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Tutorial: Transforming Condition Monitoring into effective Condition Based Maintenance

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ABSTRACT

It is clearly understood by most Maintenance and Reliability professionals that a Condition Monitoring program should identify faults ahead of failures, allowing time for scheduling of remedial works and the management of risk. It is also understood that to achieve this requires correctly identifying suitable machines for the Condition Based Maintenance program, ensuring the correct techniques are applied on the correct schedule and ensuring the measurements are correctly setup.

There is however a clear distinction between a competent Condition Monitoring program and an effective Condition Based Maintenance program which reliably saves downtime of equipment and maintenance costs.

The distinction is in how the Program is managed.

Reflecting on the authors' combined experience of setting up and developing over 30 Condition Based Maintenance programs, this paper sets out some expectations for a Condition Monitoring Program. It discusses how a Condition Monitoring program's performance is measured, and the communications strategy that will support effective controls for the management of a highly effective Condition Based Maintenance program.

INTRODUCTION

Take a plant that has a Condition Monitoring program. Why do maintenance personnel get called out at weekends? Why do failures occur on standard rolling element bearings, throwing maintenance plans into disarray? Why are unexpected failures occurring, when technologies to detect them are mature and readily available? This happens the world over and although there will always be things that happen unpredictably, this should not be the normal mode of operation. This has maintenance cost implications, process cost implications, serious safety implications, and it even has implications on the retention of personnel. The answers to these questions are not simple but can be addressed with a little understanding.

Before looking too closely at how to make a Condition Based Maintenance (CBM) program work effectively, it is helpful to appreciate the broader context of the maintenance program in which it sits. A strategic mix of Reactive, Time Based and Condition Based Maintenance is typically applied across a plant and is generally based on the asset register, the criticality of the machines and the failure modes they are susceptible to. The more complex and critical the machine the more care will be taken to ensure the correct strategies are applied from the outset. For this top tier equipment it is likely that maintenance strategies will be determined by a Failure Modes and Effects Analysis (FMEA). Where a Failure Mode or Effect is considered unacceptable, redesign will normally be applied.

The FMEA, maintenance strategy and criticality along with the asset register can then facilitate the development of job plans, workload planning and scheduling, and spare parts optimization. However these continue to be generic or based on assumptions until a feedback mechanism is used to for real data to drive continuous improvement. This feedback of real data forms part of the control loop on your management controls. This enables the program manager to either keep doing what works, or make some kind of change. The types of changes and the measures are discussed in this paper as management controls.

Although Condition Monitoring and vibration measurement are often synonymous, Condition Monitoring can involve a combination of almost any techniques, including observations from operator rounds, lubricant analysis and performance monitoring. Whatever technique is selected, it must be technically feasible and must detect the failure modes to be defended against, meet the organization's requirements and be economically justified. If it does not do that, we must again we refer to our management controls.

For example, when an unexpected failure occurs it is important to examine:

- Was it detected?
- Could it have been detected with different techniques?
- Was the correct strategy applied?
- If it was detected why wasn't it addressed?

Condition Monitoring should form part of a continuous-improvement-engine. By measuring key indicators of machinery condition and operations, the business can manage these things. An effective Condition Based Maintenance program should be used to support reliability improvement and can help the site team to:

- Minimize the downtime of equipment – to avoid exposure to the risk of plant downtime.
- Prioritize the maintenance on assets
- Manage its spares
- Ensure each unit runs to its fullest expectable Mean Time Between Overhauls (MTBO). It should be expected that rotating equipment should require "routine" maintenance such as oil freshening / replenishment, bearing replacements, possible alignment checks within its MTBO lifecycle.
- Assist in assessing realistic expectable MTBOs (as opposed to a generic "5 year service life". This can also assist managing the runtime of machines avoiding preferential running of certain units over their sister units).
- Eliminating root causes of failure, inefficiency, waste, and excessive costs

Many plants succeed in attaining this promise, and Condition Based Maintenance is deeply embedded in their culture. Others have been less successful, even with a highly competent Condition Monitoring program in place.

With the advent of ISO18436 [4], there is a solid framework for the competence of Condition Monitoring professionals. There is a smorgasbord of technologies, including the IIoT and artificially intelligent solutions to suit every budget, with an ever growing array of standards to support the use of this equipment and data. This paper will not look at these aspects of Condition Monitoring.

Instead the paper will focus on some aspects that must be considered for every Condition Based Maintenance program, alongside the implementation of a competent Condition Monitoring program. The paper will focus on the management controls, and the roles, responsibilities and the communications strategy that need to be in place for this to succeed.

ROLES AND RESPONSIBILITIES

To those who operate successful Condition Based Maintenance programs, it is clearly understood what the roles and responsibilities are for those involved. It is also understood that there needs to be sustained engagement from those at the top of the organization.

Defining a strategy and referring to it really helps everyone stay aligned. This is particularly relevant if any part of the program is outsourced

The Roles – The Tasks

A latent risk, or cause of failure-to-succeed long term, is that there is an incomplete understanding held in the organization of all the tasks involved in the Condition Based Maintenance. It is often the case that tasks are completed by conscientious personnel who take great pride in their work and personally have an understanding of what needs to happen. This is terrific for the business, but what happens when that person is sick or retires?

An example of this may be that a Condition Monitoring technician observes a slightly noisy bearing and at the end of the shift decides to put a couple of shots of grease in the bearings, to help out. In this example several tasks have actually happened:

- Condition Monitoring identified the requirement for maintenance
- Communication of maintenance requirement
- Completion of maintenance
- Verification that work was satisfactory (during next rounds).

