided by CM diagnostic and prognostic capabilities. Over the last 15 years, linking CMMS and CM technology was mostly a vision easily dismissed as infeasible or at best too expensive and difficult to warrant much investigation. Now, the available technology in CMMS and CM solutions has made it possible to achieve such a link relatively easily and inexpensively. Integration of a MKM component with the CMMS and CM environments introduces risks of creating additional information islands and complexities if not properly designed, developed and implemented. One promising approach for integrating MKM into overall solutions that also integrates CMMS and CM data is utilization of SOA (Service Oriented Architectures) in combination with implementation of software agents. The danger of trying to intimately integrate MKM, collaborative structures, CMMS and CM into one unified solution is that the overall solution with a high probability will be sub-optimized if not planned and implemented properly. This is especially dangerous when implementing solutions with a high rate of change in structure and processes – MKM is one of these types of solutions. Currently the most viable route for integrating CMMS, CM and I-Maintenance modules and solutions is to integrate at the end-user level, utilizing a combination of application servers with end-user environments that allows for modular integration of different information sources, services and functions.

A high specification CMMS can perform a wide variety of functions to improve maintenance performance. It is the central organizational tool for World-Class Maintenance WCM, primarily designed to facilitate a shift in emphasis from reactive to preventive maintenance. It achieves this shift by allowing maintenance professionals

to set up automatic PM work order generation. A CMMS can also provide historical information that is then used to adjust a PM system to minimize repairs that are unnecessary, while still avoiding run-to-failure repairs. PMs for a given piece of equipment can be set up on a calendar schedule or a usage schedule based on measurements and readings. A fully featured CMMS also includes inventory tracking, workforce management, purchasing, in a package that stresses database integrity to safeguard vital information. The final result can be optimized equipment up-time, lower maintenance costs, and better overall plant efficiency dependent on the ability of the maintenance staff to use the systems and processes, factors highly dependent on the knowledge level and experience of the maintenance staff. On the other hand, CM system should accurately monitor real-time equipment performance, and alert the maintenance professional to any changes in performance trends. There are a variety of measurements that a CM package might be able to track including vibration, oil condition, temperature, operating and static motor characteristics, pump flow, and pressure output. These measurements are squeezed out of equipment by monitoring tools including ferrographic wear particle analysis, proximity probes, triaxial vibration sensors, accelerometers, lasers, and multichannel spectrum analyzers. The preferred CM systems are expert systems that can analyze measurements such as vibration and diagnose machine faults. Expert system analysis can place maintenance procedures on hold until absolutely necessary, thus extracting maximum equipment up time. In addition, expert systems should offer diagnostic fault trending where individual machine fault severity can be observed over time.

MKM allows for effective dissemination of experiences, manuals, collaborative structures for access of internal and external specialists and knowledge resources. In the context of support for the CMMS the MKM can integrate management of documentations, instructions, access to remote servicing, decision support and experience capture and management. In the context of support for CM the MKM can support the analysis processes of CM data by access of collaborative structures for internal and external specialists, in addition provide access to external CM analysis tools / computational engines and interaction with external vendors specialized support structures. The MKM component can be instrumental in the ability of the maintenance staff to properly interpret the results from the measurements and computations. Both CMMS and CM systems have strong suits that make them indispensable to maintenance operation improvements. CMMS is a great organizational tool, but cannot directly monitor equipment conditions. A CM system excels at monitoring those equipment conditions, but is not suited to organizing your overall maintenance operation. The logical conclusion, then, is to combine CMMS and CM technologies into a seamless system that avoids catastrophic breakdowns, but eliminates needless repairs to equipment that is running satisfactorily. The MKM environment can have a strong role in improving the accuracy and quality of the analysis and the resulting decisions. MKM also has an important

role in minimizing the risk for mistakes and human error in the implementation of the decisions and the quality of the maintenance work performed on the work floor or in the field. It also allows for improved quality of the decisions made over time due to more accurate feedback of experiences and observations by the maintenance operators.

