Perspectives of Return On Investment (ROI)
Evaluations for Online Condition Monitoring Systems

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Introduction

Before launching a Condition Monitoring (CM) program, plant operators have to identify the goals, such as increase of machine uptime, prevention of failure of critical machines, protection of workers from the consequences of machine damages, and enhancement of product quality.

Best start is to conduct a comprehensive survey of the relevant equipment, review the operating characteristics and maintenance records. Prime candidates for continuous Condition Monitoring include machines that,

- Run 24 hours a day
- Perform functions that are crucial to the production process (e.g. single line processes)
- Have high failure consequences
- Are expensive to maintain
- Could pose a risk to personnel safety or the environment.

Examples include machines used in continuous processes, e.g. plastic production, where a service interruption could ruin an entire production run. Those with high failure consequences include turbine generators, and equipment located in hazardous environments. Also consider machines that experience frequent failures because of a tough operating environment — common in mines, cement plants, and fertilizer plants.

Share of three different factors influencing the Return On Investment (ROI)

Perspective 1: Operational benefits

A Condition Monitoring system positively affects:

- More equipment uptime
- Increased MTBM (Meantime between Maintenance)
- Maximum utilization of component lifetime
- Production rates
- Optimized Overall Operational Effectiveness (OOE) of the process and plant.

Examples:

- Continous monitoring allows machine operation until scheduled shutdowns, although some values (e.g. vibrations) are less than perfect.
- Performance diagnostics enables process managers to save energy cost and increase the asset efficiency.
- The early detection of leaking valves, seals or piping saves penalties for environmental pollution.
- Remote access from the system vendor allows expert support based on the customer systems data. Also, perfect system adjustments without wasting money and time for travelling to the site(s) on which the system is/are installed. Especially relevant for offshore applications such as FPSO, LNG carrier and others.

Perspective 2: Maintenance benefits

Condition Monitoring system positively affects:

- Maintenance campaign costs - less work orders, targeted activities
- Substitutes preventive, offline measurements, perhaps executed from costly external service companies
- Reduced labour time and associated costs.
- Shorter MTTR (Meantime to Repair):
  - Costly and time consuming consequential damages have been avoided
  - Knowledge of the failed component allows targeted repairs instead of trial and error-campaigns
- Less capital commitment for spare part inventory

Perspective 3: Risk avoidance

"Risk" is the product of the two factors *consequence* and *probability*. For financial justification, the factor *consequence* is presented in monetary units. Example: If a compressor fails catastrophically, a potential *consequence* is $200,000 of production loss, labour and spare parts.

If this event occurs at a *frequency* of once every ten years, this represents an annual risk of $20,000 per year, but if it occurs every two years, the annual risk is $100,000.

Condition Monitoring can substantially reduce the cost of *consequence* (avoidance of catastrophic and consequential damages) as well as the *frequency* (realtime and continuous diagnoses of bad actors and all relevant components).

The risk of machine failures has several severity steps that need to be considered when starting the return of Investment (ROI) calculations:

- Normal Loss (cost for production loss and maintenance campaigns during scheduled shutdowns)
- Probable Maximum Loss (cost for massive maintenance or new machine with associated production losses)
- Maximum Possible Loss (massive machine damage, loss of product, HSE issues, environmental pollution, fire, business interruption)

A worthwhile investment ?

Condition Monitoring (CM) systems theoretically reduce both, equipment downtime and maintenance efforts. The majority of CM systems are vibration based and focused on the components with historically long periods of downtimes per failure. When it comes to the financial justification of investments in CM, many studies assume that the system is perfect and will always inform the user ahead of any impending failure. However, this is not always the case and false alarms as well as missed failures will produce costs. These imperfections and their effects on Operation and Maintenance have to be part of the equations as the payback periods increase.

When investing in a predictive maintenance system, two methods of assessing the economic incentives can be used.

Payback period gives information whether the investment in the system pays for itself within a defined period of time. The result is expressed in time (years, months).

$$\frac{\text{Investment (\$)}}{\text{Annual profit of investment (\$)}}$$

$$\frac{\$110{,}000}{\$75{,}000} = 1{,}4 \text{ years}$$

Calculation of the Payback period.
The ***result*** *is expressed in* ***time****.*

Return On Investment (ROI) measures the amount of return on an investment in a specified time period relative to money spent. To calculate the ROI, the return (or benefit) of an investment within a time frame is divided by the cost of the investment, and the result is expressed as a percentage or a ratio.

$$\frac{\text{Return (\$) in time period A}}{\text{Investment (\$)}} = ROI_A$$

$$\frac{\$360{,}000 \text{ in 12 months}}{\$280{,}000} = 1{,}29_{12m} = 129\%$$

Calculation of the ROI.
The ***result*** *is expressed as a* ***percentage****.*

In any case, operators have to precisely sum all cost and efforts associated to each detected failure to perform the equations.