However, this is not measured, recorded or acknowledged. Over time the technician does this more and more, but the real need for greasing isn't being captured, until that person leaves the role and the rate of bearing defects significantly increases.

Another example is the actual task of monitoring equipment. Often it is assumed that because a route of machines is scheduled to be monitored, that the machines are monitored as scheduled. However, there are obstacles to monitoring, including temporary barriers or machines simply not running. If the compliance of data collection is assumed and not measured and reviewed, the data collection cannot be managed. Under these circumstances a blind spot is created where it is believed a machine is being monitored regularly, and it never gives any issues until the day it is started up; at which point it fails. This example shows that in Condition Based Maintenance there are more tasks than simply collecting and analyzing data, and completing maintenance. This example shows there are tasks to measure, review and drive data collection compliance.

	Task	Outcome	CM Engineer	CM Team Leader	Technical Assistant	Reliability Engineer	Maintenance Supervisor	Mechanical Technicians	Planner	CMMS & Tagging co-ordin	IT Support	3rd party Laboratory
1	**Vibration Analysis (Platform Collect Data)**											
1.01	Platform personnel collect vibration data as per SAP work orders and upload data to AMS database.	Data	○					●				
1.02	Vibration data is analysed and notifications are generated in SAP as required.	Notifications	●									
1.03	Where data is more that 2 months overdue, notifications will be raised for data collection within 1 week	Notification for overdue data	●									
1.04	Where poor quality data is collected an action is to be raised to recollect the data.	Action to recollect data	●					○				
1.05	Where poor quality data is collected CM GROUP will delete the data. This is imperative for maintaining the schedule integrity.		●					○				
1.06	Where machines are recommissioned/brought back on line after maintenance, baseline and inform CM GROUP of work.		○					●				
1.07	Reporting database is updated		●									
2	**Oil Analysis**											
3	**Pump Performance Testing**											
4	**Motor Current Signature Analysis (Platform Collect Data)**											
6	**Routine Reporting**											
7	**Formal Reporting**											
8	**Remedial WO planning and execution**											
9	**Programme Management**											

Figure 1: Except from a typical Condition Monitoring RACI Chart

The next section discusses Management Controls, and risk is a major factor in determining what needs to be managed and measured. It is recommended that a risk analysis of a Condition Based Maintenance program is conducted to try and uncover blind spots. Mitigating tasks can then be identified and introduced to the processes.

There is substantial benefit in identifying the processes and tasks that need to happen within a given program. Figure 1, shows an excerpt from a typical RACI chart for a Condition Monitoring program. Through experience, it is found to be substantially beneficial to start with the obvious tasks. Often the mitigation to any risk involves adding a task or identifying a task that is already part of the unwritten process. A word of caution though:

- Do not write so much detail that it is impossible to follow;
- Although the tasks identified are part of a process, the work is being conducted on a day to day basis – be realistic about how closely it will be followed. Be willing to update the written tasks to reflect what actually is happening, because the process will evolve and become more efficient.

Once the processes and individual tasks are identified, it then becomes possible to define responsibilities.

Responsibilities

With regard to responsibilities, firstly acknowledge the role of the Plant Manager. Everyone answers to this person and they are responsible for the revenue, profit and budget for the facility. They also have a legal responsibility for the safety of everyone on the site and the Health, Safety and Environmental impact of the site. Anyone managing a Condition Based Maintenance program may consider that the Plant manager:

- Provides the mandate for the work
- Signs-off on the maintenance strategy, which includes Condition Based Maintenance
- Signs-off on the operational strategy
- Provides budgets for both monitoring activity and maintenance activity
- Manages the Maintenance, Operations and Reliability Managers

It is imperative that those with have authority to impact the Condition Based Maintenance program understand their role and are bought into the program. This will be discussed more in the section on Communications Strategy. They also need to have the information and authority to affect their role in the program, and this will be discussed in the section on management controls. They need to also be held accountable for effecting that work, this clearly is the role of the Plant manager, but the Plant Manager can only do so if there is clear information about the performance of the program and the roles and responsibilities.

Beyond the Plant Manager, it is necessary to be very clear about who is doing what. Figure 1, gives an example of how this could be documented.

Broadly the Responsibilities of other key players in terms of the Condition Based Maintenance program will be:

Operations:

- Operate the machinery as per design
- Allow access to the equipment for monitoring and maintenance activity

Maintenance:

- Conduct remedial works
- Backlog / budget
- Work with operation targets

Reliability:

- Optimize uptime of equipment
- Identify opportunities for improvement

Condition Monitoring:

- Provide meaningful recommendations
- Provide accurate diagnosis

MANAGEMENTS CONTROLS

It is often said that a system is perfectly designed for the results it delivers, and that you can only improve what is measured.

In order for a Condition Monitoring program to be considered a Condition Based Maintenance program it needs to be seamlessly integrated into the wider maintenance process and therefore the measurement criteria used to assess its overall performance should focus on the following two areas to determine whether it is fit for purpose or not.

- Condition Monitoring as a maintenance task – how well is data collected analyzed and faults detected?
- Condition Monitoring as a function of the overall maintenance system - and how Condition Monitoring is used to enhance the effectiveness of in achieving its overall goal of maintenance by serving the needs of production and ultimately the wider business through high plant availability.

Shortfalls in performance against expectations should be clearly visible and immediately obvious to allow the relevant changes to be made in a timely manner to continuously improve.

