SOLUTIONS

THE MAGAZINE BY PRACTITIONERS FOR PRACTITIONERS
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b. Best practices implementation guidance to set expectations and provide feedback
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b. Implementation of proven processes and methodologies
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b. Gap analysis – written report to leadership team
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CONTRIBUTORS

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FROM THE CHAIR

Happy New Year fellow members and colleagues! A fresh year is once again upon us and I look forward to everything 2019 has to offer with SMRP. I am excited to start the year with Career and Technical Education Month® this February. This month-long public awareness campaign launched by the Association for Career & Technical Education (ACTE) works to celebrate the value of career and technical education (CTE) and the accomplishments within the many verticals of CTE. While CTE works to shed light on professions that require special training, the ACTE depends on organizations within each professional vertical, such as SMRP, to advance career education and training for their members. As with many of the professions CTE covers, a majority of maintenance and reliability professionals are set to retire and there isn't a new generation of professionals behind them to take their place. CTE Month is a valuable reminder to us that maintenance and reliability education is crucial for our organization moving forward.

During CTE Month, I encourage you take the time to talk to students and introduce them to maintenance and reliability. Show them how today's professionals work on complex assets, integrate the industrial internet of things (IIoT) into their work, and utilize state-of-the-art equipment. If you can, offer to host a career week at a local school or check with nearby technical colleges to participate in their CTE Month activities.

Looking ahead to March, SMRP is set to host our first international event, the 2019 Symposium in Lima, Peru, March 6-7, 2019. The event includes two days of track sessions, general sessions, certification exams, opening and closing keynote addresses and networking opportunities, all tailored to Spanish-speaking practitioners and professionals. Attendees from across Latin America will gather for this Symposium, which offers maintenance, reliability and physical asset management attendees access to our society's education and network of members. Additionally, leading organizations such as Accenture, GE Digital, Fikal SAS, APTIM, Schulmberger, AES Corporation, Ingredion and Hudbay will be onsite for attendees to gain exposure with industry-leading companies. Attendees will also have the opportunity to take the CMRP, CMRT and CAMA exams on March 7, earning their credentials onsite.

As we look further into the year, SMRP is excited to host a second Symposium in Phoenix, Arizona, June 26 - 27, and will round out the year at the 27th Annual Conference, October 7 - 10, in Louisville, Kentucky. Don't miss the chance to learn from experts and network with your peers around the world this year with SMRP. I look forward to seeing you at the next SMRP event.

Vlad Bacalu, CMRP, CMRT, CAMA
SMRP Chair

The New Optimum Replacement Time Methodology for Aged Equipment

The UFCC compressor Case Study

Dr. Eduardo Calixto, CRP, CFSE, AFSP

The New Optimum Replacement Time Methodology for aged equipment supports the best replacement time decision related to aging assets where preventive maintenance (PM) is not able to recover the reliability to an economically feasible state. Such proposed methodology encompasses different methods through implementation steps such as Reliability, Availability, Maintainability (RAM) analysis, lifetime data analysis, reliability growth analysis and equipment operation cost analysis. The main different of the previous methodology is that the expected operational cost proposed is based on the Crow-AMSSA model. In order to demonstrate such methodology, I have assessed the critical compressor of the UFCC refinery plant in the following case study.

Failure and Repair Data Analysis

Fluid catalytic cracking (FCC) plants convert the high-boiling, high-molecular weight hydrocarbon fractions of petroleum crude oils into more valuable gasoline, olefinic gases and other products. In order to predict future performance and define the FCC's critical equipment, the RAM analysis is performed. Once the RAM analysis scope is defined, the lifetime data analysis (LDA) is the next step. The LDA is based on the historical failure data of FCC plants in operation. Thus, by collecting the failure and repair data from equipment files, it was possible to obtain the proper data and perform the LDA by using statistical software (Reliasoft Weibull++) to define PDF parameters for each piece of equipment that is part of this study. To ensure the accurate representation of data collection, maintenance professionals with knowledge of each piece of equipment took part in this stage.

Tag	Failure Mode	Failure Time (Years)		Repair Time (hour)	
		PDF	Parameters	PDF	Paremeters
EC301 A	Turbine Bearing	Gumbell	μ 4,5; ∂ 2,04	Lognormal	μ 3,08; ∂ 0,64
EC301 A	Gas Valve 1	Exponential	λ 0,5426; γ 0,0946	Normal	μ 47,6; ∂ 40,8
EC301 A	Gas Valve 2	Weibull	β 0,5418; η 1,2061; γ 0.6185	Normal	μ 36,4; ∂ 20,94
EC301 A	Seal Leakage	Gumbell	μ 4,97; ∂ 0,24	Weibull	β 0,77; η 4,23; γ 2,36
EC301 B	Gas Valve 1	Weibull	β 0,51; η 2,85; γ 0,298	Lognormal	μ 3,21; ∂ 1,73
EC301 B	Gas Valve 2	Weibull	β 0.418; η 0,64; γ 0,6049	Loglogistic	μ 3,3; ∂ 0,75
EC301 B	Turbine Bearing	Normal	μ 3,56; ∂ 0,1	Normal	μ 24; ∂ 1
EC301 C	Turbine Bearing	Gumbell	μ 4,09; ∂ 1,61	Lognormal	μ 2,93; ∂ 0,92
EC301 C	Gas Valve 1	Gumbell	μ 4,09; ∂ 1,61	Lognormal	μ 3,05; ∂ 1,09
EC301 C	PSV Valve and Others	Normal	μ 2,07; ∂ 1,21	Lognormal	μ 2,72; ∂ 1,52

Figure 1 - Furnace failure and repair PDF parameters. Source: Calixto, E, et al 2012

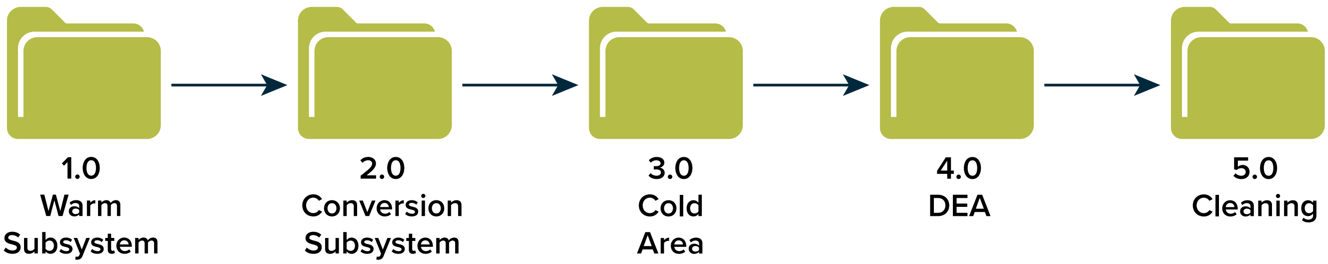

Figure 2 - Fluid Cracking Catalytic System RBD. Source: Calixto, E, et al 2012

Reliability Diagram Block Modeling

Before performing the Monte Carlo simulation, it is necessary to create a reliability diagram block. In this way, it is important to be familiar with the production flowchart details that influence losses in production. Consequently, some statements and definitions about equipment failure impact on the FCC process were applied to the Reliability Block Diagram (RBD) modeling. Figure 2 shows the FCC system RBD model. At a top-level configuration, whenever any of the critical subsystems are unavailable, such as warming, conversion, cold area, diethylamine (DEA) and cleaning, the FCC system is also unavailable. The main FCC profile information points are:

- The availability target is 98 percent in five years
- The facility supply had 100 percent availability in five years
- The total production per day was 55 m3

Simulation

RAM analysis simulation was performed using BlockSim software. The Monte Carlo simulation allows for the creation of typical life cycle scenarios for the system by considering the RBD model, reliability and maintainability of the PDF's input data. The entire UFCC plant unit was modeled through RBDs, considering the redundancies and the possibilities for bypass in each equipment or system configuration, as demonstrated in Figure 2. The Monte Carlo simulation allows for the assessment of operational availability to verify if the target of 98 percent in three years will be achieved. If the operational availability target is not achieved, it becomes necessary to improve the critical equipment operational performance. This simulation was performed concerning a five-year lifetime – 1,000 simulations were run to confirm the results. The results show the UFCC will achieve 99.81 percent operational availability in five years and is expected to have five equipment failures during this period.

Critical analysis

The critical analysis defines which subsystems are the most critical and which equipment has the most influence on operational availability, and consequently, production losses. There are two indicators applied to demonstrate criticality: Reliability Importance (RI) and Down Event Critical Index (DECI).

RI shows how much influence one subsystem or equipment has on system reliability. By using partial derivation, it is possible to demonstrate that increasing the reliability of one subsystem or piece of equipment can improve the whole system reliability. The following equation shows the mathematical relation:

$$\frac{\partial R(System)}{\partial R(Sub - system)} = RI$$

Despite this relation, some equipment or subsystems may be prioritized due to repair time having an expressive impact on system operational availability. This means the operational availability impact is the most important parameter, despite reliability being highly influential in system performance. However, RI is the best index to understand the equipment reliability target achievement.

In this case, the RI is the best index to show how much improvement the system can accommodate. However, it is necessary to consider availability. In the FCC system, the most critical subsystems are the cold area and conversion subsystems based on the RI and DECI assessment. Figure 8 shows the RI assessment results.

After critical analysis, it becomes clear that no improvement actions are required in the FCC system in regards to the operational availability target achievement.

The DECI was also used to assess which equipment causes more shutdowns in the FCC system, and despite the low number of shutdowns and k/n configuration, it was found that compressors EC-01 A–C are responsible for most, as shown in Figure 9. Despite the compressors being the most critical equipment, the fluid catalytic cracking system achieved the availability target (99.91 percent in five years) and through the target achievement point of view, no improvements are required in this system. However, these compressors have operated for more than 20 years, and despite increasing corrective and preventive maintenance (PM) costs, they require optimum replacement time analysis to decide when they must be replaced.

Sensibility Analysis: The Optimum Replacement Time

After critical analysis, it becomes clear that no improvement actions are required in the FCC system in regards to the operational availability target achievement. However, optimum replacement time assessment is required to decide when the compressors need to be replaced to reduce the operational cost and FCC shutdown risk. Therefore, the following assessment will be considered in the sensitivity analysis:

- Optimum replacement time
- Phase block diagram analysis

In the first case, it is necessary to assess each compressor and define the future optimum replacement time considering the operational costs for each piece of equipment, which includes maintenance, purchases and costs related to loss of production. Despite the k/n configuration, such compressors do not impact FCC's operational availability, but have increasing operational costs over time. Figure 10 shows the optimum replacement time philosophy based on a cost perspective.

