Engineering Optimization through the qualified use of CMMS and Predictive Software

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Abstract
Aiming to reach both Engineering and Maintenance Optimization the complex Managerial tasks of an Enterprise ceased of being predictably analyzed solely through linear algorithms requiring multidisciplinary approaches. Through properly placed in process sensing tools the key issue of Enterprise Maintenance becomes mainly a Proactive one, a relevant model being the optimization through the qualified use of CMMS software. CMMS (Computerized Maintenance Management System) packages may be used by any organization that must perform maintenance on equipment, assets and property. A CMMS focused on machine optimization provides a flexible application for plant personnel. Enterprise applications can restrict a focused optimization of specific equipment. If the enterprise application is focused on cost reduction and complete asset management, it might miss the very techniques that reduce cost. Corrective and preventive maintenance scheduling must be flexible as designed for machines by a CMMS system. Predictive Maintenance (PdM) is an algorithm based on the analysis of the history of failures. Report the impending failure of equipment by analyzing values that exceed or trend toward an alarm limit. The predictive software can set alarm limits statistically or by a group of machines. So, modeling the Maintenance Management activity becomes a compact and focused system without the influence of enterprise restrictions, as the operating Davison CMMS software proves.

Keywords: CMMS, PdM, RCM, Condition-Directed Maintenance

1. Maintenance management- the dynamics of the paradigm
On the last century Maintenance Management has gone through some amazing changes on the same time with the equipment- the physical resources used to manufacture, process, transport, and serve.
In the first part of this century, machines were relatively simple, sturdy, and long-lasting. When the main moving parts or parts that came into contact with the product wore out, they would be rebuilt.
Today, equipment is typically a complex hybrid of electromechanical devices; electronically controlled; with hydraulic, optic, or pneumatic subsystems (fig. 1). It is characterized by replaceable components on a base structure. Because of its complexity and precision standards, failure patterns are somewhat random. Often, it is built to last for a predetermined use, to balance capital, operating, and disposal costs. However, equipment design and use are changing, and so must maintenance to keep pace.

In the next 25 years, the equipment has to become even more modular and automated to increase its operating flexibility. Also, with continued marketplace globalization and competitive pressures, it must be both highly precise as well as robust. So, the failure rate will likely mimic that of complex equipment systems, but there will be
an even stronger need for predictable performance based on online condition monitoring, exacting diagnostics, and lightening-fast response. Such a fast evolution of maintenance concept has already a benchmarking example on the automobile, which has changed tremendously over the past sixty years. The new top-line cars have on-board diagnostics that rival those in jet aircraft, thus making the major oil companies to close most service stations because there is so little demand for car repairs, despite major increase in the number of automobiles on the road.

What does this mean for maintenance management? Looking to the past for guidance emerges an interesting picture (tab.1, fig. 2): if the first generation of maintenance management had a strategy of run-to-failure the present and the future ones are based on prediction and reliance.

Table 1: Maintenance Management Generations

<table>
<thead>
<tr>
<th>Generation</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th (?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRATEGY</td>
<td>BREAKDOWN</td>
<td>PREVENTION</td>
<td>PREDICTION</td>
<td>RELIANCE</td>
</tr>
<tr>
<td>Structure</td>
<td>Central craft groups</td>
<td>Multi craft teams</td>
<td>Multi skilled trades</td>
<td>Poly skilled technician</td>
</tr>
<tr>
<td>Failure Management</td>
<td>Operate to failure</td>
<td>Scheduled overhaul</td>
<td>FMECA and CMMS</td>
<td>Self-analysis</td>
</tr>
<tr>
<td>Data Management</td>
<td>Card files</td>
<td>Mainframe functions</td>
<td>Fully functional CMMS</td>
<td>Fully networked Stations</td>
</tr>
<tr>
<td>Measures</td>
<td>Throughput</td>
<td>Availability</td>
<td>Equipment Effectiveness</td>
<td>Probabilities</td>
</tr>
</tbody>
</table>