The maintenance system

While the specifics of maintenance systems vary from industry to industry and plant to plant, based on their individual business circumstances, the detail of which is out-with the scope of this tutorial, it is important to have a basic understanding of the 5 principle processes which must be in place for a maintenance system to be effective and how they relate. A more integrated approach to implementing a Condition Based Maintenance program can be by achieved by understanding the principals of the maintenance system and how the Condition Monitoring program can influence it. The below diagram outlines the basic fundamental components of a maintenance system which must be in place to be effective.

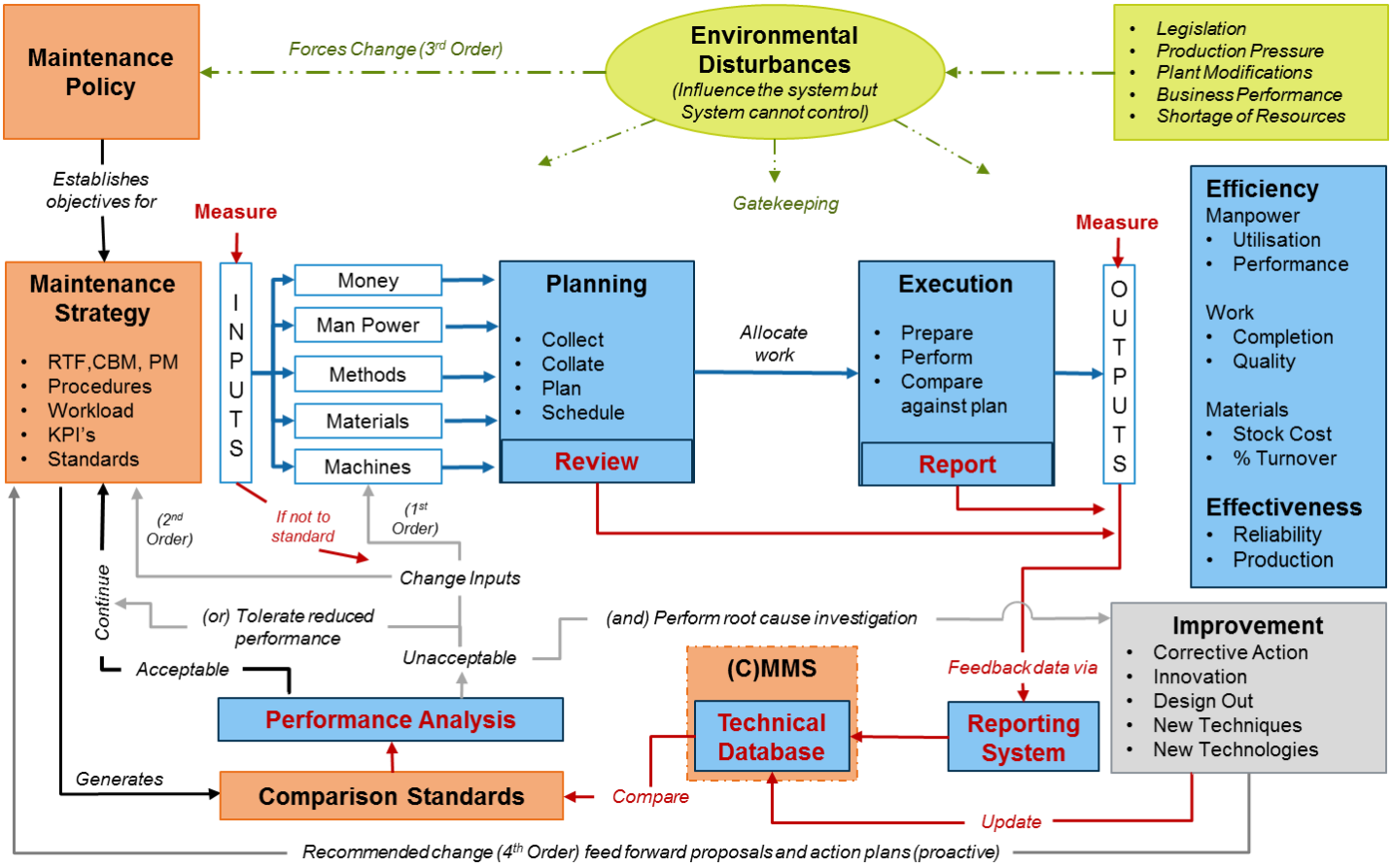

Figure 2: Maintenance System Process (University of Manchester, 2015)

The strategic process (color coded orange) is the management/decision making element of the system and ultimately provides all the inputs required (University of Manchester, 2015). It is this process which has determined, and put in place, the Condition Monitoring program (or determined not to, if a program is not in place), sets the budget and determines whether this activity should be implemented by the in house organization, an external specialist vendor or a combination of each. It is worth remembering that the Condition Monitoring strategies in place are often generic and typically high level, directed at the whole plant and based on machine classifications, and not individual pieces of equipment. This is with the exception of the most critical equipment, which typically undergo a full FMEA, FMECA or RCM study to determine specifics such as online monitoring systems etc. It is only once the Condition Monitoring program is up and running that the high level requirements are broken down to the specifics of the individual pieces of equipment and then finely tuned through the feedback system mentioned below. This is based on things such as access restrictions, running conditions/run times which can impact or even hinder the original approach to be taken.

The work process (color coded blue) is the element which plans and executes the maintenance task using the inputs (in the form of money, manpower, methods and materials etc.) supplied by the strategy. The outputs of this system at close out/completion of the maintenance task are around efficiency and effectiveness.