Indeed, cost is not the only aspect to be considered in the decision to replace equipment. It is also necessary to access additional aspects, such as expected number of failures based on the proposed Crow-AMSAA RGA model prediction. The complete approach to assess the best time to replace the equipment is described in Figure 11.

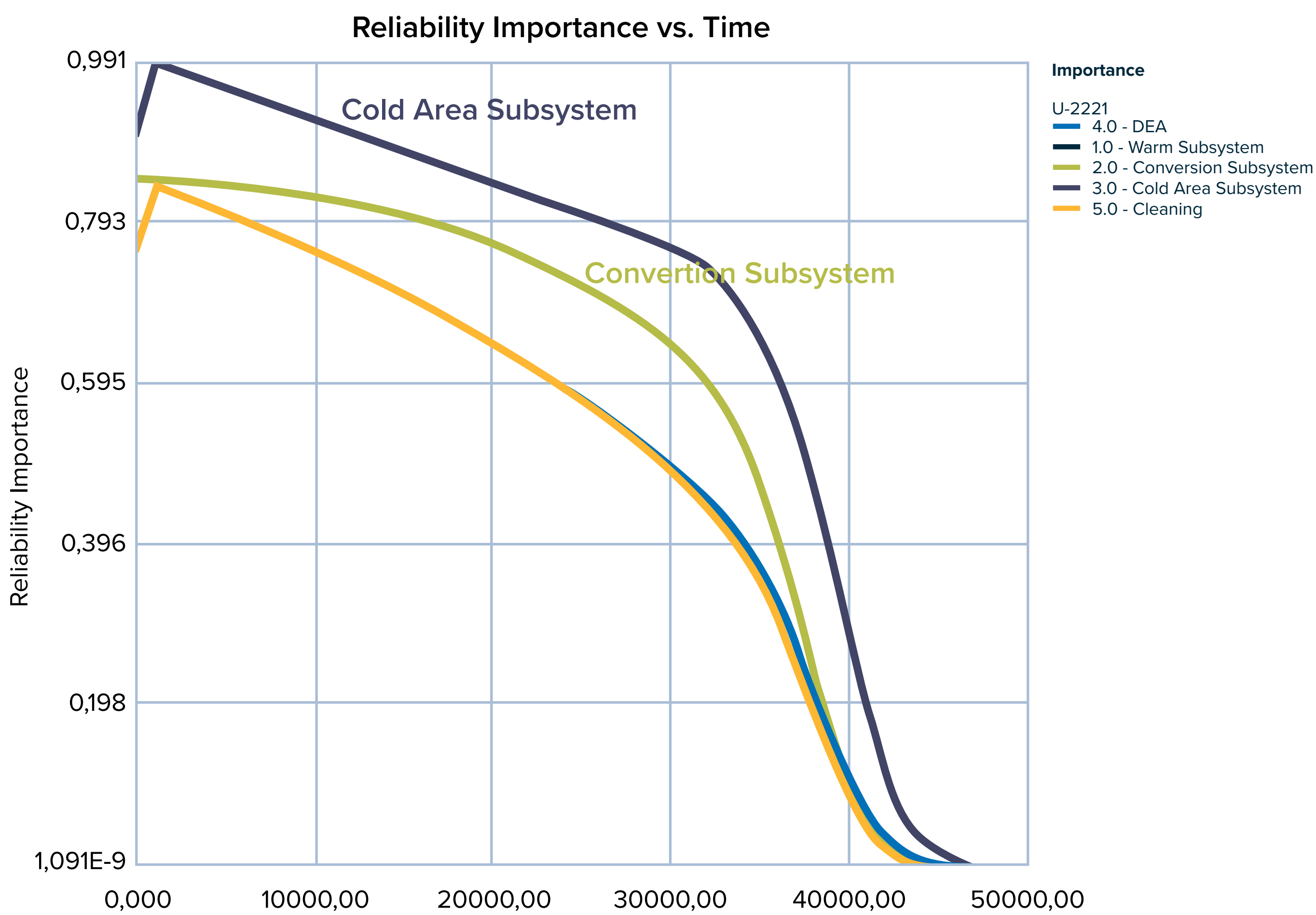

Figure 8 - Reliability Index. Source: Calixto, E, et al 2012

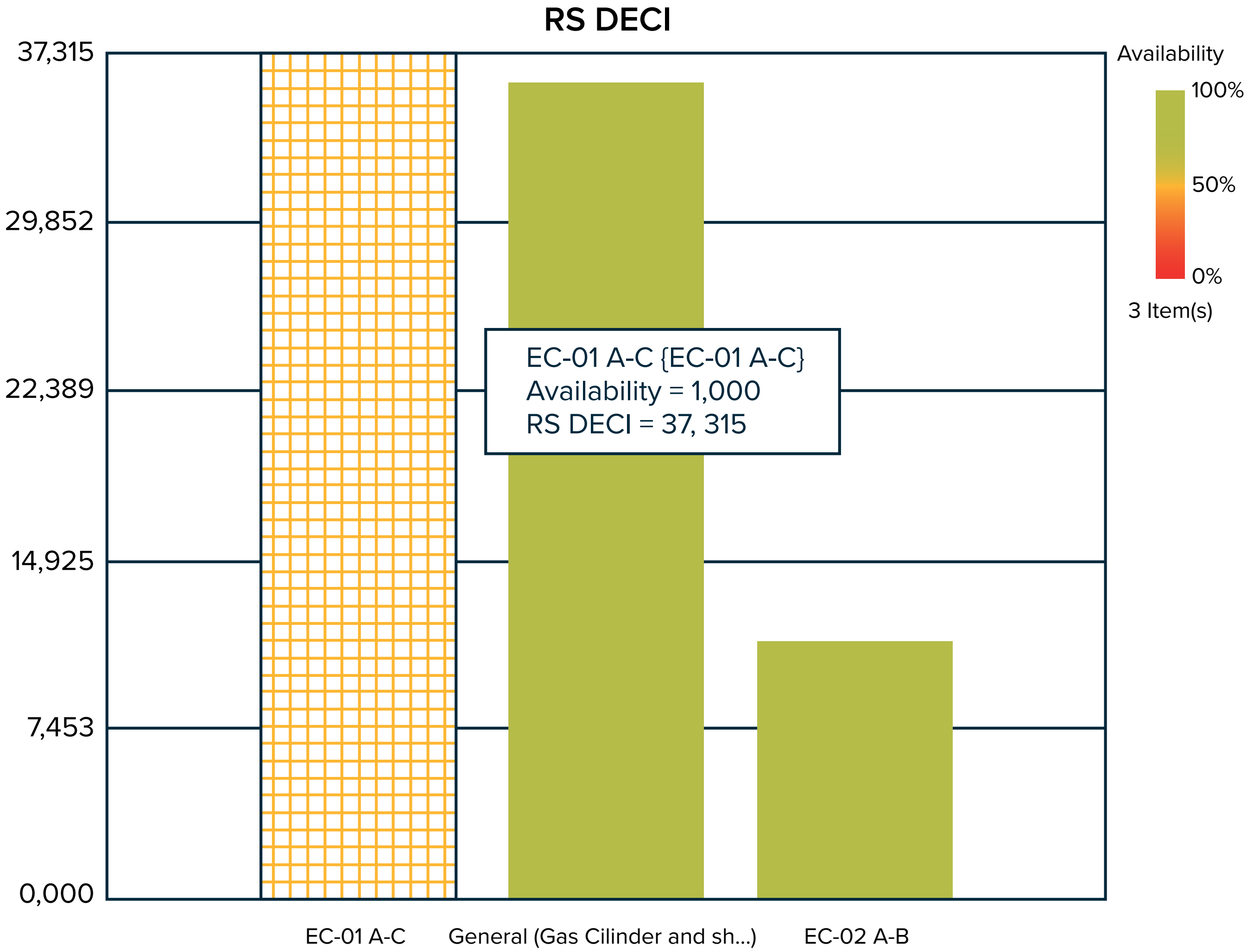

Figure 9 - Down Event Critical Index. Source: Calixto, E, et al 2012

For instance, the lifetime data analysis for compressor A revealed increasing failure rates for most of the components, as shown in Figure 12. However, the lifetime data analysis is not enough to decide if compressor A needs to be replaced. The next step is to perform the reliability growth analysis. Depending on the result of this analysis, you can then go to step four and access the operational cost for the critical equipment. Based on the life cycle analysis, compressor A reveals that after equipment overhaul, there is still an increasing failure rate for most of the components, as shows Figure 12.

Based on Figure 11, the next step is to apply the Crow-AMSSA Model. This model was introduced by Dr. Larry H. Crow in 1974. It is a statistical model that uses the Weibull distribution parameter to describe the relationship between accumulated time between failure and test time. This approach is applied in reliability growth analysis to show the effect of corrective actions on reliability when a product is being developed or even in repairable systems during the operation phase. Thus, whenever improvements are implemented during testing (test-fix-test), the Crow-AMSAA model is used to predict reliability growth and the expected cumulative number of failures. The expected cumulative number of failures are represented mathematically by:

$$E(N_i) = \int_0^T \rho(t)dt$$

The Crow-AMSAA model assumes that intensity failure is approximately the Weibull failure rate, thus intensity of failure on time is:

$$\rho(t) = \frac{\beta}{\eta^\beta} T^{\beta-1}$$

Using the initial failure rate as:

$$\lambda_i = \frac{1}{\eta^\beta}$$

If the cumulative failure rate is approximately the failure intensity we have:

$$\lambda_c = \beta\lambda_i T^{\beta-1}$$

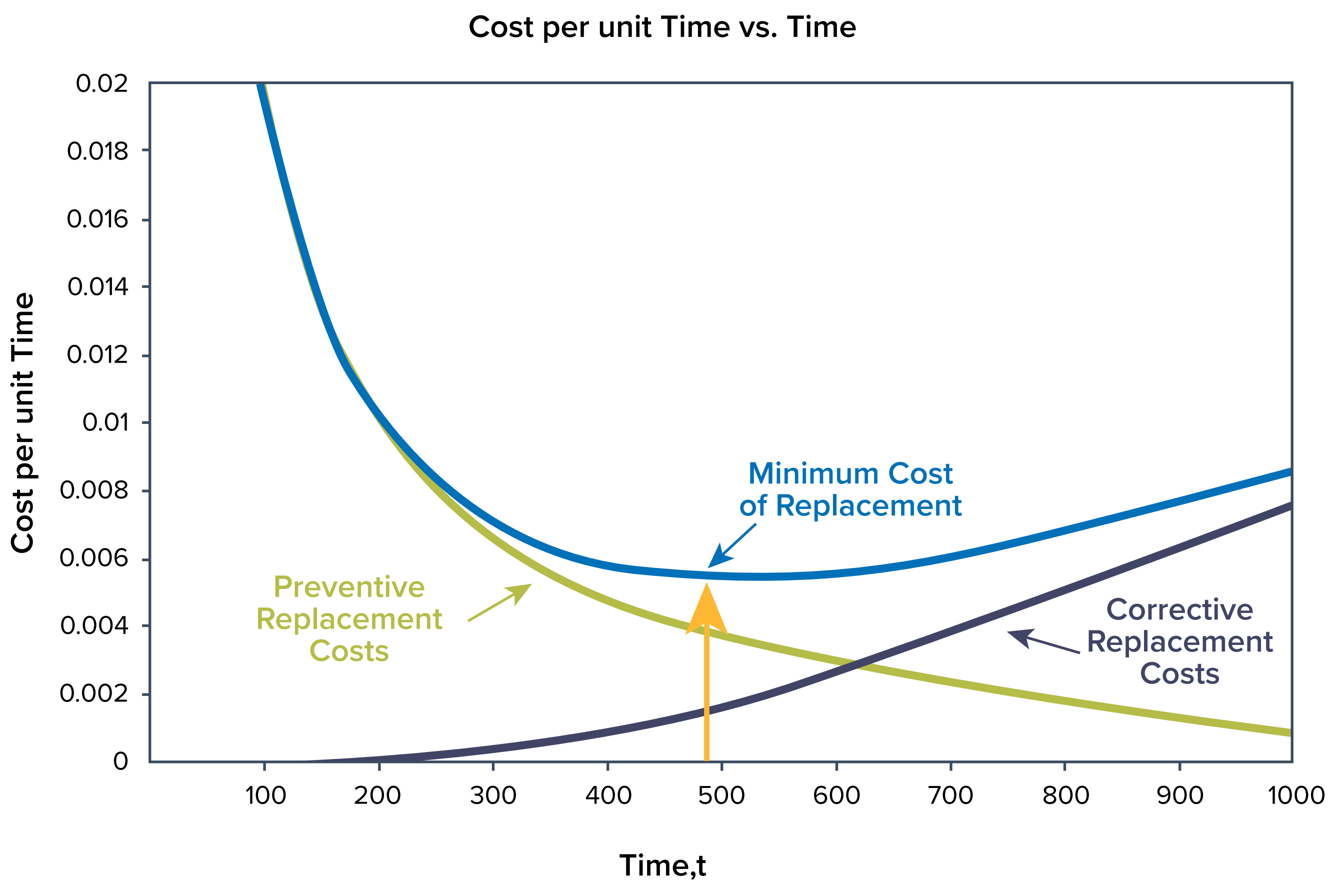

Figure 10 - Optimum Replacement Time. Source: Calixto, E, et al 2012

The time to failure is defined by the equation:

$$T_i = \left(\frac{E(N_i)}{\lambda_i}\right)^{\frac{1}{\beta}}$$

The preceding equation describes failure intensity during testing and depends on the increase, decrease or constant of the β value. In fact, β is a shape parameter of the intensity failure function in the Crow-AMSAA model. Thus, in this model when β > 1, the reliability is decreasing over time because failure intensity is increasing, or in other words, the corrective product actions are not improving the product. When β < 1, the intensity of failure is decreasing over time, or in other words, the corrective product actions are improving product reliability. When β=1, the product behaves as if no corrective action has taken place and intensity failure is constant over time. It is important to keep in mind that the b in the Crow-AMSAA model describes intensity failure behavior and has no relation to the Weibull distribution shape parameter. The growth rate in the Crow-AMSAA model is 1-β. The Crow-AMSSA model assessment was applied to compressor A, as defined in Figure 11 as step three of the optimum replacement time methodology. In case of equipment in operation, the model considers the effect of PM and replacement as well as all other operational effects on equipment performance.

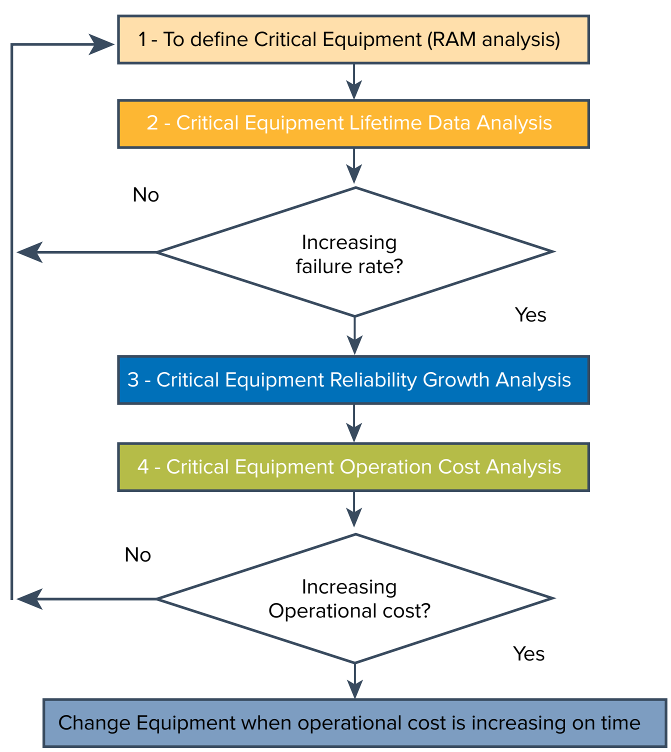

Figure 11 - Optimum replacement time methodology. Source: Calixto, E, et al 2012

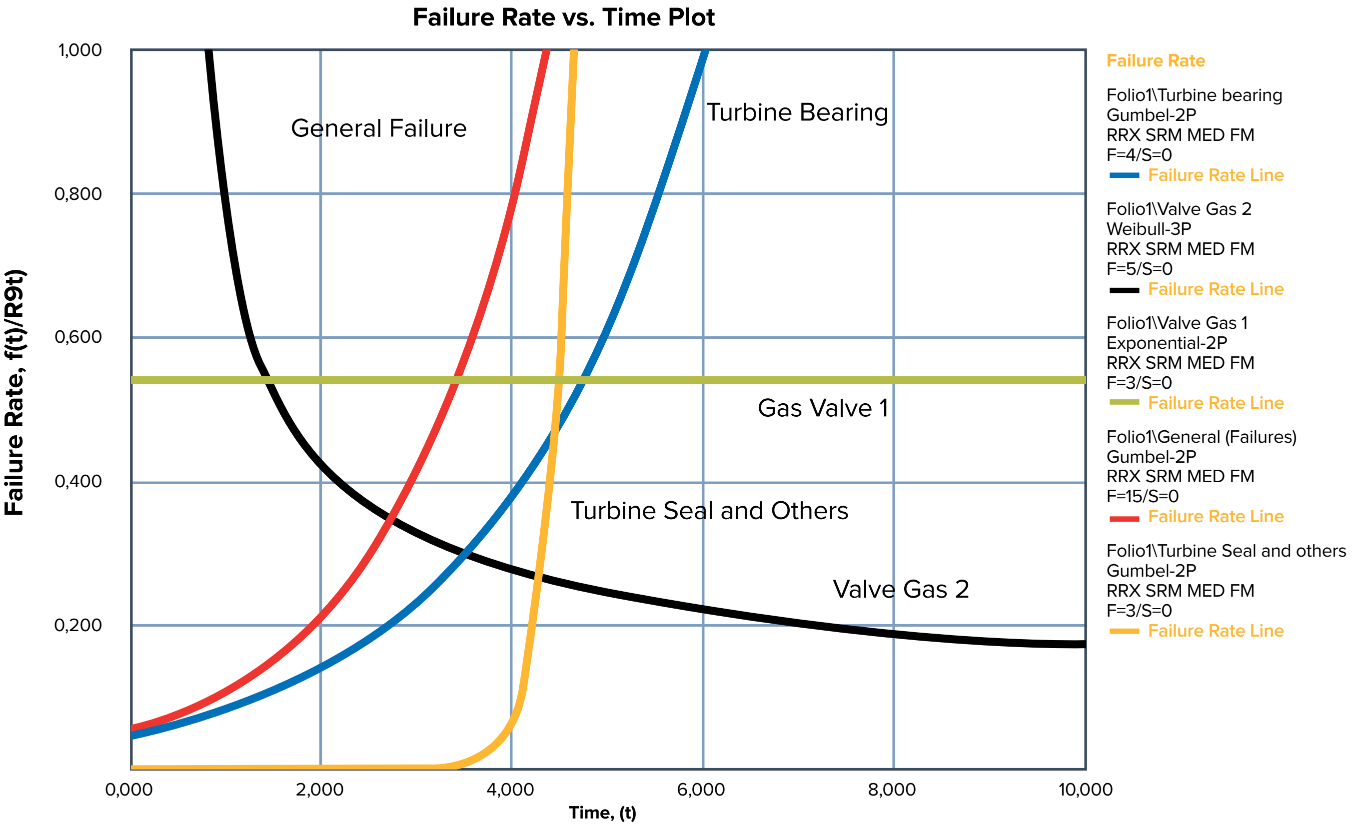

Figure 12 - Compressor A LDA failure rate functions. Source: Calixto, E, et al 2012

When β > 1, the failure intensity is increasing and mean time between failures (MTBF) decreases, or in other words, the preventive maintenance actions and replacement are not improving or recovering (as good as new) the equipment performance. When β < 1, the intensity of failure is decreasing over time and the MTBF is increasing, or in other words, the preventive maintenance or replacement actions are improving equipment reliability. That happens only if the equipment of some component is replaced for another one with higher reliability or in the case of equipment re-design. When β=1, the equipment recovers the reliability to 'as good as new' state due to the PM and replacement effect on the equipment. The intensity failure and the MTBF are constant over time. Figure 13 shows the cumulative number of the failures and Figure 14 shows the MTBF trends.

