Using Decision Support to Reduce OpEx at Valero Paulsboro

Valero's Paulsboro refinery makes innovative use of the Decision Support capabilities within System 1 software to proactively manage both rotating and non-rotating production assets. As a result, operating expenses—not just maintenance expenses—are reduced.*

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Valero's Paulsboro Refinery, located on 950 acres in Paulsboro, NJ, was first commissioned in 1917, and currently has a capacity of 195,000 barrels per day. The refinery has a fuels crude unit, lube crude unit, distillate hydrotreater, FCC complex, Delayed Coker, Reformer, Lube Plant and Alkylation unit. The refinery employs nearly 550 individuals and is an OSHA VPP Star site.

Throughout the refinery's years of operation, its maintenance strategies and practices have continually evolved. Today, condition-based maintenance is used extensively and employs a mix of permanent and portable technologies, depending on asset criticality. Low criticality assets are addressed by a portable data collection system. High- and mid-criticality assets are addressed by online systems. For its most critical assets, Paulsboro uses Bently Nevada* continuous machinery protection systems in conjunction with System 1 software. The assets in this category include the plant's gas turbines in power generation service, steam-driven and motor-driven centrifugal compressors, hydrogen reciprocating compressors, utility air compressors, and liquid ring compressors for flare gas recovery. Mid-criticality assets in the refinery's coker unit are addressed by a Bently Nevada Trendmaster* system, a permanently wired "sensor bus" architecture that takes condition monitoring measurements several times per hour. Both the continuous monitoring systems and the Trendmaster architecture are tied into System 1 software for a unified online condition monitoring environment.

Managing Below the Alert Level

One of the keys to Paulsboro's success with condition-based maintenance is their practice of managing machinery "below the alert level"—a euphemism describing the use of condition-based alarms that are well below operator-level "alert" or "danger" alarms normally associated with pre-shutdown and shutdown conditions respectively. Alarms set purely to notify machinery specialists of impending problems allow operations to continue uninterrupted while appropriate actions are taken "behind the scenes," such as scheduling appropriate maintenance, planning an outage, or recommending changes to operating or process conditions that will slow or halt failure progression on the affected asset. This level of "preemptive" maintenance drives the Paulsboro refinery to the far left limits of the P-to-F curve (Figure 1). In addition to fewer process interruptions, operating at this end of the P-to-F curve results in higher product quality, improved asset availability, and increased operating profits.

IN THE TWO YEARS SINCE THIS SIMPLE—BUT EFFECTIVE—DECISION SUPPORT RULE HAS BEEN IMPLEMENTED, IT HAS BEEN INVOKED TEN TIMES, RESULTING IN TEN PLANNED, ROUTINE, FILTER REPLACEMENTS WITHOUT A SINGLE "URGENT/EMERGENCY" WORK ORDER BEING NECESSARY.

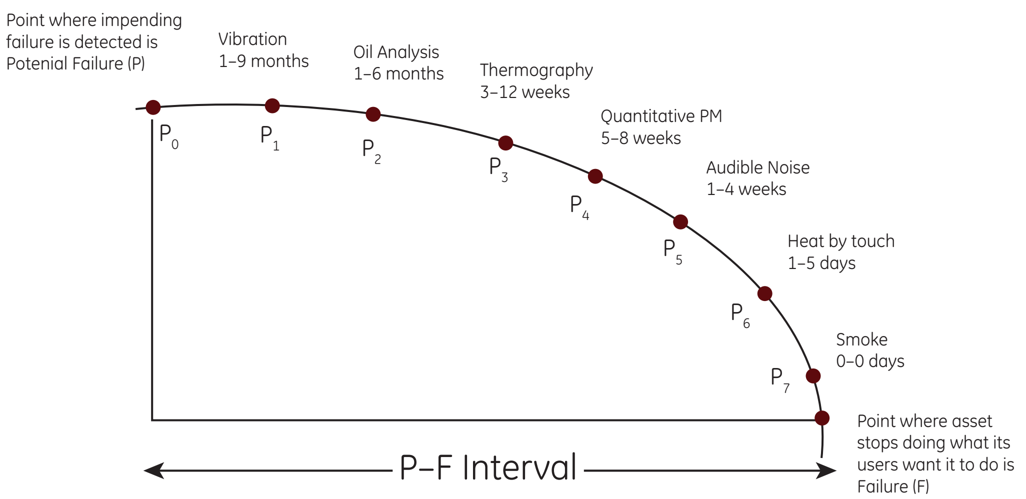

Figure 1. The so-called "P-F curve" showing qualitative time relationship between Potential Failure (P) and Functional Failure (F). P_0 represents the earliest time at which an impending failure could conceivably be detected. P_1 through P_7 represent various detection methodologies and their typical capacity for advance warning. The further to the left (closer to P_0) one can operate for any given asset, the easier it is to plan maintenance and lower the likelihood of "surprise" functional failures.