- **Efficiency**
  - Manpower - Utilization (how many productive hours were used overall) and performance – i.e. was the person adequately skilled to complete the full task i.e. all data collection and analysis.
  - Completion – To what level was the task completed – in relation to Condition Monitoring this would be compliance to schedule. If data was not collected, what was the reason for this – which can then be channeled back through the feedback process discussed below
  - Quality – Was the job completed? Were the processes for doing so fit for purpose? Again referring to Condition Monitoring, this would be whether the data collected was meaningful and sufficient to enable a proper analysis of the failure modes

- **Effectiveness**
  - Ultimately this is an ongoing metric which is continuously measured and relates to overall business effectiveness through maintenance, hence things such as safety performance, plant availability/capability, quality of product output, and OpEx costs etc. are considered here. At the Condition Based Maintenance program level these are things such as how often have unplanned breakdowns occurred on equipment covered by the Condition Based Maintenance program, or how many improvement initiatives have been driven directly from the Condition Based Maintenance program data– e.g. lubrication, or shaft alignment if found to be a common theme within the data.

The feedback process (color coded red) analyses and reports on the results of the work system (blue) and compares them to the predetermined standards and introduces a trigger mechanism based on deviations away from standard to routinely feed the continuous improvement process. The alternative, of course, would be to do nothing and subsequently tolerate the reduced performance temporally or even permanently. On occasions this may be the best approach to take especially if the asset is nearing its end of life and the improvement is not feasible.

The continuous improvement process (color coded grey) is without doubt the most crucial element to ensure the system is sustainable for the long term. Any system without continuous improvement built in will eventually fail. It is this process which reactively corrects the deficiencies via the feedback system by understanding the specifics of the failure, identifying the requirements to prevent reoccurrence and introduces changes to either the maintenance inputs (the money, methods, manpower, materials or machines) or strategy. It is also this process which proactively seeks improvement through innovation, new technologies /techniques etc. An example of this in condition monitoring is the growing use of artificial intelligence for machine learning to detect and diagnose faults with equipment or process. Another example of this is the relatively recent introduction of motion amplification to assist with troubleshooting sources of high vibration.

The environmental process (color coded green) is not controlled by the process but is made up of things which can influence the maintenance system such as changes to legislation, demand for product and shortage of resources. A common cause of failure for Condition Monitoring programs, which fits into this bracket, is loss of key personnel. While these elements cannot be specifically controlled by the system an element of gatekeeping can be put in place to minimize the effects of these.

Measurement Criteria
Performance measurement of the Condition Based Maintenance program should not be time consuming to collate, rather it should autonomously flow to the relevant stakeholders to trigger relevant actions through the system directly, or an established communication plan.

Ultimately the only measurement criteria being used should be that which will trigger a change in behaviors and the actions driven from these should have a clear effect on measurement criteria itself.

Some Condition Monitoring programs report their benefits solely in terms on cost avoidance e.g. if we hadn't detected this then it would have cost $y. While this type of measure can be useful to draw attention to the direct value of the program, particularly when supported with other metrics the problem with this measure alone is that can lose credibility over time, as the benefit relies on subjective estimates and assumptions.

The other problem with this metric is that cost avoidance does not appear on a company's financial statement, so there is no recognition of it at senior management level. Hence there is a requirement to utilize metrics which focus on things which impact on a company's bottom line such as;

- Increasing production efficiency, throughput capacity or OEE
- Reducing OpEx, by things such as reducing labor, maintenance or energy costs
- Increasing safety performance
- Improving product quality

The metrics below have been found to be successful in assessing the effectiveness of a Condition Monitoring program and identifying the specific contribution the Condition Based Maintenance program has on the company's overall maintenance performance. This addresses 3 of the common obstacles outlined in by Kamalina Srikant & Theresa Woodiel [7].

Keep in mind that figures and statistics are useful for large programs and for benchmarking. For smaller programs it may be a case of simply identifying and examining the exceptions to the criteria detailed below. The key point is that this is feedback to allow control and improvement.

Examples of Condition Monitoring Program Measurement Criteria
The aim of these measurements is to establish how well the condition monitoring is performing at detecting and analyzing faults.

Data collection compliance –To establish what has been done and when in relation to its schedule, and also what has not been done and why, which is equally (and arguably) more important. It should be possible to understand and manage why data has not been collected e.g. equipment was on standby, down for maintenance or something different such as the equipment is on a level control and run time was too short to collect data. By documenting these reasons and acting on the feedback, the relevant changes can be made through the continuous improvement process. This compliance metric can be broken down by criticality of machine if required to ensure focus is being spent on the right areas.

An example of this is taken from an offshore platform that was conducting vibration monitoring, requiring 5 days per month on the platform. Monitoring of data compliance highlighted a high number of machines were not being assessed. This triggered a review to find why this was happening. It was revealed the vibration analyst did not have enough time to carry out the scope due helicopter timetable to the platform: a late arrival time and an early departure time effectively left only 3 days to complete the 5 day work scope. The corrective measure was to extend the platform visit to incorporate reporting time (normally carried out upon return onshore) as well as data collection. This resulted in the number of machines not being assessed significantly reducing which can be seen in Figure 3.