Based on Figures 13 and 14, the equipment performance decreases in time even with PM implementation. Therefore, it is necessary to access the operational cost as defined in the fourth step of the optimum replacement time methodology approach. Therefore, the CROW-AMSAA Model is applied to predict the future expected failure. By doing so, the total cost in a specific period of time will be described as:

$$C(t_r) = C(Ac) + E(N_t) \times C(M_t)$$

$C(Ac) = Acquisition\ Cost$

$E(N_t) = Expected\ Number\ of\ Failure$

$C(M_t) = Maintenance\ cost\ per\ failure$

Since the optimum time to replace needs to define the operational cost, along with time, the prediction of cumulative number of failures needs to be broken down into an interval of time. This can be done based on graphic observations, demonstrated in Figure 13, or by defining the time to expected failure based on the following equation:

$$T_i = \left(\frac{E(N_i)}{\lambda_i}\right)^{\frac{1}{\beta}}$$

Where:

$T_i = Time\ to\ failure$

$E(N_i) = Expected\ Number\ of\ Failure$ in time i

$\lambda_i = initial\ failure\ rate$

By applying this equation, the current cumulative number of failures plus one, is represented as value. Based on this definition and using the other equation's parameter values, it will be possible to predict when the next failure will occur . Since the study case intend to predict the next five years of operational cost, the prediction will be based on a five year interval of time.

$$C(t_i) = C(Ac) + F(t_i) \times C(M_i)$$

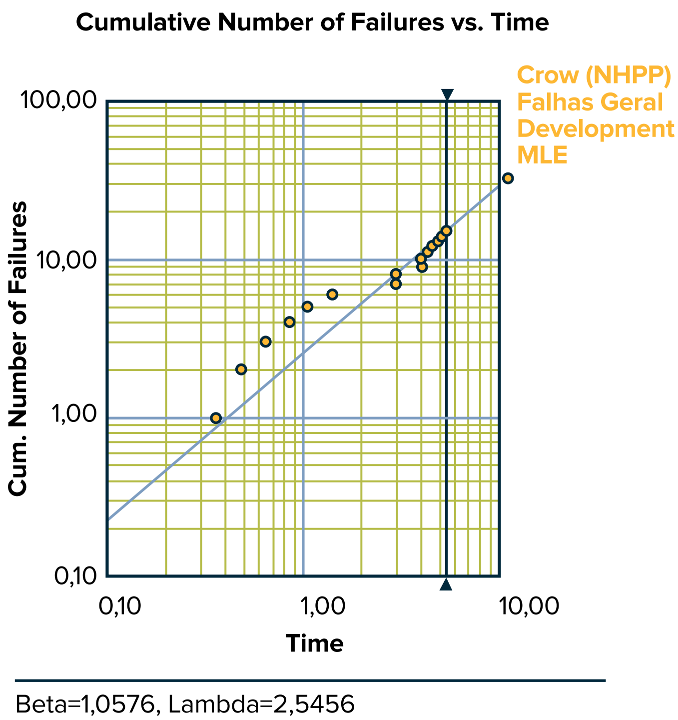

Figure 13 - Cumulative number of failure vs. time. Source: Calixto, E, et al 2012

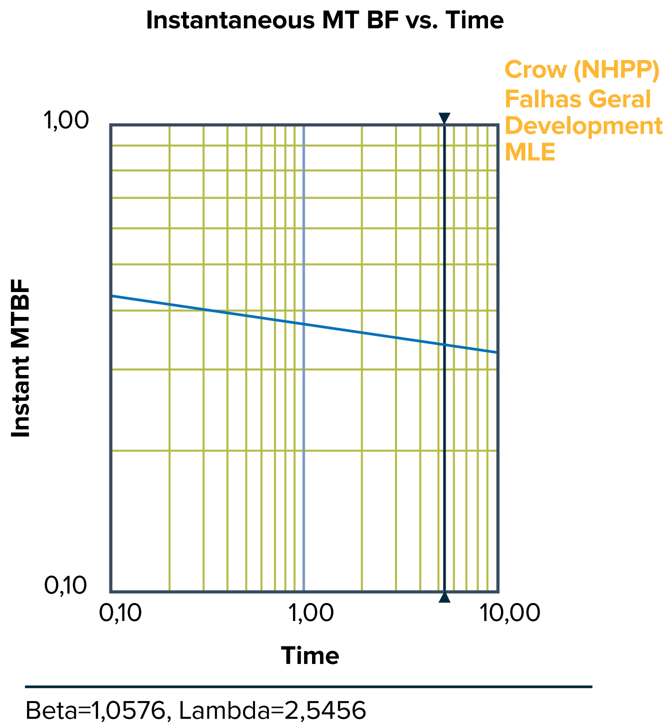

Figure 14 - Instantaneous MTBF vs. time. Source: Calixto, E, et al 2012

Where:

$C(t_i) = \textit{Operation cost in time i}$

$C(Ac) = \textit{Acquisition Cost,}$

$F(t_i) = \textit{failure in time i}$

$C(M_t) = \textit{Maintenance cost per failure}$

And

$F(T_i) = 1$

For each unit of time, the marginal operational cost is defined by the equation:

$$C(Mt_i) = \frac{C(t_r)}{t_i}$$

Where,

$C(Mt_i) = \textit{Marginal cost in time i}$

$C(t_r) = \textit{Cumulative Operational cost in time i}$

$C(t_r) = C(t_i) - C(t_{i-1})$

$t_i = \textit{Time of failure}$

By plotting each marginal cost in a graph evaluating cost versus time, the optimum replacement time is defined by the operating costs increase point, which is four and a half years, as shown in Figure 15.

The optimum replacement time analysis was performed for other compressors and all of them presented increasing costs after four years and must be replaced. The second and final sensitivity analysis uses a phase block diagram analysis to assess the impact on system operational availability related to not replacing such compressors. The phase diagram methodology's main propose is to simulate the system in which configuration changes over time (simulation time). Thus, for the FCC system case, it was possible to simulate three scenarios, as shown in Figure 16. The phase diagrams are simulating three different scenarios. The first shows the system operating for the first six months without one compressor and the other two and a half years with three compressors. The second scenario shows the system operating with two compressors for over six months at one and a half years, and the third scenario shows the system operating without one compressor in the last six months after three years of operation.

This study achieved the main objective – to identify if and when it is necessary to replace any critical equipment.

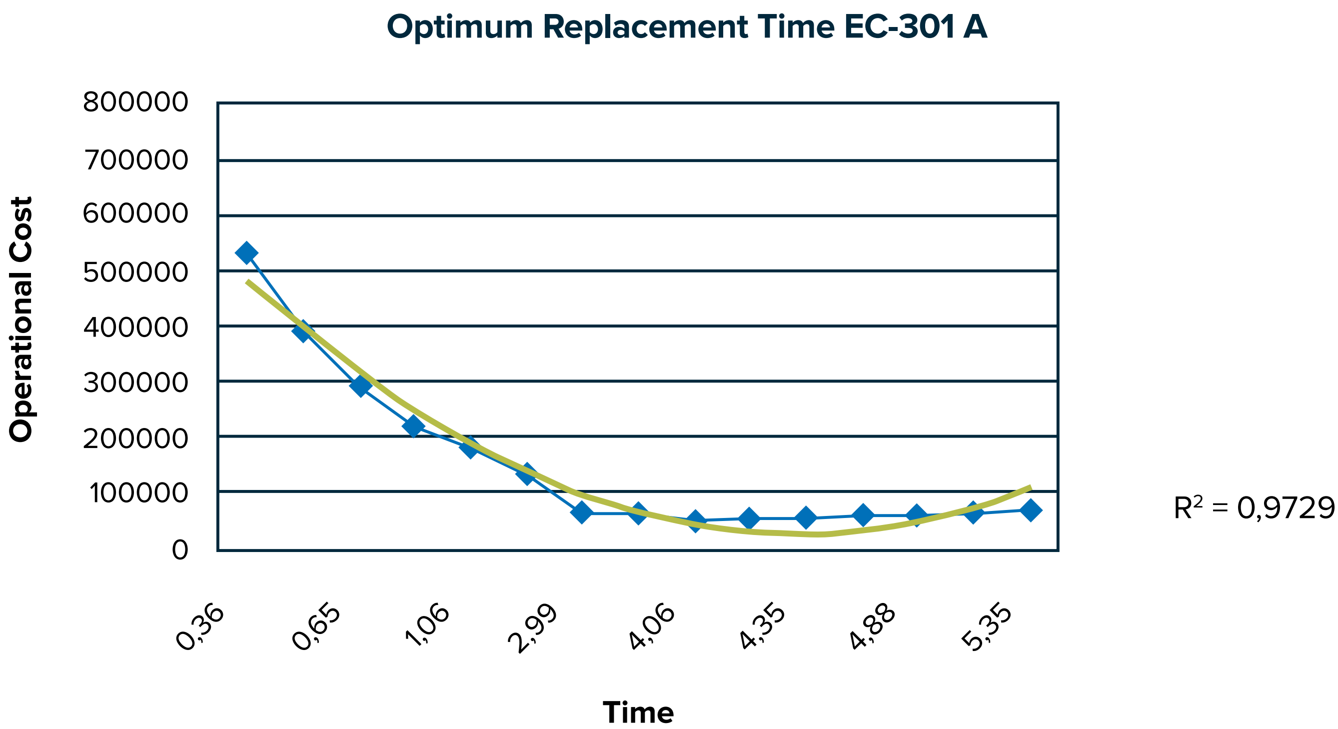

Figure 15 - Compressor A life cycle analysis. Source: Calixto, E et al 2012

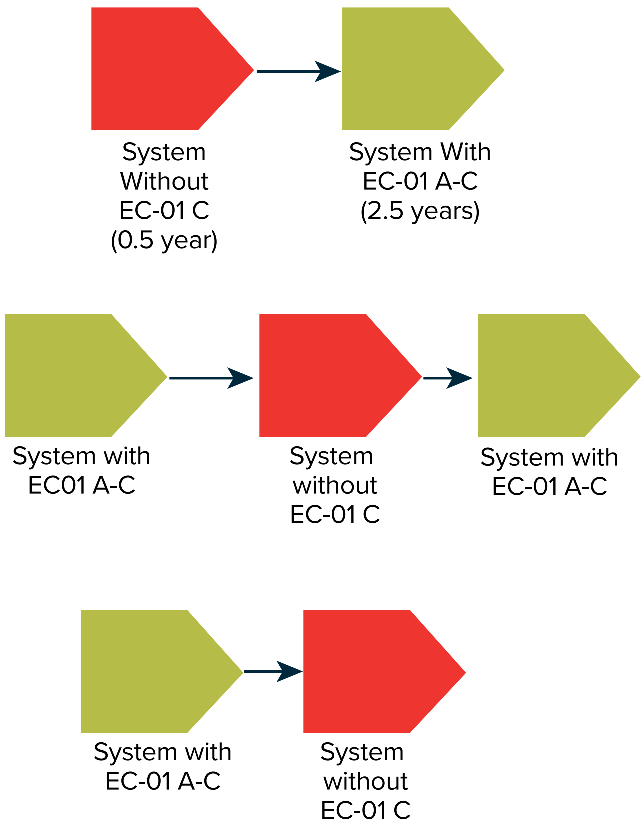

Figure 16 - System phase diagram for three scenarios. Source: Calixto, E, et al 2012

In the first case, the system achieved 97.7 percent availability in three years, in the second case the system achieved 97.34 percent availability in three years, and in the third case the system achieved 98.49 percent availability in three years. In these scenarios, three years of operation time was used, as most FCC systems will operate and supply other systems that operate for three years.