While establishing a sufficient number of condition monitoring alarms can be very effective for the reasons noted above, managing too many alarm levels can become quite onerous and a balance must be found in the quest to move "farther to the left" on the P-F curve. One way to achieve this is by relying not only on level-type alarms, but also on technologies that automate the data analysis and anomaly detection processes that human experts would use if manually reviewing data. Paulsboro has been particularly innovative in their use of System 1 software's Decision Support capabilities in this respect. The Decision Support module in System 1 allows users to embed their subject matter expertise for a particular asset (or class of assets), and detect asset problems automatically. While many users employ the Decision Support module to detect anomalies with the rotating machinery monitored by System 1 software, what has set the Paulsboro facility apart is their use of the system on non-rotating assets as well. By bringing process data from the plant's Distributed Control System (DCS), turbine control systems, and Process Historian into the System 1 database, Paulsboro is able to apply the Decision Support engine in innovative ways such as:

- Analyzing and detecting anomalies on assets for which only process measurements are available —such as filters, heater tubes, and pressure relief valve rupture disks.
- Addressing applications outside of conventional "condition monitoring," such as stack emissions monitoring.
- Detecting problems in non-rotating portions of turbomachinery, such as gas turbine hot gas path components.

To address this mix of conventional rotating machinery, fixed equipment, and process-related applications, Paulsboro uses both GE's machinery expertise in the form of pre-configured RulePaks, and their own expertise in the form of custom rules written by their resident subject matter experts. In this way, Valero has created

Decision Support capabilities tailored specifically to the needs of their Paulsboro operations. As detailed in the following six case history synopses, the system is delivering substantial value and has become an integral part of their operating and maintenance decisions.

Case Histories

CASE HISTORY #1: Naphtha Hydrotreater Feed Filter

The filter at the front end of the Naphtha Reformer has a direct effect on the quality of the final product. Bypassing this filter, or choking the process by operating with a clogged filter, both have serious operational consequences, making the filter's condition a critical part of the Reformer process.

A review of historic data showed that these filters are replaced every 45 to 90 days; however, 35% of the work orders initiated for filter replacements were categorized as "urgent/emergency." Work performed under such conditions interrupts the maintenance team's planned activities for the day, diverting resources, disrupting schedules, and adding both maintenance and operational costs. Valero saw an opportunity to monitor filter degradation and shift from "unplanned and urgent" to "planned and routine."

Two pressure sensors on either side of the filter are fed into a Paulsboro-written rule in the System 1 Decision Support module. The rule first subtracts the two pressure signals to create a "virtual" differential pressure signal. This differential signal is then trended and compared to empirically derived "normal" values. For example, experience had shown that 6 PSI of differential is the point at which maintenance personnel should be initially advised. This was configured as a "level 1" severity in the system, triggering a notification to maintenance planning engineers to watch the differential pressure twice a day. At 9 PSI, the severity is upgraded from 1 to 2 (which is still below the Alert level – level 3). Once at severity 2, another notification is sent; this time, to enter a work order for a planned filter replacement.

Should the differential reach 15 PSI, an alert, or severity level 3 alarm is sent. At this level, the work order will be upgraded to "urgent/emergency." Finally, if the differential pressure reaches 30 PSI, a level 4 "Danger" notification is sent, instructing the operator to immediately open the bypass valve to prevent damage to the unit.

In the two years since this simple—but effective—Decision Support rule has been implemented, it has been invoked ten times, resulting in ten planned, routine, filter replacements without a single "urgent/emergency" work order being necessary.

CASE HISTORY #2: CCR – Recycle Gas Compressor

Commissioned in 2004, this unit is relatively new. However, within nine months of operation, the unit needed to be shut down due to high vibration levels. A water wash was performed and the unit was returned to operation. However, as part of Valero's efforts to "manage below the alert level," the team examined data from the machine to see if they could be more proactive in the future. They found that a particularly reliable advance indicator of the need for a water wash was a change in the compressor's balance condition. They further found that, for this machine, the inboard bearing's X-Y probe pair was the most sensitive to balance condition changes from compressor build-up. After consulting with one of GE's Bently Nevada machinery diagnostics engineers, Valero formulated a customized algorithm that looked at orbit shape, vibration levels, and rate-of-change in vibration levels to provide early detection of changes in balance condition, and thus to help schedule water washes.