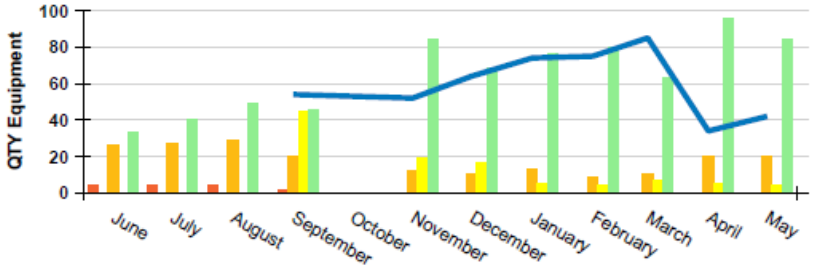

Figure 3: Condition Monitoring compliance and equipment condition (Blue line indicates number of machine not assessed)

Analysis turnaround time – How quickly is the data being analyzed and reported? If only the compliance of data collection is being measured, thinly spread resources often prioritize this. This can lead to analysis being delayed which shortens the available time to respond to a problem. In worst case this can be after an equipment failure.

An example of this is the catastrophic failure of a diesel engine, driving a fire water pump at a remote location, during routine testing. Oil analysis results, for a sample taken more than 1 month prior to failure, were received 2 days after the engine failed; they indicated excessively high levels of iron. The protracted turnaround time on analysis of the sample was considered unacceptable and was attributed to delays in the samples being shipped to the laboratory. Following this a policy change was implemented such that oil samples be air freighted to the laboratory, in order to reduce turnaround time. The turnaround time was then actively measured as a KPI of the program.

Accuracy of diagnosis – Comparing the suspected and confirmed fault allows the effectiveness of the condition monitoring task and analysis/diagnosis to be determined. Ultimately there are 3 states which can result from a diagnosis

- Correctly diagnosed fault – the desired state for all diagnosis
- Incorrect diagnosis of the faults specifics however a fault is still evident - corrective maintenance task is justified
- Incorrect diagnosis where no fault is evident –the corrective maintenance task is unjustifiable

The last 2 states listed should act as a trigger for an investigation to identify an opportunity to improve such as;

- The methods/techniques being applied for detection
- The frequency of the methods/techniques being applied
- The training/competence of the diagnostician on failures of this equipment type and detection methods being used.

Number of breakdowns – Looking at the breakdown events on equipment covered by the Condition Monitoring program allows light to be shed on areas where the Condition Based Maintenance program has potentially failed or not performed as required. Measuring and trending the number of breakdown events on the equipment covered by the Condition Monitoring program can be an effective way to determine how well it is performing overall. In the early stages of the program it can be used to gather momentum in the program when the number of breakdowns typically reduce or following any major changes to the program help determine the effect of these. The number of breakdown events also act as a trigger to allow light to be shed on areas where the Condition Based Maintenance program has potentially failed or not performed as required. There are many reasons why this may be the case, for example the techniques applied were never intended to detect the failure mode or the machine was not made available for data collection, the important thing is to understand whether there was a shortcoming, what it was, why this happened, and what the (potential) consequences were through a Root Cause Analysis. This will then provide an opportunity for the Condition Monitoring program to improve and prevent reoccurrence.

Examples of Condition Based Maintenance Program Measurement Criteria

As well as the above condition monitoring program criteria a Condition Based Maintenance program should extend its metrics to understand how this is impacting the wider maintenance metrics which typically include

- Unplanned downtime losses
- No of Injuries/Accidents due to equipment failure
- Overall Equipment Effectiveness (OEE)
- Mean Time to Repair
- Cost of maintenance per Assets base – typically around 2.5 percent of asset base [6]
- Reactive maintenance – Target less than 10 percent of all maintenance activities to be reactive i.e. breakdown [5]. Note this would not include corrective work driven from the Condition Monitoring program which is usually planned in.
- Planned Maintenance – Target >90 percent of maintenance as planned [5].

While the above metrics identify performance of the maintenance department as a whole, which is of utmost importance to the business at management level, they do not specifically indicate the direct contribution of a Condition Based Maintenance program. This can be done by introducing the following metrics at program level.

Amount of work generated by Condition Monitoring – This can be measured either by man-hours or count of tasks and is to determine how well the Condition Based Maintenance program is affecting maintenance of the plant. Numerous studies have taken place which indicate that best practice is 50 percent or more. An advantage of this measure is that it can also be split into both a leading indicator by looking at the planned activities in weekly, 30 day, or 90 day plan, but also as a lagging indicator by looking at the actual tasks carried out or in the maintenance backlog.

Time to implement actions from Condition Monitoring – The purpose of this is to ensure that actions are being progressed in a timely manner, and that faults are being managed accordingly.

Many faults identified from Condition Monitoring require prompt action, these include greasing bearings and aligning machines. For these remedial actions the life of the machine is extended by acting promptly, yielding a high value. However, other faults, such as impellor wear may be factored into longer term plans for overhaul, planning this type of work for a more opportune time can yield the highest value. To use this measure effectively, it is necessary to classify faults and remedial actions. Figure 4 shows the elapsed days to close out issues, detected by the Condition Monitoring program, on a problematic pump. These were typically corrected in a timely manner before the overall condition has deteriorated by detecting the issues early on.