Conclusion

This study achieved the main objective – to identify if and when it is necessary to replace any critical equipment. In order to carry out such an assessment, the optimum replacement methodology was proposed. As described in Figure 11, one must consider the definition of the critical equipment quantitatively based on RAM analysis methodology, lifetime data analysis implementation, reliability growth analysis implementation and operational cost analysis. RAM analysis performed in the fluid catalytic cracking plant has shown that even when a system achieves its target, it is possible to improve system performance from an economical perspective by performing optimum replacement time analysis for equipment with increasing operational costs. In addition, the phase block diagram methodology was applied to assess different system compressor shutdown scenarios over time. This is a powerful tool for modeling systems, especially those that change their configuration over time. Such methodology implementation requires a historical failure data of the critical equipment, as well

as detailed information considering operational cost. Based on CROW-AMSSA Model, the prediction of operational cost can be complex if the prediction of future expected failure is performed based on different equipment components and failure modes. On the other hand, a detailed approach may be well applied for cases where only some of the components need to be replaced. The prediction of operational cost can be based on preventive maintenance, corrective maintenance or both. This case study considers a worst-case scenario, where the preventive maintenance does not avoid failures in the equipment. It is also necessary to consider that since events are evaluated on an equipment level, it is not possible to have detailed information on the effectiveness of PM for each component. However, it can be done in a more detailed study. The proposed methodology will be applied to other aged critical equipment to define the best replacement time.

The replacement of aged asset is a big challenge that the oil and gas industry faces often. The decision to replace equipment may affect not only the asset performance, but also the overall economic performance and safety. Therefore, a structure and methodology is necessary to be implemented in the evaluation of aged equipment.

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Reliability Starts with Materials

Randy Riddell, CMRP, PSAP, CLS

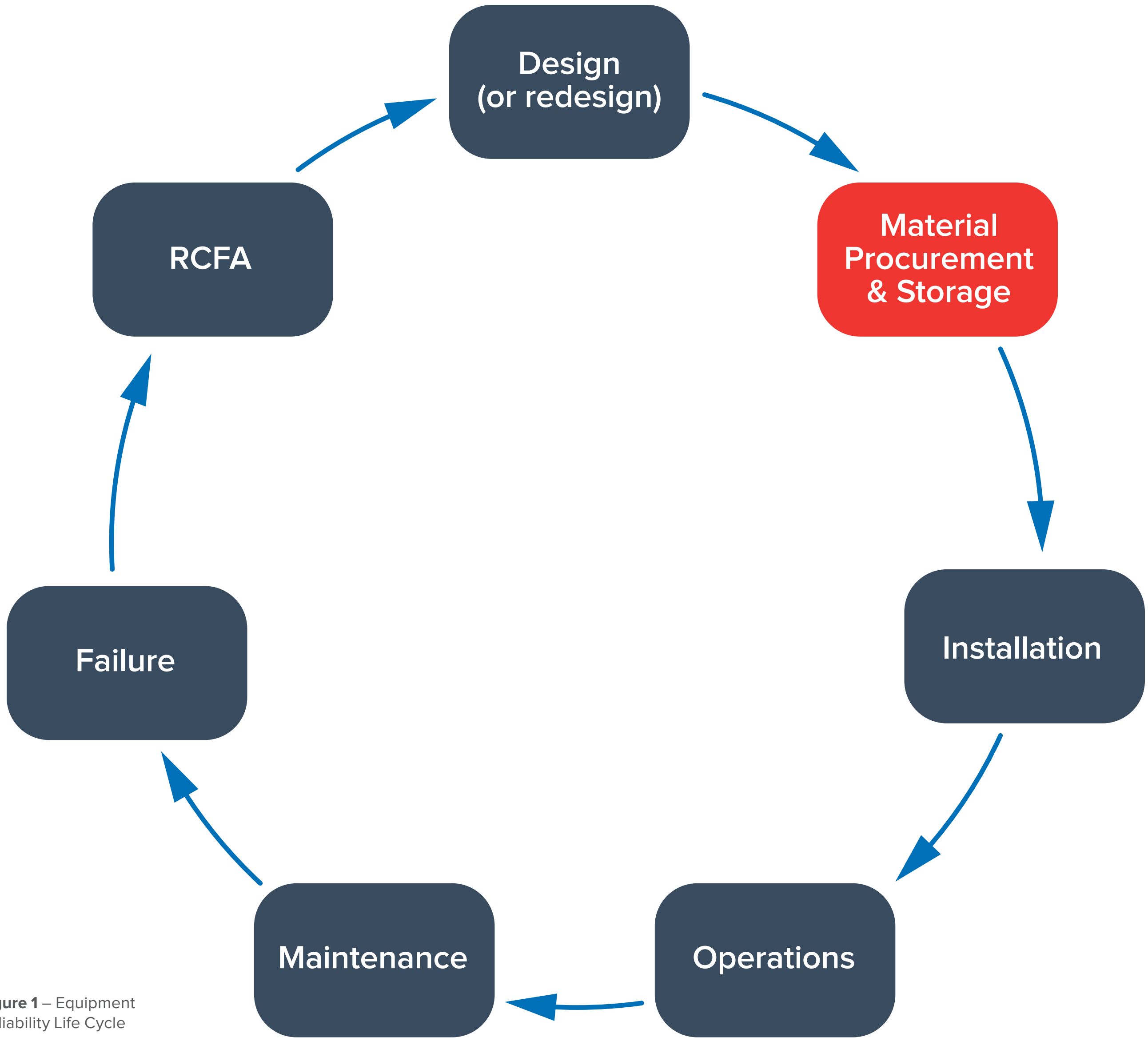

Figure 1 – Equipment Reliability Life Cycle

After system design, materials make up the first step in the reliability life cycle of manufacturing equipment. However, materials management is often the least invested area in reliability planning. There are several other parties that can affect reliability before maintenance even comes into the picture. These include the original equipment manufacturer (OEM), shipping carriers, distributors or plant storerooms. Each time a material is handled or stored, there is an opportunity for a defect to be introduced. For the scope of this article, let's explore some of the material-reliability areas.

One of the first questions often asked about spare-part materials is "Do we have the correct parts for our equipment?" For instance, is the spare pump the correct size, type, impeller diameter or metallurgy? Are the spare bearings the type, clearance (C0, C3, C4) and seal? Do we have spare bolts that are the right grade, metallurgy and correct threaded length? These are typical examples where other materials will fit but are not correct for the application.

A common activity to reduce storeroom costs might involve a part substituted to save money on the front-end only to find the quality is not the same as the original part. Counterfeit parts are also something to watch for, with many cheaper alternatives from overseas or new producers trying to break into the market. Some may even go so far as to put a name brand on the part. Keep in mind, not all parts are the same quality so use caution with supplier selection. Substandard parts that are often substituted include bearings, seals, fasteners, pipefittings and electrical components.

Another key point where materials risk flaw is in reverse engineering. The goal with reverse-engineered parts is typically to save money, cut lead-time or both. This can be a risky move if

Figure 2 – Damaged pump part from poor packaging

Shipping and handling damage begins at the OEM and often depends on proper packaging. Choice of cardboard or wood with strapping can mean the difference in receiving damaged materials or not, as shown in Figure 2. Orientation of material, strapping or use of foam shock-absorbing fillers can insulate parts from shipping damage. Length of transit, type of vehicle used or even the path of transit can all have negative effects on the final product condition. For instance, I once ordered a pump with a new vibration sensor installed. It was supposed to be initiated after installation but was turned on while at assembly on October 17. As shown in Figure 3, the pump vibration sensor recorded very high static vibration during shipping, from October 21 to 23.

I once saw a storeroom located across a set of railroad tracks. Material crossed the tracks at least twice to get to their use point. This was not good for bearings coming across on a fork truck but that happened regularly. Seals on rotating equipment may need special attention. Shipping clips on cartridge steals should be tight while in storage and shipping.

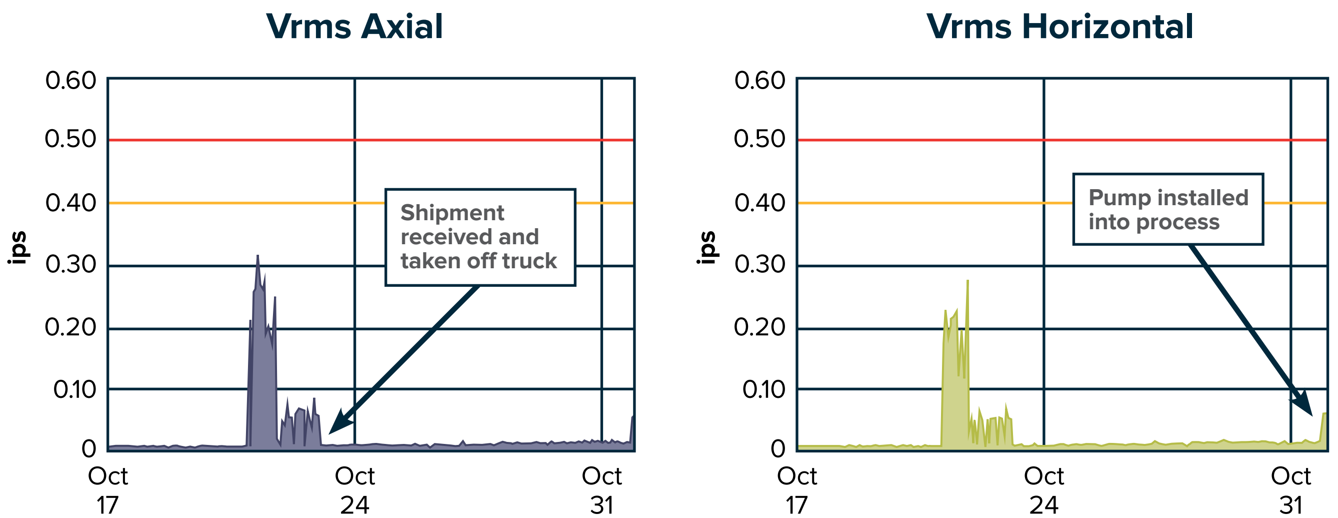

Figure 3 – Pump vibration elevated while in shipping.

a supplier or manufacturer does not have the technical capacity to complete the task. However, the liability falls on the plant seeking the alternate supply, not the supplier. This can be a key battle line, as pressure increases from corporate leaders to cut costs. It takes an experienced plant-reliability leader to articulate why using a cheaper supplier or reverse engineering parts may cost more in the end. So many factors play into spare materials management, and it only takes one or two details to make the spare an unreliable part.