While the off-the-shelf RulePak for centrifugal compressors is able to detect and isolate unbalance, Valero's algorithm provides even more sensitive detection because it accounts for the idiosyncrasies of this particular machine and its changes in balance when compressor build-up is the root cause. The ability to "personalize" the system in this manner is particularly valuable to Valero.

CASE HISTORY #3: Gas Turbine Burner Monitoring

The gas turbine used for generating power at Valero has 10 burner cans and 13 thermocouples for measuring exhaust gas temperature (EGT). The thermocouple corresponding to a particular burner can is a function of generator load and is defined on a "Swirl Chart." Valero has configured the swirl chart for this particular turbine in System 1 software, allowing the data from each thermocouple to be associated with the correct burner can.

[Editor's Note: For more information on exhaust gas temperature measurements and swirl chart compensation, refer to the article "Exhaust Gas Temperature Capabilities Now in System 1 Software" pp. 88-89, ORBIT Vol. 25, No. 1, 2005]

The temperature spreads between these various thermocouples are then analyzed by the Decision Support engine to detect combustion problems or thermocouple (TC) problems. The higher the temperature spreads, the higher the alarm severity.

During startup and run-in following Valero's last outage, the system notified them that two adjacent TCs on the EGT (Exhaust Gas Temperature) map were experiencing higher temperatures than the rest, and the plenum area was subsequently investigated for damage. Although some insulation faults were found and corrected, the higher temperatures remained. Normally, Valero would have been hesitant to produce full load from the machine under such conditions. However, the EGT map capabilities showing Exhaust Gas Spread and adjacent TC differentials provided personnel with the confidence they needed to conclude that full load conditions were not damaging the machine. This hot gas path monitoring is all accomplished through the System 1 Decision Support module. Based on the severity of the alarm, e-mail and text messaging notifications are generated and routed to the correct level of the organization, from operations and maintenance personnel all the way up to the Plant Manager level when the severity is high enough.

CASE HISTORY #4: Asphalt Heater – Decoking Plant

The asphalt heater tubes can be affected by two potential problems:

1. Overfiring

Overfiring results in loss of creep strength and can lead to premature tube failure. Fortunately, it is relatively easily addressed. The seven heater tube temperatures are brought in to the System 1 database via an interface with the plant's distributed control system. A simple rule in the Decision Support module then compares tube temperatures against empirically derived maximum limits, obtained by examining historical operating and maintenance data for the tubes. Depending on the severity of the temperature violation, a level 3 or 4 alarm is generated. An inspection engineer then uses this data to assess the situation and tailor appropriate actions, such as creep strength analysis.

2. Clogging

Clogging affects unit efficiency, and although more complex to address than overfiring, it is still straightforward to implement in the System 1 Decision Support engine. The algorithm computes the average weekly temperature of the unit and compares the present week against the previous week. Increases above certain limits are cause for concern and trigger a notification for the process engineer to review operating parameters. He uses this data to analyze inlet conditions and feed compositions, determining their affect on decoking time. By triggering notifications to the process engineer at the right time, the decoking process is optimized, saving time and money.

CASE HISTORY #5: Rupture Disk Monitoring

Pressure relief valves (PRVs) protect piping, vessels, compressors, and other pressurized assets from excessive pressure conditions. While a PRV is intentionally designed to open under over-pressure conditions (i.e., 120% of design process pressure), the process conditions are often extremely corrosive. If the process gas were allowed to continuously contact the PRV, the valve would quickly corrode, resulting in leakage or seizure. Both conditions are unacceptable as leakage results in reportable incidents and associated penalties from regulatory agencies, while valve seizure could cause the pressurized asset to fail catastrophically.