2. Concept overview

Table 2: Acronyms on Maintenance Management and CMMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AO</td>
<td>Availability</td>
</tr>
<tr>
<td>APC</td>
<td>Advanced Process Control</td>
</tr>
<tr>
<td>CEM</td>
<td>Common Equipment Model</td>
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<tr>
<td>COO</td>
<td>Cost of Ownership</td>
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<tr>
<td>EDA</td>
<td>Equipment Data Acquisition Tracking</td>
</tr>
<tr>
<td>EPT</td>
<td>Equipment Performance</td>
</tr>
<tr>
<td>FDC</td>
<td>Fault Detection and Classification</td>
</tr>
<tr>
<td>M-Ratio Maintenance</td>
<td>ratio between scheduled/unscheduled maintenance</td>
</tr>
<tr>
<td>MTBF</td>
<td>Mean Time Between Failure</td>
</tr>
<tr>
<td>MTTR</td>
<td>Mean Time to Repair</td>
</tr>
<tr>
<td>OEE</td>
<td>Overall Equipment Effectiveness</td>
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<tr>
<td>PdM</td>
<td>Predictive Maintenance</td>
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<tr>
<td>PM</td>
<td>Preventive Maintenance</td>
</tr>
<tr>
<td>PPM</td>
<td>Predictive and Preventive Maintenance</td>
</tr>
<tr>
<td>PTTF</td>
<td>Predictive Time to Failure</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>SMC</td>
<td>Statistical Machine Control</td>
</tr>
<tr>
<td>SPC</td>
<td>Statistical Process Control</td>
</tr>
<tr>
<td>SVID</td>
<td>Status Variable ID</td>
</tr>
<tr>
<td>TBM</td>
<td>Time-based Preventive Maintenance</td>
</tr>
<tr>
<td>UBM</td>
<td>Usage-based Preventive Maintenance</td>
</tr>
<tr>
<td>WIP</td>
<td>Work-in-Process</td>
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</tbody>
</table>

Figure 2: Definition of maintenance

Figure 3: Components of Maintenance
**Preventive Maintenance** is a schedule of planned maintenance actions aimed at preventing unscheduled equipment down time. It is traditionally based on elapsed calendar time or fixed unit count usage:

- Predominantly time and usage based
- Daily, weekly, monthly
- Wafer count- or RF count-driven

**Condition-based Preventive Maintenance** is an enhanced method that applies advanced analysis techniques to data from equipment components, modules, or other sources to identify performance indicators, such as thresholds, control limits, voltage, etc., requiring preventive maintenance. Condition-based PMs are intended to maximize the availability and productivity of the equipment while optimizing maintenance costs:

- Optimizes the availability of the equipment
- Includes conditional and time-based preventive maintenance
- Uses real data to determine when PMs should be done
- Uses data from all possible data sources that can be obtained as input
- Applies advanced analysis and scheduling techniques
- Aims to reduce scheduled downtime, usage of consumables/parts, and optimization of maintenance effort and costs. “Optimum” may vary among users or equipment type and related costs for implementation, as may the important input parameters to analytical algorithms.

**Predictive Maintenance** is a maintenance technique that uses data from equipment and other relevant sources (i.e., FDC, APC, Yield learning, PM history, etc.) These data allow events and trends in performance and equipment settings to be monitored through advanced analysis techniques and failure behavior profile matching. Analysis of component performance data and other indicators enable the identification, give warning, and prioritize impending or imminent unscheduled failures in advance. Predictive maintenance is complementary to condition-based preventive maintenance.

Predictive maintenance is supported by high performance equipment data availability and well developed factory systems. The goal of a successful maintenance strategy is to incorporate all aspects of equipment data and develop a program to limit non-planned maintenance by reacting to this data through various predictive and planned activities.

![Figure 4: Predictive and Planned Activities](image)

### 3. Key Elements of Maintenance Management

One of the core characteristics of both Preventive and Predictive Maintenance is “data sharing”. PM and PdM have to use data from all available sources as to provide the best performance monitoring and predictions. When determining what sources of data are available and relevant, the entire environment that the equipment operates in should be considered. For instance for a specific R&D lab (fig.5). Implementations should evaluate the usefulness of the data in improving equipment availability, maintenance cost, and OEE and make that data available to the PPM systems.
Figure 5: Predictive and Preventive Maintenance Data and Implementation Environment

The type and extent of data for each of the components of comprehensive PPM solutions will vary depending upon their role. Preventive maintenance requires the simplest data set, whereas predictive methodologies require much more data in both amount and type.