Another issue that often arises may be the parts are correct but you don't have enough in quantity. A plant has a spare impeller but does not have the O-rings, or maybe you have the correct bearing but not a spare lock washer. Reusing a lock washer may result in a broken tab, which can lead to bearing failure. Errors from reusing worn or defective parts can lead to failure before the main component even fails.

Storage is another step in the process where damage can occur. Typically, less than six months is considered short-term storage for most rotating equipment such as gearboxes and pumps while some materials have expiration dates that vary. The first in, first out (FIFO) principle, a best practice for all stored material, is especially critical with limited shelf-life items. Many chemical consumable items, such as Loctite and Permatex, have around a two-year shelf life. Rubber-based materials are typically good for five to six years if properly stored; however, factors such as heat, UV light and chemical environment can negatively affect the life of these components. This is another reason why minimizing these factors in spare part storage is important, as shown in Figure 4.


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Many bearing manufacturers will say that 30 percent of bearing failures are due to shipping, handling and storage issues. Bearings should be stored on their sides, not on their ends as shown in Figure 5. Local vibration is more likely to cause false brinelling damage when stored on the ends. Boxes are also subject to fall over and cause damage. Bearing slushing compounds that protect bearings from storage corrosion are typically good for seven to eight years, depending on the relative humidity of the storage location. In general, target ambient conditions should be in the 30-50 percent relative humidity range and 40°F - 100°F. It is also important to limit temperature change to less than 35°F - 40°F in a 48-hour period to minimize condensation on cold metal surfaces. Vapor phase inhibitors should be used for long-term storage of rotating equipment that is stored for more than six months. This is typically good for at least two years, and with good sealing, it may last another four to five years beyond that.

Figure 4 – Drive belts stored nearby equipment in the field

When installing bearings, be sure to coat the bearing with an oil that has a rust and oxidation (R&O) or corrosion inhibitor. Heating bearings will often remove the slushing compound's effectiveness, which can leave them vulnerable to corrosion storage damage. Lube for life bearings (sealed bearings) have a five-year life mostly due to the lubricant. While they may last longer, significant life has been lost if the bearing is installed after being on the shelf for five years. Oil may also bleed from the grease, with long storage time affecting bearing lubrication. This may require a re-evaluation of preventative maintenance (PM) strategies.

Airborne pollution can also have a negative effect on material reliability.

Another ambient condition to take into account is vibration. Some rotating equipment such as electric motors should be stored with rubber padding. Rotating equipment should have shafts rotated on a schedule to prevent bearings from failing due to corrosion or false brinelling. The rotations should be different each time (avoid whole number rotations) so as not to put the bearing in the same position each time. While

Figure 5 – Improperly stored roller bearings

Figure 6 – Bearing housing storage open to contaminants and corrosion

there is no standard for how often to conduct rotations, most recommendations will be monthly or every other month, up to a six-month maximum for shafts to be rotated. Multistage pumps and shafts should be stored vertically; rotors stored horizontally should be rotated to avoid rotor bow.

Airborne pollution can also have a negative effect on material reliability. A study was conducted on an open oil sample in a plant storeroom with normal open-air conditions inside the building. After three months, the storeroom sample went from 38,000 particles to 97,000 particles < 14μ. This same contamination from airborne particles gets on any open spare material, such as the bearing housing shown in Figure 6. Any precision equipment should be sealed and covered so the insides are protected from contamination. Desiccant bags may also be placed inside sealed housing to reduce moisture effects on the steel housings. The iron oxide later becomes a contaminant.

Shafts are often forgotten when it comes to storage reliability. If the relative humidity is high enough and the shaft is not protected, shaft corrosion can cause as much as 0.5 to 1 millimeter per year of surface degradation, as shown in Figure 7. With a target shaft fit of .001/.0015", the shaft material loss from corrosion will affect bearing and coupling fit leading to poor reliability after installation. There are several types of coatings, such as CRC-SP-400 spray or Versil pak, which will coat shaft surfaces and protect them from corrosion. Shafts should also be wrapped to protect against impact damage and dents. These surface defects may seem minor, but the surface stress concentration can lead to fatigue fracture down the road.

Figure 7 – Unprotected motor shaft in storage under general corrosion attack

So, what should be done to ensure reliable materials are readily available? Having material specifications are a good start to ensure the plant is ordering and stocking the correct material. Examples would be a specification for a lubrication filter for media type (fiberglass or cellulose) and an absolute filter rating, such as 5μβ1000 element. Proper documentation to track materials in a computerized maintenance management system (CMMS), such as bill of materials (BOM) and purchasing specifications, are also vitally important to ensure proper material management.

Has the spare part been given the proper storage location for long-term reliability? It may need to be relocated to a better storage environment. Does the plant storeroom have adequate storage and infrastructure to support proper material storage practices? Often ignored, training for storeroom personnel or anyone who is handling materials is the best way to get material storage issues under control. Maintenance rarely has the time or opportunity to correct storage issues inside the storeroom. The right ways to handle and store material for reliability is not something storeroom personnel automatically know.

With so many places where materials can go wrong, maintenance leadership must look for ways prevent these hidden failure opportunities. Where can you extend your equipment reliability even before it is installed? An audit of your plant's spare part storage is a good start.

Organizing for Reliability:
Maximizing Your Reliability Software Investment

Timothy Payne, CMRP

Aligning equipment reliability work processes with reliability software is essential for an effective and sustainable equipment reliability program. You will not be successful by just throwing software at your problems.

Many organizations successfully implement costly and complex reliability software suites only to find that that their expectations for improved reliability and reduced costs fall well short of expectations. The software vendor in-house implementation team are often blamed. Sometimes, performance really does improve but falls off after three to five years as those who implemented the software move on to other assignments. Management is puzzled and wary of software vendors and internal visionaries.

Efforts fall short when companies confuse implementing "reliability software" with implementing a "reliability process." Both must be done, as one enables the other. Since reliability is really a business process, software is just a tool for managing the process.

Here we will examine a few proven techniques that will help focus your reliability efforts and take maximum advantage of reliability software.

Understanding 'Reliability, the Process'

A successful reliability program is organized around the basic reliability work process. Software should enable and enforce reliability procedures. Procedures must be updated as part of any software solution so that staff understands expectations. Understanding the elements of the basic reliability process allows you to organize around it and then implement staffing to operate and maintain both the software and the process, software solutions and administrative guidance such and policies, procedures and guidelines.

Essential Reliability Program Elements

The following suggestions are based on my experience as plant staff and as a consultant.

1. Organize around the equipment reliability process
2. Establish asset criticality assessment guidance
3. Establish a Plant Health Committee to oversee and focus the reliability program
4. Implement an equipment reliability scorecard
5. Create a "Top Reliability Issues" list
6. Establish a risk informed work order priority system
7. Capture key work history

Adopting these suggestions will help practitioners and plant managers take full advantage of modern reliability software. Good process plus good software will also help achieve the elusive "reliability culture change" that is often discussed but less often achieved.

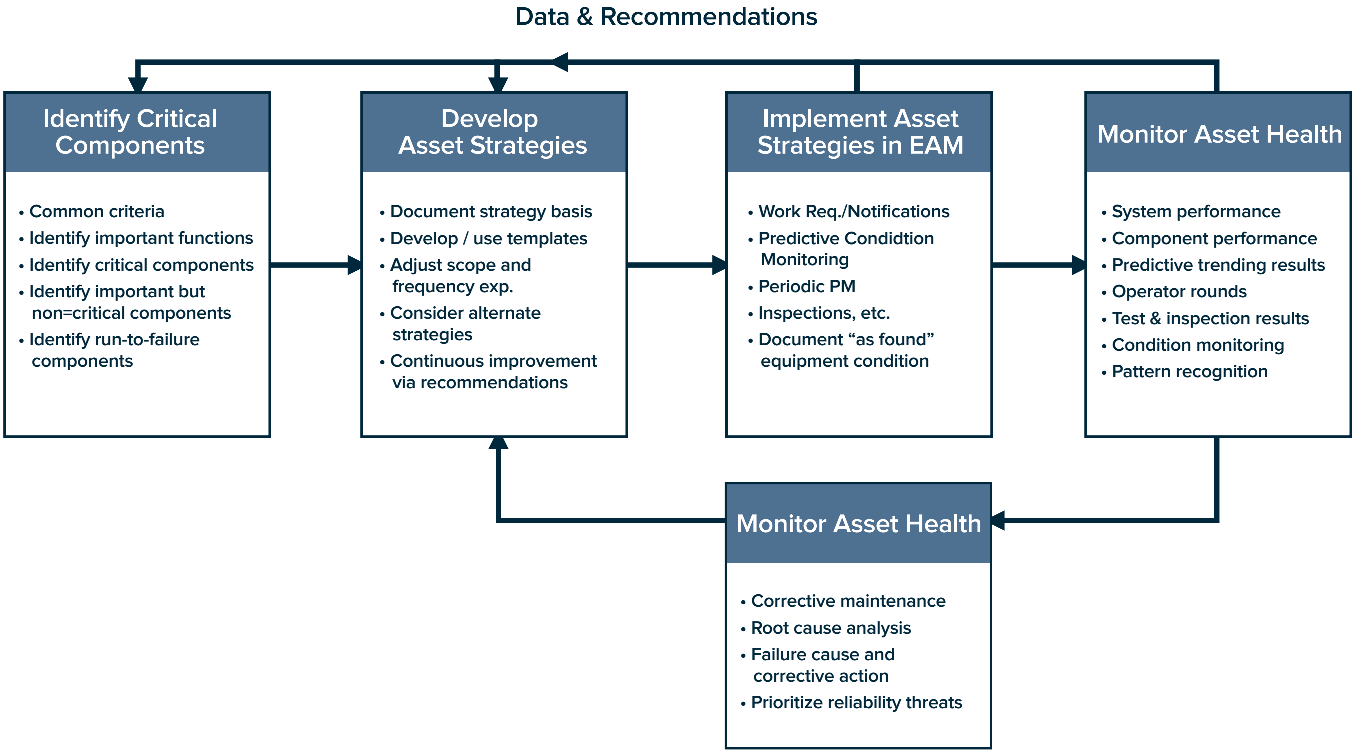
Number 1 – Organize Around the Reliability Process

Who is going to operate and maintain your expensive reliability software machine? You will not be successful by just throwing software at your reliability problems. You must also organize to properly attack them.