To isolate the PRV from the corrosive process gas, a rupture disk is used. The disk is a sacrificial, thin metal membrane designed to fail at a predetermined pressure. Further, it is designed using materials that are impervious to the corrosive process gases. As shown in Figure 2, the disk is placed in series with the PRV. This arrangement ensures the following:

- The PRV will not normally be exposed to the corrosive process fluid/conditions, thus preserving the PRV's integrity
- Even a defective PRV (such as one that does not fully seal itself in its valve seat) will not leak to the atmosphere under normal process conditions

Under normal conditions, an intact rupture disk isolates the PRV from seeing process pressures; thus, $P_{PRV} \approx 0$. A fully ruptured disk results in $P_{PRV} = P_{Process}$. A faulty disk, such as with a pinhole leak, results in $P_{PRV} \neq 0$. Thus, anytime P_{PRV} is non-zero under normal process conditions, the disk is either ruptured or faulty (e.g., pinhole leak, etc.) and corrective action needs to be taken.

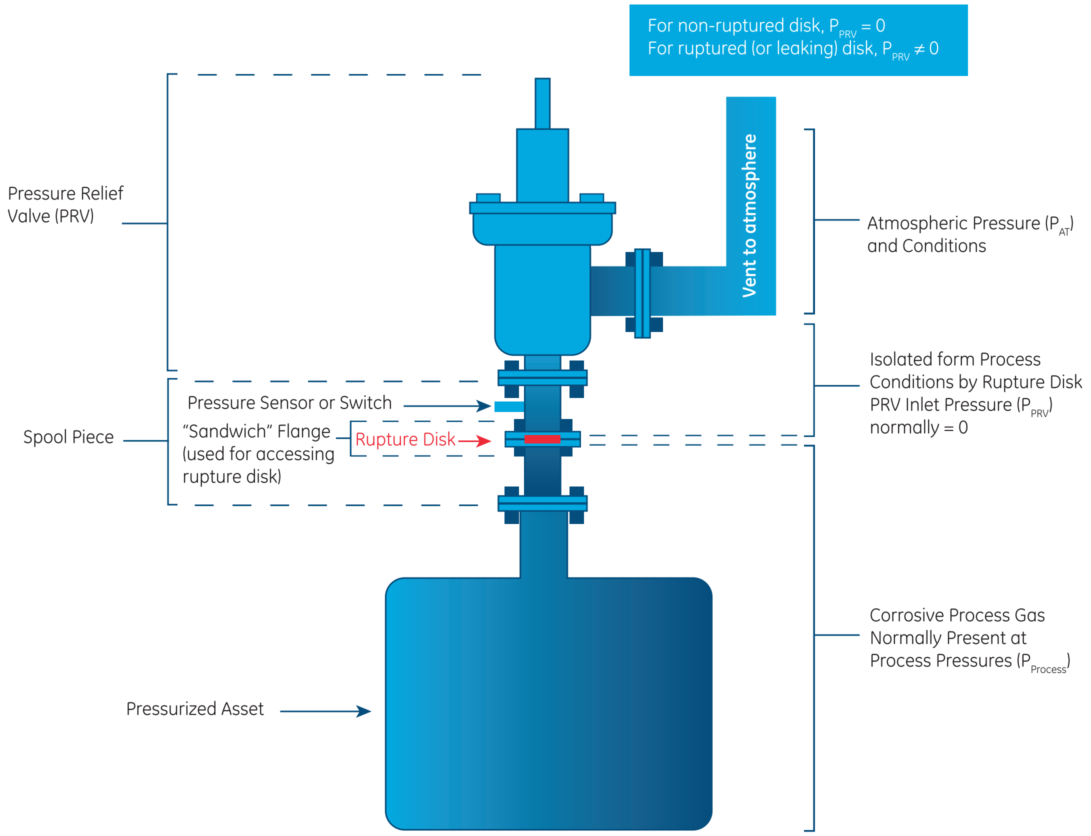

Figure 2. Pressure relief system consisting of a rupture disk in series with a Pressure Relief Valve (PRV). Both rupture disk and PRV are designed to open at over-pressure conditions, protecting the pressurized asset by venting to the atmosphere. By using a rupture disk made of corrosion-resistant materials, the PRV is isolated from the corrosive effects of the process gases, preserving the integrity of the PRV. The rupture disk has the added benefit of ensuring that process gases will not leak to the atmosphere at normal pressures, even if the PRV is leaky.

To help Paulsboro manage their rupture disks and ensure regulatory compliance, a pressure sensor (or switch) is installed in the spool piece to measure P_{PRV}. A simple rule in the System 1 Decision Support engine detects when P_{PRV} is non-zero, and sends an e-mail notification to the engineers responsible for the affected area of the plant. They then inspect the disk and replace it with a new one if found ruptured or otherwise defective.