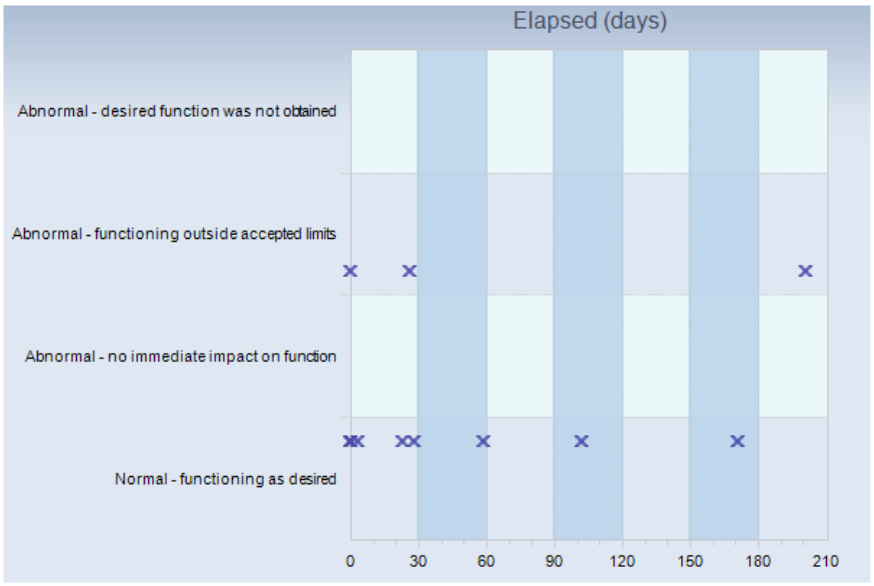

Figure 4: Elapsed days to Implement Actions vs Condition of equipment at time

Improvement initiatives/ opportunities driven from Condition Monitoring – This is a measure of how the Condition Monitoring program is used as one of the drivers for continuous improvement - by taking a high level view of what has been going on from a Condition Based Maintenance perspective to identify whether there are any common themes. These themes may include the types of faults being detected, certain machine classifications, individual equipment tags (bad actors) etc, see Figure 5 and Figure 6 . It is then possible to identify potential connections and determine what can be done to improve. This can be particularly useful for comparing multiple sites, or areas of plant which share common maintenance strategies. If problems are similar across multiple plants then this may be an indicator that a review of the strategy is required. Whereas, problems that are specific to a site or area, indicate the implementation of the strategy may be the problem.

The benefit and return on investment of such projects/initiatives can be assessed based on actual costs spent on the problem to date (quantified opportunity), cost of implementation, and reduction of costs once root cause of the problem has been removed. This benefit of the improvement initiatives can also be linked to the Condition Based Maintenance program.

Return on investment (ROI) – This can be estimated by money spent on the program against the maintenance and production cost avoided - there are many methods which can be applied. The most important point thing is to use a transparent method which can be accepted by the business. This is an indicator which should be used with care for the aforementioned reasons. That being said, this measure can demonstrate the specific value the Condition Based Maintenance program generates separate from other business initiatives. Another benefit can come from estimating the potential cost of not doing work (averted losses), to actually drive the maintenance. For example, one plant we spoke to estimates the average cost of pump repairs at $6000/ pump, this compared to the cost of greasing the bearing makes for a simple decision.

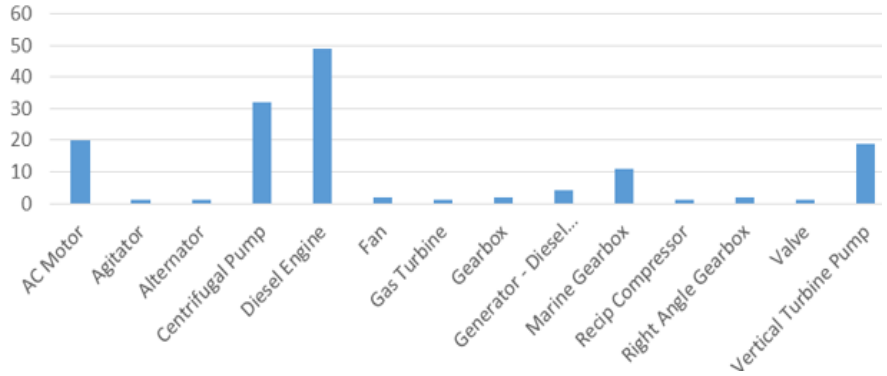

Figure 5: No of Defects identified by Condition Monitoring by equipment type (Actual data 3 years)

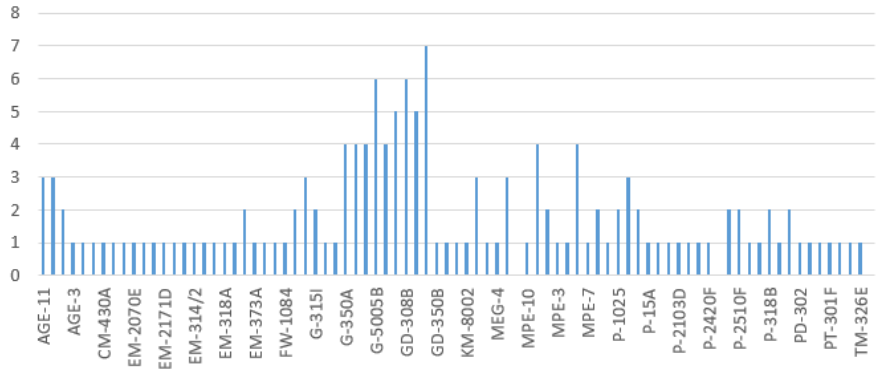

Figure 6: No of Defects identified by Condition Monitoring by equipment tag (Actual data 3 years)

COMMUNICATIONS STRATEGY

Those designing a Condition Based Maintenance program need to be explicit about who needs what information. As already discussed this won't be perfect at first and it will be necessary to change over time, as personnel change and new technologies become available. Communication also needs to work both ways. So a communication strategy needs to be developed.

The Condition Monitoring Report – Instigating remedial works

What is clear is that most stakeholders are not going to read the Condition Monitoring report. Therefore no Condition Monitoring Communication Strategy should rely on a technical report.