Technology providers are trying to develop advanced tools while the maintenance departments often struggle with daily problems of implementing, integrating and operating such systems. MKM systems can have a vital role in speeding up effective implementation of these more advanced ICT centric solutions by integrating competence resource structures into the solutions, allowing the end-users of different types to get support and instructions optimized for their own work roles and work contexts. MKM systems can supply infrastructures for experience capture and management supporting the maintenance departments to manage ever-increasing complexities in assets and process flows. The CMMS and CM technology providers or the users do generally not know the feasibility of applying CMMS or CM technologies, but apparently they seem to improve the efficiency of the maintenance activities. The users combine their experience and heuristics in defining maintenance policies and in usage of condition monitoring systems – an approach that can be effectively supported by a well functioning MKM implementation. The existing maintenance systems seem to be a heterogeneous combination of methods and systems in which the integrating factor of the information and business processes is the maintenance personnel, personnel that often cannot utilize the full functionality of the underlying systems. The information in the maintenance systems goes through these human minds forming an organizational information system and creating a high reliance on the expertise of the maintenance staff. Thus, increasing the support for the human component in the overall system to perform their work more accurately, securely and more effectively improves the overall maintenance processes and the effectiveness of the overall operations. In this context MKM has an important role to fill at the same time as the vulnerability for the organization due to loss of vital staff can decrease [9].

With emergence of intelligent sensors to measure and monitor the health state of the component and gradual implementation of information and communication technologies (ICT) in organizations, conceptualization and implementation of E-Maintenance is turning into a reality [1]. While E-Maintenance techniques can provide benefits to an organization, seamless integration of information and communication technologies (ICT) into the industrial environment still remains a challenge. It is necessary to understand and address the requirements and constraints from the maintenance as well as the ICT standpoints in parallel. Thus, increasing the support for the human component in the overall system to perform their work more accurately, securely and more effectively improves the overall maintenance processes and the effectiveness of the overall operations. In this context MKM has an important role to fill.

II. AN INTEGRATED APPROACH TO ASSET MANAGEMENT

Two main maintenance information sources found in the industries to be merged: Computer Maintenance Management systems (CMMS) and Condition Monitoring (CM). CMMS uses context-specific textual data to record information such as asset load and usage, component failures, servicing or repairs, and inventory control. Although for a given platform, there may exist several different implementations, the underlying structure is typically heavily regulated, allowing for a large base of consistently structured data. These systems are the core of traditional scheduled maintenance practices and rely on bulk observations from historical data to make modifications to regulated maintenance actions. CM systems collect component-specific quantitative data to assist maintenance crews in the identification of failures that are imminent or have already occurred. Typically there exists no standardization in the way data is collected across platforms or vendors, primarily because the technology is still in its infancy. There is still a need to investigate and debate on the type of information required for asset health diagnostics and information used to meet CBM objectives. CMMS environments do not today effectively support client platforms. More advanced resources such as multimedia and integrated collaborative environments, are useful for effective remote support and interaction with internal and external specialists. Core functionalities for effective experience capture are not present in current CMMS environments - the main challenge is the lack of effective meta-data management. CMMS, CM and MKM have to be linked. The measurements and analysis implementations supported by MKM and made by a CM package must be available to maintenance planners who work with a CMMS for the purpose of scheduling predictive and other types of work orders, these maintenance planners are also supported by MKM. In the past, maintenance organizations that used both CMMS and CM technologies linked the two systems by inputting CM data manually into the CMMS. While this is an acceptable way to transfer data for the purpose of scheduling predictive maintenance work orders, it is also time-consuming. Another CM data transfer method that has been used recently is a passive data exchange, which involves writing pertinent CM data to a specified local or network directory. Relevant data to be exchanged includes equipment identification, date and time stamps, repair priority, repair recommendations, and observations.