<table>
<thead>
<tr>
<th>Preventive Maintenance</th>
<th>PM</th>
<th>should be based on data, such as the expected life of consumable parts or historical data on the useful life on the equipment. Preventive maintenance is traditionally based on elapsed calendar time or fixed unit count usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage Based Preventive Maintenance (UBM)</td>
<td>Maintenance activities carried out at predetermined intervals of usage</td>
<td></td>
</tr>
<tr>
<td>Time-Based Preventive Maintenance (TBM)</td>
<td>Parts that have to be exchanged/repaired at predetermined intervals of time</td>
<td></td>
</tr>
<tr>
<td>Condition-Based Preventive Maintenance</td>
<td>CBM</td>
<td>Is an enhanced method based on equipment or other possible data collection and analysis. Various advanced analysis techniques and data collection methods are currently being used to achieve more competitive equipment availability and productivity. Condition-based PMs are intended to maximize the availability and productivity of the equipment while optimizing maintenance costs. This also reduces planned downtime and thus increases availability.</td>
</tr>
<tr>
<td>Predictive Maintenance</td>
<td>PdM</td>
<td>Predictive maintenance identifies impending or imminent unscheduled failures and generates advanced warning and prioritization. To make predictions that are usable in a real environment, there are four essential components: input, methodology, output, and use. However, predictive maintenance is complementary to condition-based preventive maintenance.</td>
</tr>
<tr>
<td>Input</td>
<td>Data about the condition of equipment and facilities, fab./lab performance indicators, and maintenance. - <em>Internal data</em> about performance and condition of equipment, equipment components and other sources e.g. additional sensors within the equipment - <em>External data</em> and events including FDC, EPT, PM history, SPC, SMC, etc.</td>
<td></td>
</tr>
</tbody>
</table>
| Methodology | It should monitor single parameters, trends, performance of equipment and additional data sources:  
- Equipment parameters (electric, mechanic, pressure, chemical, etc.)  
- Fab performance indicators (number of processed wafer, used recipes, WIP, etc.)  
- Facility data  
- Availability of equipment  
- M-Ratio: Scheduled/unscheduled downtime |
- MTBF
- Cost of ownership
- Statistical and other analysis and failure behavior profile matching should be included.
- Information that identifies the possibility of concurrent failures or that allows for prioritization of maintenance on imminent required maintenance is important.

Event-driven failures that do not need trend data (FDC data may be an input source for fault prediction) should be included. The PdM system must analyze the input data according to rules and models defined. It then calculates the optimum time to do maintenance. Warning must be given in advance so that activities can be scheduled.

### Output
- Early warning must be given of impending or imminent failure conditions to distribute the workload and avoid simultaneous downtime of many pieces of equipment.
- The maintenance schedule should be automatically adjusted.
- Unscheduled downtime is reduced by early warnings giving a chance for scheduling.
- Maintenance-related costs are reduced as maintenance is done close to the latest possible time reflecting usage, condition, data, etc.
- Repair and overhaul time is reduced as early indication gives a time window for preparing activities.
- The spare parts inventory is reduced as early indication gives the chance to order parts when needed.

Consequently, the scope of predictive maintenance (PdM) should be expanded so that it would naturally include smart preventive maintenance. PdM should be used to improve preventive (PM) and condition-based maintenance (CBM). PdM may be applied to a subset of equipment where unique requirements or failure modes have been identified and need to be prevented. Whether such a system can be used depends on factors like availability of data and knowledge to interpret the data into an estimate for equipment behavior and on related costs for implementation.

### 4. Implementation challenges
Naturally each system has its own characteristics, historic, and maintenance requirements. One of the most challenging areas to implement a Maintenance Management System is a R&D facility. R&D Labs/Institutes have to deal with two demanding processes at the same time: to create new procedure/product/technology keeping at optimum the existing assets through proper maintenance (fig.6, 7, 8).

All these demanding steps are required in order to identify the present state of all assets and their relationship during regular or foreseen R&D processes in “AS IS” dBs.

These provide not only the key elements for identifying the “bottle necks” on the labs activities (Process Map-fig.9a), but also the tools for properly analyzing their causes (Cause Map-fig. 9b) as to timely elaborate adequate solutions having a traceable recording of the entire problem and of its related issues/processes, installations, equipments, etc.

![Figure 6: R&D Lab tasks](image1)

![Figure 7: Maintenance Management tasks](image2)
Even more, on a TQM system approach - one of the basic requirements for any R&D accredited lab- each topic of a Cause Map may be ranked according its overall weight on the process, and thus a more detailed analysis can be conduct regarding the influence of equipment/devices on the research outcome. Under such circumstances the accurate preservation of dBs, their interoperability and above all, their flexibility are compulsory.
Davison Software CMMS offers solutions to all these requirements for large plants, small and medium sized enterprises as well as for their lab facilities (in an Enterprise Integrate System approach), but also for independent R&D units (institutes).

5. Challenging deployments of CMMS
CMMS is meant to be flexible although some areas of activities are traditionally considered as far from predictability, as those related to R&D. Even if R&D lab assets are fewer than those of a plant their exploitation characteristics and management requirements (fig. 10) are more demanding. There are mainly modular/ multi-purpose devices, equipments and installations that might take part on different processes and technologies. Thus the reliability of each of these devices might infringe the outcome of the research and jeopardize the overall R&D activity.