Generic Equipment Reliability Process Model

Any successful reliability program executes each of the elements in the simple diagram below. Each process element communicates on the lines with the others through data, displays and recommendations. Each element requires people and an administrative structure. Answer the following questions to get started:

- Will there be a central reliability organization with reliability analysts and engineers, or will each facility have these individuals, or will there be a combination?
- Will there be a set of corporate playbooks setting expectations and providing detailed guidance, or will each facility be developing their own?



Building the Reliability Organization

Create clear alignment, roles and responsibilities for support of the work processes at the corporate and site levels. Key people should be versed in the reliability process and be CMRP certified or pursuing certification.

Corporate Level

- The overall program is best owned and managed at the corporate level to ensure consistency
- Experts with Reliability Centered Maintenance Analysis (RCM), Weibull Analysis, Reliability and Maintainability Analysis (RAM) Modeling, and similar special skills that are in lesser demand at the sites are best managed in a centralized organization
- Functions like maintenance strategy templates, health monitoring policies and key performance indicator (KPI) driven scorecards could be managed at the corporate level
    - Typically two to five can handle this, depending on fleet size

Site Level

- Local maintenance strategy is best owned and managed by site subject matter experts who adjust corporate templates based on local operating experience
- Maintenance engineers that are in high demand should be located at these sites
    - Typically one to two engineers, depending on site size

The corporate and site organizations must support each other. Reliability goals are rarely achieved in a corporate or site leadership vacuum.

Number 2 – Establish Asset Criticality Assessment Guidance (Risk Matrix)

When maintenance, operations and engineering all work with the same definition of risk, the organizational priorities begin to align. Turning line of sight visibility into risk enables better decision making around prioritization and resource allocation.

Example Actions After Asset Criticality Has Been Determined

Queries and graphs can be constructed to:

- Search backlogs and adjust work order priorities
- Cancel proactive maintenance strategies on run-to-failure components
- Ensure asset strategy and health monitoring include critical components
- Perform bad actor analysis by system and equipment type to determine which critical asset strategies should be reviewed and optimized first

Number 3 – Establish a Plant/ System Health Committee

Reliability is a plant function, not an engineering or maintenance function. Time and resources must be applied at least monthly – more often as a program starts up – to allow the staff to focus on the reliability process and solving the problems it flushes out. This cannot be left to the working level operators of the software.

A scorecard or two will help you understand 1) how well the organization is doing to adopt the new processes, software and culture and 2) how well the process is actually working.

The plant/system health committee is the one-stop shop for all things reliability. It focuses on the process and coordinates reliability activities. The plant manager chairs a cross functional team of operations, maintenance, engineering, planning, inspection and other key reliability roles. The essential tasks of the committee are:

- Meeting frequently, usually monthly
- An agenda-driven focus on plant reliability
- Using metrics to identify equipment issues and reliability threats
- Managing the 'Top Reliability Issues' list and action plans

Number 4 – Implement Reliability Process Scorecards

A scorecard or two will help you understand 1) how well the organization is doing to adopt the new processes, software and culture and 2) how well the process is actually working. Fully adopting the process, software and culture leads to a working process and a working process leads to better performance and lower costs. Check the SMRP Best Practices 5th Edition for indicators related to the five pillars and how to calculate them. Pick a few key indicators for your first scorecard and expand as you learn.

Leading Indicators – Activities and processes that will get you where you want to go. Examples:

- Preventative maintenance (PM) compliance and timelines
- Schedule adherence
- Asset strategies in place for critical components

Lagging Indicators – Shows the results of your leading indicators.

Examples:

- Forced production loss rate
- Corrective maintenance (CM) to PM ratios
- Mean time between failure (MTBF)
- Corrective maintenance costs

Number 5 – Create a Top Reliability Issues List

An important purpose of the process is to flush out threats to reliability, determine their causes and then manage them to closure. These are designated reliability threats, not just the 'bad actors' charts generated by the software.

Example In-Line Work Order Prioritization Scheme				
Component Criticality (lookup or use criticality matrix)	**WORK TYPE** Consider Component and Redundant Spare Condition			
Use for prioritizing "broke/fix" work. CMMS should retain color (orange) and rank (2B) so that basis is understood throughout screening, planning, scheduling, and field work processes	Component Failure or Significant Performance Degredation with Redundant Spare in Poor or Failed condition (or no spare)	Component Failure or Significant Performance Degredation with Redundant Spare in Degraded condition	Component Performance Degraded or Failed with Redundant spare in Excellent condition	Non-Plant Equipment
Critical Component (Crit A)	**1A**	**1B**	**1C**	**N/A**
Control Room Deficiency, Annunciators, Operator Work Arounds, Significant Security Deficiency, Regulatory Compliance Threat	**2A**	**2B**	**2C**	**2D**
Important Component (Crit B), Minor Safety and Security issues, emergency equipment	**3A**	**3B**	**3C**	**3D**
Non-Critical Component (Crit C or D), Building Structures and Support Systems, Site Facilities, Tools and All Other	**4A**	**4B**	**4C**	**4D**

Red - Begin immediately and work around the clock

Yellow - Start immediately during normal work hours

Orange - Schedule within three weeks

White - Schedule within 12 weeks

Green - Work when time allows

A reliability threat is defined as a non-broke/fix issue or vulnerability that requires:

- Cause determination
- Development of solution options
- Implementation plan for the selected solution

Reliability threats include repetitive and long-term issues as well as obsolescence and aging issues. They do not include day-to-day broke/fix issues. In general, if you can solve the problem with a work order, it's not a reliability threat.

Number 6 – Establish a Risk-Informed Work Order Priority System

When setting work priorities, one should consider asset criticality AND equipment condition – good, degraded or failed – AND condition of the installed spare, if one exists. Enhance the work priority matrix to ensure the right work is being done on the right equipment at the right time. An example is shown below.

Number 7 – Capture Key Work History

Failure Coding

This concept has bedeviled the industry for decades. We want useful failure data but we drown the people trying to close work orders in possible causes and codes. Frustrated workers just pick "other" or something that is similar on the first several menus. We suppress free text descriptions in favor of codes and often don't get the best of either.

Often, free text "work performed" fields accurately describe what failed and what the craft thinks happened. With the advent of cognitive analytic software that can extract useful data from free text, it is for this approach to be fully exploited and to eliminate excessive menus and codes. Instead of suppressing free text, we should encourage descriptive entries that software could mine and codify.

Use the Equipment Hierarchy

Write work orders to the lowest reasonable level of the equipment hierarchy, such as motor, pump or valve. Do not permit work orders to be written against just the plant, unit, system, or miscellaneous. This will mask where the work and costs are really located.

Know What Initiated Your Corrective Work

Establish and enforce guidance for use of breakdown indicators or work order type and priority to identify which problems "you found" (proactive maintenance) and which problems "found you" (reactive maintenance).

Collect 'As Found' Data for PMs

This practice enables the collection of powerful metrics for assessing maintenance effectiveness. For example, an excessive amount of additional work needed on compressors discovered during PMs suggests wrong PM scope or PM intervals that are too long. Similarly, an excessive number of 'as found' conditions of "excellent" when performing chiller filter changes suggests PM is performed too often. Create indicators that trigger reviews based on 'as found' PM codes.

'As Found' Condition Codes

AF-1 Superior. PM performed but component was still in excellent condition

AF-2 As expected. PM performed without need for additional corrective work

AF-3 Measured parameter within tolerance but adjustment performed (applies typically to instruments)

AF-4 Measured parameter outside specified tolerance and adjusted (applies typically to instruments)

AF-5 Degraded beyond PM scope. Performed additional corrective work

AF-6 Failed or unanticipated failure. Component found in failed condition

NA Not Applicable. Non-plant equipment. Turnaround/outage preparation

Comments: PM Scope OK? PM Frequency OK? Other comments on this task?

Where do we start once the software is in and training complete?

This question often emerges in the latter part of software implementations as the eventual owners of the software and management begin to understand that they also have a process to execute. Depending on the experience and maturity of the organization, any of the following are good places to start. If a plant health committee is being implemented, it should guide and focus the selected approach.

- Determine who is going to do the bulk of the analysis work once the software is ready. Will it be plant staff, contractors or some combination?
- Determine criticality on assets. Since asset criticality drives everything, give some thought to what assets review and in what order. There are techniques for making this task more manageable. One method is to start by assessing criticality on all assets that have ever been worked on. Then classify the remaining assets next.
    - There are many actions you can take with asset criticality to gain immediate value. Review the example actions under item 2 above to get some quick wins.
- Take the population of existing PMs and validate their underlying strategy, including criticality of the assets they address.
- Select a known-problem system or bad actor dashboard and apply the processes and software tools to improve performance.
- Select a pilot system and apply the basic tools to learn how to do the entire process from beginning to end.