The CMMS program would routinely check this directory, and if a transfer file is found, the CMMS reads it and imports it into the CMMS database. Historically, this method of data transfer has been very specific to formal cooperation between various manufacturers of CM and CMMS software. The passive data transfer method is better than manual data entry, but still falls well short of the total automation and instant access to information that is possible when the CMMS and CM program are totally integrated. Integration of MKM solutions can support effective training and learning of the staff responsible for the data capture (increasing the quality), the staff

responsible for the analysis and the information / experience exchange between internal and external specialists when developing the CM processes and results implementation. In future scenarios the CM analysis can be performed remotely, eventually by different companies with different specializations. A MKM environment can aid the internal analysis staff in selecting the correct CM analysis & modeling vendor / analysis approaches and handle the eventual initial training efforts needed for the services and analysis efforts. Integration has been addressed this far largely from the view point of representing the collected information to the end-user (operator or manager) in an effective manner, i.e., bridging the gap between information collected from plants and equipment and the enterprise resource planning (ERP) platforms. A major initiative has been the development of information integration specifications to enable open, industry-driven, integrated solutions for asset management. However, some of the efforts to standardize the E-Maintenance platforms currently underway are: Machinery Information Management Open Systems Alliance (MIMOSA) [2], GEM@WORK [3], CASIP [4] and PROTEUS [5].

Such platforms provide an information schema at the application-level and an application programming interface (API) to communicate with the underlying protocol stack. To our knowledge, existing communication technologies are not well-suited for reliable and timely delivery of appropriate data between distributed end-systems in industrial environments; this, in our opinion, remains a critical missing link in the seamless integration vision. Added to this is the current lack of effective integration of knowledge management structures into the overall maintenance environments. Effective integration of MKM solutions will become vital over time due to the increasing complexity of processes and products in combination with increased competition for knowledgeable staff and specialists. The main challenge for future maintenance systems is to effectively support the end-users of different types in their efforts to manage a complex work environment, complex and advanced assets and processes and management of their overall work situation to decrease stress and risks.

A. Integration of data sources

The first step of integrating a CMMS, CM and MKM packages into an automatic system is setting up a way for the systems to communicate. In the case of CMMS and CM technologies the first step can be to set up consistent data in each system that will allow them to communicate using a common base of information. Next, there must be a system of data cross-references between the sensors, meter tags, or other measurement tools in a CM system and the appropriate module in the CMMS that associates readings in one system with readings in the other. Meter readings or alarm triggers that are out of the acceptable range set up in the CMMS should trigger a pre-defined work order. Any discrepancy in this cross-reference for a piece of equipment will nullify the link for that piece of equipment, making the ability to predict problems

problematic. This makes the initial planning of data entry rules and database setup a critical part of the pre-integration process. The third step is to provide a direct link between the systems' data tables. This is referred to as an "active exchange" of data. In today's environment, CMMS databases feature open architecture such SQL, Oracle and others. The most obvious obstacle in the integration of CMMS, CM and MKM data and information is the disparate nature of the data types involved, and attempts to remedy this problem have been met with inconsistent implementation and limited scalability. The first such technique is to assign the qualitative CMMS data with quantitative indexing, allowing for CM data to be separated into discreet maintenance states. Integration of MKM systems and environments has not been a factor at all in these earlier implementations due to the specialization of the vendors of the CMMS and CM system vendors – Knowledge Management has been seen as a separate area with its own markets and usage contexts and not viable to integrate in an efficient manner into CMMS and CM environments. It is the responsibility of the maintainer to correctly insert the appropriate fault or work code into the maintenance logs, which to date has not been done with sufficient accuracy or consistency to be deemed reliable. The example presented in figure 1, is a demonstrator of an integrated end-user environment supporting modular and work context-centric approach to information management for multiple organizational layers in an I-Maintenance structure. This demonstrator presents the ability to support end-user adaptation of the overall work environment depending on work roles, deployment environment and user access control structures. It also presents a concept for end-user controlled mash-up (systems able to present and manage information from many disparate information sources and services – all presented in one unified end-user environment). This demonstrator is based on research covering end-user environments for qualified maintenance of advanced technical systems (military fighters) allowing integration of knowledge / practices / experiences / standards management into a unified and integrated environment [8].