Usually research labs operate complex equipments having different systems to be maintained, often by accredited service providers. However, the lack of process running perspective (Process Map) would increase either the maintenance costs or the fault probability, raising the overall R&D Risk.

![Figure 10: Standard Laboratory Management issues](image)

Although not so obvious as in the plant maintenance managerial tasks the basic concepts/requirements are almost the same (fig.11)

![Figure 11: Impact-basic concept](image)
Businesses, regardless their specific area (R&D should be managed to be profitable also) want more from their equipment; the ability to produce high-quality products, at minimum cycle times.

Today, there is great interest in predictive maintenance (PdM)—using condition-based monitoring (CBM) to warn of impending failure, and analytical tools such as failure mode effect and criticality analysis (FMECA).

With CMMS, information is much easier to store, manipulate, and review.

6.1 Expert Systems
It takes a real expert to understand problems in complex equipment today, but especially the R&D labs area is equipped with complex installations and systems. Often, it takes a team of specialists when it comes to most complex equipment.

These experts will use all information on hand, not just data from CBM sensors. They review data from equipment histories and manufacturing design and information from similar equipment in like environments. They also use their personal wealth of experience, which is essential to interpret all this data, from all these sources.

Presently a leading-edge maintenance management diagnostics include:
- Condition monitoring using vibration, lubrication and thermo-graphic analysis for generating data.
- CMMS for pulling all the data together.
- An expert system applied to one of the condition-monitoring techniques to recommend ways to diagnose the input data.

Expert systems have been developed to capture an individual’s expertise. Briefly, these systems operate under a set of rules: they ask, you answer, and they lead you to the root cause of a symptom.

![Figure 12: Expert System Data Flow](Image)

![Figure 13: Equipment identification (allocate ID)](Image)

![Figure 14: Equipment complete description (related to flexible ID allocation)—Davison CMMS](Image)
For example, spectrographic oil analysis data for wear debris, additives, and contaminants, combined with data on viscosity and dilution can be entered into a database.

- The expert system has a resident knowledge base built by people who understand the engine design and operation and the failure mechanisms.

- It also has set of rules to decide what to do with the oil data, given the knowledge base. (fig. 12)

Research is now being conducted on expert systems that can do even more. For example, they can deal with situations beyond those covered by a strict set of rules for an equipment model, being flexible enough to generate new rules.

6.2 Equipment information

Although the Process Map is clearly described during the CMMS implementation some new issues might occur. These refer especially to allocated IDs and their lack of flexibility during the time.

Many CMMS failed to be properly exploited and ceased to be used because of this immovable ID code describing the equipment/device and all its related history. Unlike those systems Davison Software CMMS (PM) and PdM are normalized so all changes keep their related information; the equipment numbers can be changed and all history still remains related to the equipment.

So, both PM and PdM are designed for flexible startup with incomplete data thus enabling the daily routine of Reliability Centered Maintenance. Each building block of the Davison Software has the equipment priority as a default priority for work orders. Consequently, Preventive maintenance (PM) can be scheduled by Equipment Priority and PredictMate® (the PdM software) triggers condition for Directed Preventive Maintenance.

Figure 15: PM-Davison Software- Equipment the core component of the system

Figure 16 Davison Software- Work orders with insufficient parts
In addition to the usual tracking of parts inventory, an important report is the report for Work Orders with insufficient parts. This facility allows users to list work orders that do not have enough parts and thereafter to report or email the parts needed for these work orders from the work order window (fig.16, 17).

7. Conclusions

Maintenance management is rapidly becoming an engineering specialty, like civil, mechanical, metallurgical, and electrical engineering, several universities offering undergraduate and postgraduate courses in Maintenance Engineering, a really Engineering Optimization area with potential impact on all equipment related domains. On the R&D labs daily routine many emphasize a life-cycle approach to physical asset management: getting the people responsible for operating and maintaining the equipment, involved in its design, manufacture, installation, and modification, although the performance of any machine is largely inherent in the design. Therefore, it will become more common to see the roles blurred between those who design and those who maintain. Running Expert Systems as PM and PredictMate® to assist the Maintenance Management tasks, having clearly mapped all the undergoing processes of the R&D facility and maintaining dBs with all data related to installations, equipments, devices, human resources, etc. the predictability of the R&D activities is proactively determined. The present Maintenance Management strategy is between Predictive and Proactive, but this is an emerging area and each progress on other technologically related issues may bring new refinements, as the last century’s history has already done (fig. 18) rising the trend away from simple repair after failure to complex blends of engineering and the human element. One thing is certain: the sophistication and complexity of how the equipment is made and what it can do must be matched by the same level of expertise in maintenance strategy and tactics.

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References