That said a technical Condition Monitoring report is an important record. Anyone operating a Condition Based Maintenance program needs to understand how this report will be used. In most cases, the primary function of the Condition Monitoring report is to allow the analyst to follow their diagnosis from month to month, to understand what was seen at any given movement and to allow the next analyst to pick up the line of thought.

In most cases this 'Condition Monitoring' report neither instigates work, nor propagates understanding of what has been seen and what has to be done. This is because the user of the report often does not have time to digest the nuances of the analysis. This is often compounded by having several different technologies to digest reports from. If this is not fully considered when designing the Condition Based Maintenance program, relying on this as a communication strategy will be the programs downfall.

Meeting and discussion are a good way to communicate between the Condition Monitoring personnel and the reliability and maintenance personnel. If these meetings do not already exist within the program they may be difficult to instigate. Busy people do not need more meetings! However, it is imperative to advocate for the value of the program, relating back to our business case, roles, responsibilities and the KPIs. Condition Monitoring information needs to be shared with maintenance and reliability personnel in order to realize any value.

The communication needs to be supported by a structure and a record does need to exist. Otherwise, no accountability will be created and no performance measures will be generated.

A database system is an effective way of bringing the findings of several technologies together. A well designed system should bring a holistic view of the machine condition for the analyst, and simplify the communication. Ideally the system should also collate the performance measures on the program, to create reliable data ready for distribution.

In his 2006 paper, Mitchel describes a process where a database application is used and is a focal point at the maintenance planning meeting each week. This is an ideal scenario. Similar success was seen with a particular best in class oil and gas operator in the North Sea, who implemented a 'Dash-Board' for their equipment. The Condition Monitoring database interfaces with the dashboard such that maintenance and operations personnel can record activities and concerns. The dashboard is used in the weekly planning meeting. This means that all necessary information is available for the planning process. The information recorded here should include concerns as well as remedial works due, as the planning needs to take full account of risk. This operator achieved an operating efficiency of 96 percent.

The ongoing dialogue between the Condition Monitoring, maintenance and operations teams should have an understanding of risk and priority.

Generally when remedial work is required, it is instigated via a Maintenance Management System (MMS) or Computerized Maintenance Management System (CMMS). If the ongoing dialogue does create an understanding of risk and priority, it is simply necessary to determine who is responsible for recording the details of the work required.

Finally, when the remedial action is completed it is necessary to get feedback on what was found and what work was done. The Condition Monitoring team should then be able to assess the condition of the remedied machine and the effectiveness of the work. From this information the program can learn and adapt to become more effective.

Communication of measures for performance and Accountability

Of course all of the above refers to the condition of the machines and the remedial actions required. Arguably this is the most critical information. However it is clear from the Roles and Responsibilities and Management Controls sections that far more, than the condition of individual machines, needs to be communicated. There are many measures shown in the Management Controls section. It is now necessary to put the information in the hands of those who can use it.

An example from our best in class North Sea operator:

The operator's mechanical maintenance technicians were responsible for vibration data and lube oil sample collection. A third party was responsible for analyzing the data. The analysis party could not directly drive the data collection. Initially the data collection was sporadic, often data was collected when machines started to sound noisy. A score card was implemented where the analysis party reported each month how much data was collected and identified machines which were significantly overdue. This then gave the maintenance manager the tools he needed to drive improvement with platforms' maintenance supervisor. The Maintenance Manager had the authority to drive this, which led to initial improvement.

An issue arose that the operations crew would not switch machines, making the available for monitoring (the world over, operations crews have their favorite machines). This is the cause of a range of reliability issues, but not knowing that a standby machine's condition introduces risk to the operation. The Maintenance Manager was not responsible for the operations personnel, but because Condition Based Maintenance was implemented strategically, and this was understood by the 'Plant Manager', the Maintenance Manager was able use the KPI scorecard to have positive discussions with the Operations Manager. As can be seen in Figure 7 the scorecard provides a simple view of program performance, this operator today has more than 90percent of this Condition Monitoring program within 2 months of its schedule; exceptions are managed individually.

The score card was then developed for this to show that not only was the Condition Monitoring program working, but that the remedial maintenance was being progressed. The Maintenance and Reliability Managers were then able to use this information in the same way to drive maintenance. This made a substantial improvement in the amount of Condition Based Maintenance completed on the operators' site and in turn has led to a cultural shift and very high operational efficiency.