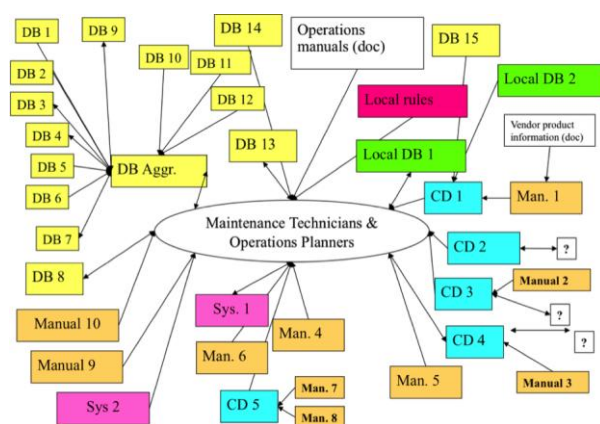


Figure 1: Integration of CM/CMMS/MKM and support for multiple work contexts. Courtesy of Enviro Data, Sweden

The above demonstrator is developed in response to information logistics and knowledge support challenges for maintenance planners and staff supporting advanced systems. Figure 2 presents an anonymized schema of different information and data sources needed for maintenance planning and work for this system. The same scenario is present in many other contexts, organizations and processes. The main challenge for managing this is to create productive and effective end-user environments to allow management and handling of all these disparate information and competence resource sources and access methods. This is a good example of the challenges for integrate CMMS, CM and MKM resources and in parallel allow for effective collaboration.

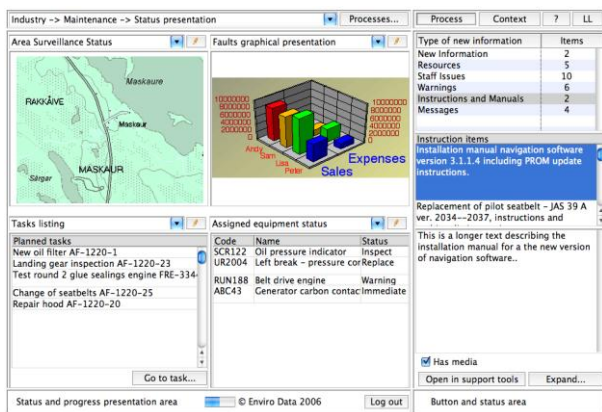


Figure 2: Example of an information sources map for a maintenance operations planner

B. Definition of Integration / Relation Process

Although there have been many recent efforts to collect and maintain large repositories of CMMS and CM data but there have been relatively few studies to identify the ways these two datasets could be related. There are even less examples of how the CMMS, CM and MKM resources can be linked and managed in effective work contexts. It is only logical to assume that written histories of maintenance records are linked to the measurements of onboard sensors, and it is in the interest of CBM research to develop a means by which these data sets can be consistently and reliably merged. At the same time relevant competence resources connected to the asset has to be effectively managed and updated in end-user environments that do not introduces additional complexities for the users during their most prevalent work contexts and processes. A full integration of CMMS and CM datasets requires a more advanced form of interfacing which more appropriately models the real-world relationships between observed maintenance and sensor data. Case studies to date have been generated by individuals who identify related events based upon their knowledge of the systems involved. For example, an abrupt change in a vibration sensor on a gearbox is assumed to be related to a recorded replacement of a nearby part. Taking an analytical approach to this decision making process is rather complex, since the determination of causality and dependence is often performed through a highly subjective process. MKMs can in this case increase

the accuracy of the analysis by effectively supplying earlier experiences, faults and conclusions and at the same time speed up the processes by allowing faster access to external specialists and competence resources of different types. An MKM environment can also support wider and more complex analysis of overall process dependencies and more complex logging of faults and corrective actions than those allowed by the current selection of CMMS's.