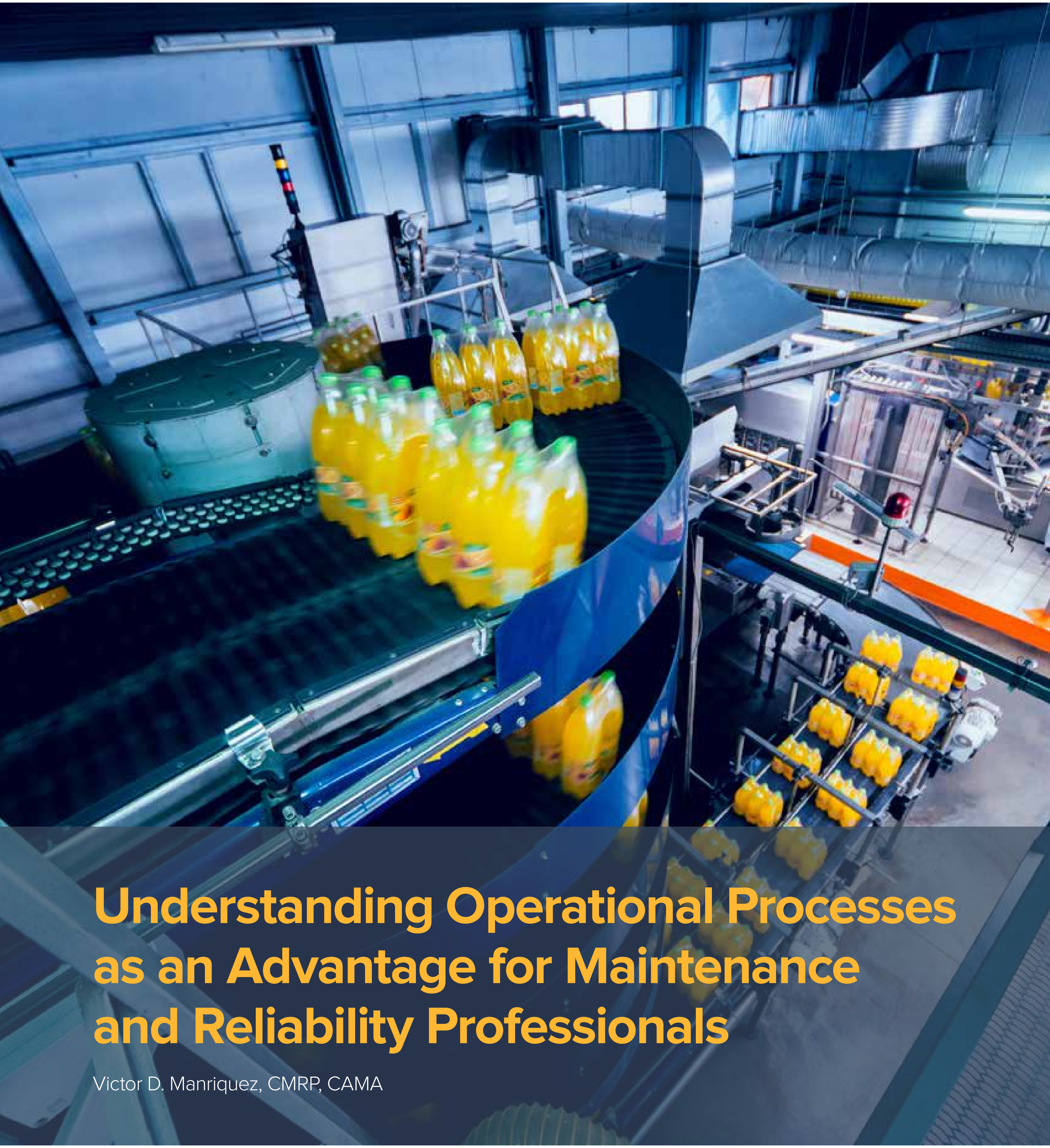
Conclusion

We are sometimes asked what are the most difficult parts of reliability projects. Projects often do not include adequate internal resources because reliability improvement is approached as a software implementation project that ignores the need to also organize around the equipment reliability process. Dedicated reliability staff is required to implement the program AND sustain your success.

To ensure your transformation is successful, management and reliability practitioners must:

- Be patient with yourselves and the staff as you learn both the new software and reliability process.
- Understand that sustained reliability improvement requires culture change in the organization. Leadership and training are required.
- Staff must understand the connection between asset performance and business performance.

Management discipline and focus is required to improve each year. This is a multi-year effort! Remember – you will not be successful by just throwing software at your problems.



Understanding Operational Processes as an Advantage for Maintenance and Reliability Professionals

Victor D. Manriquez, CMRP, CAMA

In your professional experience, you've most likely found yourself in the situation where something goes wrong with a piece of equipment, and despite several different approaches to fix the issue, nothing seems to work. The rework time increases and the operations personnel criticizes you and your team because you can't satisfy the expectations for equipment reliability. On some occasions, you may have made a root cause analysis (RCA), but the problem continues, as the solutions didn't work.

In these instances, did you know the operative process and function that the equipment realizes within it? What if the process conditions changed over time and the equipment design conditions are exceeded?

Pillar Two of the SMRP Body of Knowledge (BoK) states:

"2.1 Understand the applicable processes (document process flow, understand process parameters, understand quality specifications, etc.)

A complete process understanding across all disciplines and at all levels of the organization that influence the performance and safety can provide tremendous benefit. The ability to react appropriately to changing conditions in the process, not only related to one's direct function but the impact on the total process provides real time process control and optimization..."

This means maintenance professionals should understand the process in order to give answers to the changing conditions in the process. When we review Pillar Three in the BoK concerning Equipment Reliability, we find:

"3.2 Evaluate equipment reliability and identify improvement opportunities (measure and track performance, determine best demonstrated performance, analyze gaps, etc.)

.... When sufficient equipment data has been gathered, it can be compared with established reliability and availability expectations...Nominal design parameters and best demonstrated performance levels should also be compared with the process requirements to determine if the requirements have changed over time to the point that they exceed the inherent design capacity of the equipment. This comprehensive analysis results in clearly defined improvement opportunities for achieving equipment performance that meets expectations."

The BoK reminds us of the close relation between reliability expectations and process requirements. Keep expectations and process requirements separate, and you will be more likely to find situations where the process requirements have changed, but you haven't noticed, and the inherent capacity of the equipment has been exceeded. I have had several of these cases in my experience.

In 2000, I went to work for the first time in a mine located 4,000 meters above sea level in the mountains of Peru. I was in charge of mechanical maintenance in the ore processing plant. There was a centrifugal pump in the slope of a hill, halfway between

the plant and a sedimentation recovery pool for the plant's wastewater. The pumped fluid did not meet the head or flow expected to pump the recovered water back to the processing plant. The electrical maintenance department was required to equip the pump with a more powerful electrical motor. The original motor was around 75 HP, the second motor was 100 HP and the team had plans to install an even larger motor in the future. But we would find that the issue was not the power of the motor.

We searched the database and found a case similar to ours. First, we found that the valves we were using were designed to work with dry gas but the natural gas that reached our compressors was dragging in some liquid.

As mechanically responsible for the pump, my team looked for the pump performance curves, and we found that the pump's inherent capacity would never meet the process requirements. We provided our findings to the pump manufacturer, who then advised how to solve our problem. If you are not aware of the inherent capacities of your equipment, you can misread a series of events with no results after a large number of trials.

The second event was around 2014 on an offshore oil platform in the northern Peruvian sea with natural gas reciprocal compressors. On this platform, oil is extracted together with water and natural gas. By national regulations, after petroleum has been extracted, you must dispose of the other fluids. Companies use a portion of the natural gas in its energy generation and other related services. After that, a percentage of the natural gas can be burnt, according to environment regulations. The remaining gas is reinjected into the subsurface. A business can face fines if it burns more gas than the amount authorized.

In this event, the gas compressors showed terrible performance due to frequent valve failures. They accumulated almost 700 hours per month of non-scheduled stops because of this issue. The immediate answer suggested by one manager was to increase the valves stock as an emergency action, but that was obviously not a sustainable solution.

We decided to research this kind of failure and found the Turbomachinery Laboratory at Texas A&M University (https://turbolab.tamu.edu/). On their website, they share the proceedings from the Turbomachinery and Pump Symposia with a database of different cases to review along with other information related to turbomachinery. We searched the database and found a case similar to ours. First, we found that the valves we were using were designed to work with dry gas but the natural gas that reached our compressors was dragging in some liquid. This caused the valves to malfunction. The presence of liquid was a consequence that the process parameters changed.

With that information, we started a review of the process conditions of gas and liquid separation on the offshore platform and found that the process conditions had been changing over a few months. The rate of liquid to gas had been continuously increasing and the scrubber in charge of the separation was overflown, so the gas was dragging liquids on the compressors inlets and the valves couldn´t deal with the situation. We needed to review the process requirements and its match with the inherent capacities of the gas compressors.

In this second case, we needed to consider two aspects, the asset inherent capacity and the process requirements. If we had not looked at the process requirements, we could have been trying different approaches from the maintenance side and not getting close to the solution. Some of these emergency measures, like increasing the valves stock are also negative for the profitability of the organizations. We didn't need a short term fix that only treated the symptoms; we wanted a long term solution.

Looking at both cases

From these two cases, I can summarize a few key points that may be helpful in maintenance and reliability management:

- Keep organized and updated information about the inherent capacities of assets. This will help you and your team be aware when those capacities are exceeded and the reliability or availability expectations of that asset cannot be reached or sustained.
- Understand the operation process requirements and how assets meet these requirements to respond to changes in process and deliver what the process requires.
- Review the process flow diagrams (PFD) of your organization and be aware of the process parameters.
- Have an understanding of the ISO standards as they encourage a process approach for organizations.
- Continually seek knowledge. The information on Texas A&M University's website was helpful in my case. Other paper or research could be helpful in your maintenance and reliability problems.
- Share and spread knowledge and solutions in conferences, symposia and magazines, such as Solutions, the SMRP Annual Conference or Symposia (like the upcoming Peru event!).

Then, let's get involved with the process! We must meet the process requirements without degrading the assets by exceeding its inherent capacities and design parameters. If we do that, then the organization will be the winner.

CHAPTER NEWS

Measure Your Maintenance and Reliability Performance Using Predefined Indicators

The Global Maintenance & Reliability Indicators: 4th Edition reference book, which contains 29 metrics and indicators, is currently under review by maintenance and reliability professionals from both SMRP and the European Federation of National Maintenance Societies (EFNMS).

The updated reference book will describe the differences and similarities between SMRP metrics and indicators from the CEN - EN 15341: Maintenance Key Performance Indicators. The harmonization process will also respond to the request from many professionals to suggest which indicators should be used in maintenance processes.

If you would like more information on the project, please contact Jerry Kahn, P.E., CMRP at jerrykahn@jk-consulting.com.

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