CM KPI SCORECARD — **Jan'19**

		Objective	A	B	C	D	E	Limits
1	**Health, Safety and the environment**							
1.1	LTIs or recordable injuries caused by CM personnel.	Ensure Compliance with HSE Policy.	0	0	0	0	0	0 >0
1.2	Loss of containment caused by CM personnel or unreported functional failure detectable through CM.	Monitor Unexpected losses and ensure followed up.	0	0	0	0	0	0 >0
2	**Data collection**							
2.1	%Machines on the vibration programme, having had vibes collected within 2 months of the schedule.	To ensure data is collected on a regular basis. With data collection split over the month.	91% of 101	92% of 26	93% of 57	90% of 60	100% of 16	≥80 ≥90
2.2	%Machines, available for Production, having had vibes collected within 1week of the schedule.	Knowing why the data has not been collected.	92% of 95	100% of 24	85% of 52	81% of 59	94% of 16	≥50 ≥70
2.3	%Machines on the oil programme, having had Oil sampled within 2 months of the schedule.	To ensure data is collected on a regular basis. With data collection split over the month.	100% of 83	93% of 28	100% of 58	100% of 45	100% of 22	≥80 ≥90
2.4	%Machines, available for Production, having had Oil sampled within 1week of the schedule.	Knowing why the data has not been collected.	70% of 80	100% of 24	96% of 56	67% of 45	91% of 22	≥50 ≥70
2.5	Jan 2019 Plant Availablity	To ensure JCAMS are given the necessary oportunity to monitor the equipment.	Normal Operation	Normal Operation	FP Test	Normal Operation	Normal Operation	For Information Only
	Dec 2018 Plant Availablity		FP Test	Normal Operation	Normal Operation	Normal Operation	Normal Operation	
	Nov 2018 Plant Availablity		Normal Operation	Normal Operation	Normal Operation	Normal Operation	Normal Operation	
3	**Data /Sample Quality**							
3.1	Number of machines with incomplete vibration data	To monitor data Quality Issues.	1	-	-	2	-	
3.2	Number of machines with poor quality vibration data		1	-	-	1	-	
3.3	Number of oil samples provided with insufficient quantity		-	-	-	-	-	
3.4	Number of poor quality oil samples provided		-	-	-	-	-	
4	**Work Orders**							
		To monitor that WOs are being raised and are being completed.	Jan Total	Jan Total	Jan Total	Jan Total	Jan Total	For Information Only
4.1	Number of Notification - Outstanding		- -	- -	- -	- 2	2 3	
4.2	Number of Work Order - Created		1 6	2 2	3 10	4 9	1 1	
4.3	Number of Work Order - Technically completed		1 1	- 3	2 4	2 3	- -	
4.8	Total Number of Notifications Outstanding		1 **6**	2 **2**	3 **10**	4 **11**	3 **4**	

** UNAVAILABLE machines are not counted, if they are expected to be unavailable for 2 months or more, either because they are agreed unfit to run, out for maintenance or because their function in the process isn't required by production (ie no glycol required or no test separation required, rather than A or B not required).*

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Figure 7: KPI Score Card from a Condition Monitoring program

Using a similar Communications Strategy on a new condition monitoring program, one Texas refinery were alerted to a problem with data collection compliance. On closer inspection they were able to determine that pumps were not being regularly switched. In response they instigated a pump switching program, supported by data from the Condition Monitoring program. This has led to improved monitoring compliance, hence reducing the plants risk from hidden faults.

The Program Report – Demonstrating the Business Case

Having successfully implemented a Condition Based Maintenance program, improved operation efficiency and reduced call outs at weekends, it may seem like the benefits of the activity are obvious, but this is not the case. There will be many initiatives on the plant seeking to make improvements and the numbers for this Condition Based Maintenance program will be indistinguishable from that; unless those responsible for the Condition Based Maintenance program make it explicit.

It is necessary always to demonstrate the continued business case for the Condition Monitoring program in support of the Condition Based Maintenance strategy. Organizations routinely look to cut unnecessary headcount and costs. This drive for efficiency is part of running a healthy business and is well supported by Condition Based Maintenance, but this may not be well understood by decision makers. It is therefore incumbent on those with responsibility for the Condition Based Maintenance program to demonstrate value and show how it contributes to reliability. Without some mechanism of demonstrating the continued business case Condition Monitoring programs are very vulnerable to these cuts. Ironically, it can be the most successful Condition Monitoring programs that are at risk because low failure rates can be misinterpreted by management, leading them to believe they can cut maintenance costs further.

As discussed a successful approach is to develop a method of calculating the Return on Investment (RoI) for a program. This will often include production and maintenance costs averted and may also account for safety impacts averted. It is strongly advised when developing such a calculation that the Maintenance and Operations divisions of the organization agree to the method and the figures to be used. If they do this up front, they will be more accepting of the calculated figure at the end of the period. This proved invaluable in the oil price crash of 2015, where one oil and gas operator used the reported value of their program to defend the Condition Monitoring analysis team and level of expertise. This, in turn, helped the platforms run at near maximum efficiency, during a very challenging period.

Why are we here?

As well as maintaining the investment in the program, giving the management controls and reporting condition data, the communications strategy needs to include general information to interested site personnel. It is in the interest of the Condition Based Maintenance program to try and get maintenance and operations personnel onboard. These personnel are a substantial source of information that should not be overlooked. The most influential information will be case studies, from their own site, so consider what to share and how.

CONCLUSIONS

Condition Monitoring programs need to be set up well and need competent people to run them. The objective of the program needs to make-explicit the value expected, in order to really deliver value to the organizations who invest in them.

The Roles and Responsibilities need to be defined, from the top of the organization down to the responsibilities for the tasks and this needs to be communicated effectively. Create accountability.

Measurement criteria used to assess performance of the Condition Based Maintenance program need to identify the both the areas of the program which are working and the opportunities for improvement. The value of the program needs to be demonstrated to maintain investment.

Mechanisms for change should be explicit, try to measure performance and create opportunities for improvement.

A Communication strategy should be developed that provides a mechanism for feedback on remedial works. It should also enable management control by putting information into the hands of those who can do something with it – maintaining accountability. A focus of the communication strategy should be on demonstrating the continued business case. Finally, the strategy should aim to influence more people than just the management team, with some consideration given to demonstrating benefit to Maintenance and Operations personnel.

If you haven't already, take your Condition Monitoring Program out of its box and plug it in.

NOMENCLATURE

Computerized Maintenance Management System (CMMS)
Condition Monitoring (CM)
Condition Based Maintenance (CBM)
Failure Modes Effects Analysis (FMEA)
Maintenance Management System (MMS)
Return on Investment (RoI)
Root Cause Analysis (RCA)

FIGURES

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