The overall goal of an enhanced interfacing should seek to automate the complex process of linking events from different datasets – preferably utilizing SOA to guarantee the security of the data. Developing this system begins with a four-step investigation: historical data collection, importation into a single database, data abstraction, and data analysis. Using a wealth of historical information in combination with knowledge of system components, software agents are under development that attempts to bridge the gap between the data types by allowing for the proximity, severity, and rarity of events across datasets to be evaluated. Figure 3 describes a process utilizing direct integration of datasets, not SOA-based interaction. Through an integrated CM and CMMS system, identifying instances where CM data is reflected by real-world events can be performed regularly. This allows for an objective determination of asset parts prone to failure and an evaluation of CM effectiveness in monitoring those regions. Based upon these evaluations feedback can be given to CMMS and CM developers to refine the means by which the data is collected, and a strategy for the next generation of fully-integrated CBM systems can be devised. This can be one of the tasks for MKM environments – acting as a collaborative platform for collecting, evaluating and analyzing earlier experiences, mitigation methods and processes and support for internal practices development.

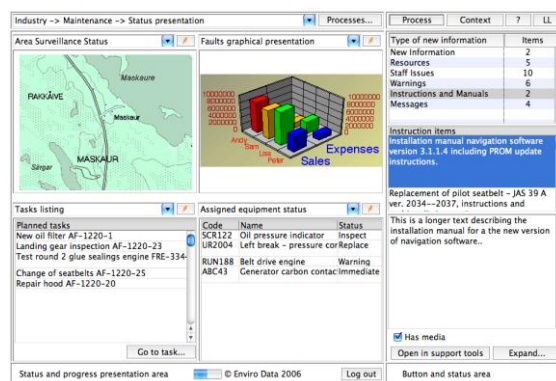


Figure 3. Depiction of the four-stage integration process

C. Data source collection

The history of Maintenance Management Systems predates the information age, it has traditionally been delegated to the unit-level for implementation. Collecting data for investigation studies has required the permission of various units, thus limiting the scale of CMMS research to date. As a result, efforts to centralize CMMS data have

been slow to materialize therefore; data collection for early integration studies remains a small sample of the future capabilities of a centralized CBM system. In contrast, CM developers have relied on automated data centralization to evaluate and validate their systems since their inception. In order to minimize risk for un-intended sabotage of the measurement data due to faulty installation routines and low experience of handling the measurement equipment the organization can utilize MKM structures to integrate effective training efforts and eventual certification processes into the overall installation and maintenance of the measurement equipment.

D. Relational data importation

Modern CMMS information is stored in large relational, or tabular, databases. This format is appropriate for an integration investigation since there are a large number of software tools available to query and investigate the tables. For the historical analysis, only certain fields are required, thus allowing for the previously mentioned sensitive data to be removed or filtered. The data subset still contains a full history of component faults and related actions, providing a comprehensive maintenance history profile while alleviating security concerns.

Importing CM data into a relational database is somewhat more challenging, since each type of sensor generates different data classes, sampling rates, and number of compiled indicators. Furthermore, each manufacturer stores the collected information in unique proprietary formats, requiring platform-specific importation software to be written. This software allows the CM data to be exported from the original interface so that it can be expanded and generalized. Once this is accomplished, the benefits are tremendous: multiple manufacturer and cross-platform data can be viewed as through generic data classes.

E. Pre-processing and data abstraction

Although both the CMMS and the CM data now co-exist within a single database where it can be queried and explored, automating the discovery of linked events requires additional processing. In their original form, the datasets only have two fields in common: asset identification and date. Relating a given maintenance fault or action, which is textual, to sensor data, which is some arbitrary data class type, can only be accomplished through the compilation of overlapping metadata. The fields that are generated characterize the location and significance of events, creating a quantified set of parameters by which the disparate data can be compared. Since CMMS is textual, it is processed using artificial intelligence (AI) tools applied to language processing (LP), [6]. LP is a subfield of both artificial intelligence as well as linguistics with a large variety of applications. It covers a many of topics ranging from machine translation to speech recognition and often focuses on a computer's ability to interpret and respond to natural human languages. A recent success in LP has been auto-summarization and information extraction. Due to the