Calculating benefits

Adding up the investment is the easy part of the profitability assessment. More challenging, but of same importance, is the realistic calculation of the benefits earned from the CM system.

Four categories should be considered:

Lost production
This cost is perhaps the most difficult factor to determine. However, on average, reduced downtime is responsible for 60 to 70% of a company's savings in this regard.

These savings will depend on the type of machine. Consider, for example, a machine that produces $10,000 worth of products per hour. By preventing a bearing failure on this machine, you could eliminate 5 hrs of downtime and a $ 50,000 loss in production.

Labour
The easiest way to calculate labour savings for a particular machine is the previous year's repair records. The number of hours spent on planned and unscheduled repairs gives a realistic indication of how much time a company can save after implementing the CM system.

Spare parts
The machine's maintenance records is a good way to determine the cost of replacement parts such as valves, bearings, and gears.

Drive power consumption
This is a little harder to evaluate because it's usually not included in maintenance records. But improving machine efficiency can substantially reduce drive energy cost.

The rate at which companies recover an investment in Condition Monitoring depends on factors such as

- Type of products manufactured
- Amount of downtime experienced
- How well they implement and use the system.

In some cases, a company can recover its investment in Monitoring equipment and training within months after initial start-up. Within a year, they can obtain as much as a four to five times Return on Investment. There are operators whose full-scale CM system paid for itself within weeks after its implementation due to the avoidance of only one major consequential damage on a reciprocating machine.

Experience shows, that CM pays back significantly fast especially during the initial start-up of new machinery or after major overhauls or main process changes.

In other cases, there may be little or no return during the first few months. Moreover, maintenance costs may increase during these early months because many new, unknown machine issues are identified, diagnosed, and corrected in a short time period. Once these initial problems are corrected, however, maintenance costs drop dramatically and remain low.

If the system is not providing a return after several months, it should be reviewed how it has been implemented - some factors may need to be changed, e.g..

- Training status of the system users
- Proper adjustment of all warning thresholds
- Full utilization of all system features and capabilities
- Diagnostic outputs are not delivered to the right destination and therefore get ignored.

Finally, operators must build confidence in the notifications and diagnostic results issued by the system. When the systems detects an uncritical, but maybe unusual, wear development, operators should hold themselves back to stop and open the machine. They rather should have an eye on the trend data and keep the machine running as long as possible, e.g. until the next scheduled shutdown. Another example to the contrary: it has been seen that brandnew parts and components fail in the first hours of operation. In this case, an immediate stop might be necessary to avoid consequential damages. This is what condition based maintenance is all about - taking action only when required.

Calculating Total Cost of Ownership (TCO)

Continuous Monitoring requires a larger investment for online data acquisition and analysis equipment plus installation. To precisely assess the Total Cost of Ownership, operators have to consider the following investments:

- System engineering and installation
- Field instrumentation (sensors, cabling)
- Monitoring and Diagnostic system (hard-and software, installation, software licenses)
- User Training and Customer Support (if required)
- System Maintenance (sensor replacement, software updates)
- Necessary external expertise and support.

Condition Monitoring system scope

Besides all calculations, the most important question to answer is *"What system fits our needs at best?".*

Condition Monitoring systems are around since decades and range from handheld devices to online diagnostic systems with neuronal network features. With the ongoing development of new technical features, system capabilities and, finally, the reliability of diagnostic results, continued the prices for such systems to increase. However, the number of production assets that qualify for continuous online monitoring increased as well. Debottlenecking campaigns and high product output-plans require more machines to be productive; former redundant machines are now onstream and an essential part of the production process. With less backup machinery available, plant operators are more than ever dependent on those machines that are required to meet the production goals. This means: Condition Monitoring systems and programs are mandatory in nowadays industries.

Machine criticality

Machine criticality is one point to start with to identify the proper monitoring technology and scope. One factor of the criticality definition is the well-known risk matrix (see below). Again, we see the above mentioned factors *Consequences* and *Probability*:

		Consequences				
		Trivial	Minor	Moderate	Major	Extreme
Probability	Rare	Low	Low	Low	Low	Low
	Unlikely	Low	Low	Medium	Medium	Medium
	Moderate	Low	Medium	Medium	Medium	High
	Likely	Medium	Medium	Medium	High	High
	Very Likely	Medium	Medium	High	High	High

Risk assessment is a challenging and complex task; rich enough to fill books. Still, in terms of *Criticality* we also have to consider aspects such as

- Process layout (single line or multi line)
- Lost profits (per hour) in case of production loss
- Availability of product reserves to keep process running downstream of failed machine
- Time and cost for shutdown and start-up caused by failed machine
- Equipment redundancy (backup machinery)
- Average MTTR of the evaluated assets
- Failure history of machinery
- Availability of maintenance experts and tools

Selecting Condition Monitoring Technology

One way to show the dependency between Criticality and CM system scope is shown the graphic below: The more critical the asset, the more advanced should the CM technology be to detect all impending failures and to avoid costly consequential failures.