A failed rupture disk does not result in an atmospheric leak unless the PRV is itself leaky. However, the PRV will corrode unless the rupture disk is promptly replaced. Thus, even if it is not now leaking, the PRV will eventually leak as a result of contact with corrosive process gases. For this reason, regulatory agencies require a ruptured disk to be replaced within 15 days and appropriate records kept. As such, the Decision Support rule also sends an e-mail notification to operation supervisors who are responsible for submitting an ICV (inter-lock control valve) bypass form. The ICV bypass form allows continued operation until the rupture disk is replaced. These records are audited by relevant regulatory agencies and Valero's ability to show these agencies that a process is in place to constantly monitor the integrity of the rupture disk helps avoid violations and associated penalties.

CASE HISTORY #6: Stack Analyzer Monitoring

The Paulsboro facility is required by law to monitor flue gas from their FCC (Fluid Catalytic Cracker) unit for CO, SO_2, and NO_X—all environmentally sensitive emissions regulated by law. The emission levels must be recorded and kept within allowable limits at all times. Monitoring is accomplished using a real-time gas analyzer that computes the concentrations of these emissions. However, to avoid violations and associated fines, it is necessary to periodically compare the gas analyzer's results with laboratory results, verifying that the analyzer is not underreporting. Paulsboro uses System 1 software to capture both the gas analyzer outputs and laboratory results, and compare them to one another. Discrepancies are flagged and appropriate personnel are notified using the Decision Support engine.

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Further, using the Decision Support module's ability to generate management-level alarms, violations are kept in check by notifying personnel whenever emissions approach maximum allowable limits. At 80% of the violation value, an alarm occurs, automatically notifying the unit supervisor and process engineer via pager. This warns them of a possible environmental violation before it occurs, providing sufficient time to proactively intervene by adjusting the process.

Rule Testing and VALIDATION

The Decision Support module in System 1 software allows user-written rules to be tested against historical data. This feature greatly aids the Valero team in validating new rules before they are deployed. It also allows them to fine tune their rules, ensuring that a rule triggers not just ***when*** needed, but ***only*** when needed. This reduces false notifications and inspires confidence in the system.

Summary and Best Practices

As these case histories have shown, Valero Paulsboro uses the flexibility and functionality of System 1 software and its Decision Support capabilities to reduce both operating and maintenance expenses. The quality of results achieved is in direct proportion to Valero's deliberate and conscientious application of several "best practices" which have been summarized in conclusion:

Best Practice #1: Allocate Necessary Resources

While the technology of System 1 software is important, it is merely an enabling factor. Without the resources to actually use the system, it cannot deliver its full potential. Understanding the importance of this human factor—not just the technology factor—Valero allocates a full-time Reliability Engineer to use and optimize the system. This individual is responsible for monitoring the health of the system, identifying new and innovative uses of the system, and developing/deploying custom rules.

Best Practice #2: Think Beyond Vibration and Rotating Machinery

Paulsboro has been particularly innovative in broadening their system beyond the normal confines of vibration data and rotating machinery to include fixed assets and even process-related applications. As a result, the value they extract is correspondingly broader.

Best Practice #3: Involve the Whole Plant

Another key to Paulsboro's success is that a much wider circle of plant personnel have been exposed to the capabilities of System 1 software and encouraged to identify opportunities where it can be applied. As a result, engineers throughout the complex are now making requests for custom rules that address various failure modes, ensuring that the system's usefulness does not remain confined to a single individual's perspective or scope. Valero's assigned Reliability Engineer is typically able turn these requests around in a matter of hours, configuring the requested rules along with testing and validation using historical and/or current data.

Best Practice #4: Customize Notifications, not just Rules

While customized rules are an important part of Valero's success, rules deal only with detection. Once a condition has been detected, no matter how simple or complex the underlying rule, notifying the right people at the right time with the right recommended actions is key to whether the system is perceived as merely an alarm generator or as an indispensible tool. Valero gives deliberate thought to the optimal number of severity levels that an escalating condition should have, to the individuals that should be notified with each severity level, to the way in which they should be notified (e-mail, text messaging, pager, etc.), and to the actions that the recipient should take once notified. This is perhaps the single biggest part of successfully "managing below the alert level" and achieving widespread visibility of system usefulness across the plant.

* denotes a trademark of Bently Nevada, LLC, a wholly owned subsidiary of General Electric Company.