specific context of maintenance management data, in which descriptions of assets faults and performed actions are stored, the lexical domain is highly restricted and text CMMS fields can be analyzed separately to create a set of interpreters which extract key information from the fault or action description. The AI LP tool outputs which component the record is in reference to and a list of other descriptor keywords. Categorical statistical analyses are performed to characterize the rarity of a given record, and a pre-programmed scoring chart assigns each record a severity based on the available keywords. One additional level of abstraction of data for CM records is generated differently depending on the data class involved. Identifying anomalies can be performed using statistical distribution analysis and in the case of multidimensional data neural networks can be used identifying which component a particular sensor or indicator is monitoring is predefined by the CM manufacturer. Often un-trained the staff use a system for semantic analysis which could have a negative effect as this increases the probability for errors and faults in the resulting analysis. Automatic semantic analysis is very dependent on the in-data -> if the users are not using coherent strategies in naming and characterizing the information the larger the potential for errors. MKM can in these cases offer support for educating the users and offer channels for end-user input regarding eventual modifications to the ontological and semantic definitions used.

F. Analysis and Correlation

The metadata is then extracted from all the available records into a single events table containing asset identification, component name, event time, a rarity parameter, and a severity parameter. The simplest method of determination of event-relatedness is accomplished through a proximity study of the metadata. The results of this analysis could then be categorized by component and identify parts of the assets where CM devices have a high success rate in identifying component faults or reflecting maintenance actions. Known problematic subsystems that do not have a high count of related CMMS and CM events indicate that revision to the sensing strategy or changes in indicator definition are needed. For these components, further analysis can be performed on the raw data to discover new algorithms for condition indicator computation. However this computation is extremely complex due to the multi-location structure of many companies with lots of information systems related to maintenance in each of them (CMMS, CM, phones, PDA, laptops, SCADA, ERP...). Replication of all data in order to perform this correlation is not feasible and would require enormous computation resources, that is why the concept of cloud computing is seen as the answer in creating these metadata from all available information.

The analysis and correlation steps demands high levels of competence and experience - which is tricky to achieve when the number of equipment is high, very large number of variants exists and there are not enough units of a specific kind to locally create high expertise on the units in

question. A MKM environment can offer structures for collaboration between the specialists and maintenance staff covering the fault modes, mitigating efforts, experiences and practices. A MKM can also offer collaborative environments for collective assistance in faults analysis and CM analysis.

III. CONCLUSIONS

Organizations can benefit greatly by integrating and synthesize information coordinated and managed from CMMS and CM systems and processes. This example of information logistics that is often characterized as E-Maintenance cannot as the research has shown fully deliver on its promises without integration and coordination with environments for management of knowledge, practices and experiences in combination with collaborative structures. This combination and integration of CMMS, CM, MKM environments (including practices and experience management) and collaborative / simulation tools and infrastructures can be labeled I-Maintenance – Intelligence-based Maintenance. I-Maintenance aims at integrating the knowledge and skills of the operators and maintenance planners into the processes to minimize costs, risks and increasing the overall performance.

This paper has shown the importance of providing maintenance managers with accurate and up to date information and insights using Maintenance knowledge systems, information and insights that will assist in the further implementation of IT in their processes and more accurately evaluate the IT systems and their contribution to the overall organizational performance. The ongoing efforts to simplify integration and coordination of systems by utilizing Service Oriented Architectures (SOA) will also allow for a faster and more effective implementation of I-Maintenance systems.

The final I-Maintenance system will manifest itself as an automated maintenance exploration interface in combination with end-use adaptable interfaces to a large number of different information sources and internal / external services. Users will be able to quickly identify possible diagnoses of faults and quickly retrieve historical

maintenance actions that were effective in resolving the problem and exchange new ideas and practices for future use. Such a system would be easily scalable across several CM platforms, several asset types, and several locations, allowing for maintainers to have information on a variety of practices being performed across the field and with parallel access to a wide range of competence resources, experiences and collaboration with external and internal specialists. The majority of CMMS vendors recognize the necessity to move forward quickly. Because of this, all attempts to integrate CMMS, CM and MKM are going to be a key part of maintenance technology in the future. Currently, this integration consists of a common framework for data exchange. No real relations and context information is extracted from the huge amount of data included in these warehouses.

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