Optimizing **Preventive Maintenance** in **Refineries,** Lessons from Two Pump Case Studies!

INTRODUCTION

Preventive maintenance optimization (PMO) is crucial in refineries and other strategic industries where unplanned downtime can be extremely costly. Maintenance strategies generally fall into **preventive maintenance** (tasks done before failure) and **corrective maintenance** (repairs after failure) A common assumption is that increasing time-based preventive maintenance will proportionally reduce corrective maintenance and sudden failures. In reality, however, **more maintenance is not always better** – the effectiveness of preventive tasks depends on an asset's failure behavior.

Studies have shown that only about **11% of equipment failures are age-related**, while the remaining 89% occur randomly with respect to operating age In other words, most failures do **not** follow a simple "wear-out" pattern, so a blanket increase in scheduled maintenance will not automatically improve reliability.

In fact, excessive or mis-timed maintenance can introduce new problems; as one reliability report noted, *"the myth of time-based maintenance providing reliability is busted – in reality, time-based maintenance can greatly increase the probability of an infant mortality failure"*

This article explores two real-world pump cases from a refinery's PMO program that illustrate how ***preventive maintenance must be tailored to the asset's reliability characteristics***. We analyze a reciprocating plunger pump (Case A) and a vertical multistage centrifugal pump (Case B), and explain why a high percentage of scheduled maintenance in Case A did not reduce breakdowns, while insufficient preventive care in Case B led to frequent failures. We will also discuss the underlying reliability distribution for each case, including the **Weibull shape factor** (**β**) and scale factor (**η**), to show how these parameters inform the optimal maintenance strategy.

AHMED El SHERIF

Asset Management & Reliability Consultant.

Asset Management & Reliability Department Head

AMOC Co.

Oil & Gas.

CMRP, CRL, CAMA, BMI

Case Study A:

Reciprocating Plunger Pump – Over-Maintenance without Reliability Gains.

Asset Description:

A high-pressure reciprocating plunger pump in refinery service. This type of pump is critical for process operations and was subjected to an intensive time-based maintenance (TBM) regime.

Plant maintenance records showed that a large majority of this pump's maintenance hours (on the order of 42% of total maintenance time) were spent on scheduled preventative tasks – routine overhauls, component replacements, and inspections at fixed intervals.

Problem:

Despite the heavy emphasis on TBM, the pump did not show a reduction in corrective maintenance needs. Unplanned breakdowns continued to occur at a steady rate, accounting for roughly 43% of maintenance activities and significant downtime. In fact, the data suggested that **downtime and O&M costs were increasing** in tandem with the heightened maintenance frequency. This paradox – *more preventive work but no fewer failures* – was a red flag indicating that the maintenance strategy was misaligned with the pump's failure characteristics.

Analysis:

A detailed failure analysis revealed that the plunger pump's dominant failure modes were not strongly age-related. Instead, many failures were **random or occurred shortly after maintenance interventions**. For example, the pump's plunger seals and valves were being replaced on a fixed schedule, yet some of these components still failed unexpectedly in between scheduled overhauls.

In other cases, the act of performing maintenance itself introduced infant mortality issues (e.g. installation errors or disturbances leading to early-life failures of new parts).

A reliability distribution analysis was performed on the pump's failure data, and the best-fit model was a **Weibull distribution with a shape factor β around or below 1**, indicating a decreasing or roughly constant failure rate over time.

Figure 1

No. of Failures	CM	TBM	CBM	MTBF (Months)	Months/PM
139	190	183	67	2.205882353	1.648351648
	43%	42%	15%		

Optimizing **Preventive Maintenance** in **Refineries**,

Case Study A

In reliability engineering terms, **if β = 1, the failure rate is constant (random failures), and if β < 1, the failure rate actually decreases with time**. This implies that the pump is more likely to fail when it is "new" (just after a maintenance intervention or installation of new components), and those that survive initial use tend to run reliably thereafter.

Essentially, the pump was exhibiting an **infant mortality or random failure pattern**, not a wear-out pattern. Under these conditions, performing overhauls too frequently provides little benefit and can even be harmful – each time the pump was opened up for preventive maintenance, it was returned to a "new" state that had a higher immediate risk of failure.

Industry best practices warn of this drawback: excessive scheduled maintenance can lead to **over-maintenance**, incurring unnecessary work and cost on components that may not need replacement, while also introducing new failure risks.

This case study confirms those warnings. As noted in the landmark RCM study by Nowlan and Heap, *the majority of failures are random* and **time-based overhauls will not prevent such failures – in fact, they may increase the failure rate immediately following the overhaul**. Case A's outcome underscores that **more TBM is not always better**.

The optimal strategy for this pump would be to scale back unnecessary scheduled tasks and focus on condition-based maintenance (CBM) or improved installation quality. By monitoring condition (for example, using vibration analysis, Ultrasound, or performance indicators) rather than overhauling on a rigid schedule, maintenance can be performed *"only when truly needed"* – addressing problems based on evidence of wear or degradation. This minimizes intrusive work and avoids injecting infant mortality failures, thereby reducing both downtime and maintenance costs.

Case Study B:

Vertical Multistage Centrifugal Pump – Under-Maintenance Leading to High Failures

Asset Description:

Case B examines a vertical immersed multistage centrifugal pump at the refinery. Unlike the previous case, this pump had a very **low percentage of time-based and predictive maintenance** applied.

Preventive tasks accounted for well under 25% of its maintenance activity; essentially, the pump was run to failure with only minimal routine checks. Little to no condition monitoring (vibration, temperature, etc.) was in place – what the case data refers to as low "CBM" (predictive maintenance) involvement.

Problem:

Because of the minimal proactive maintenance, the pump experienced a high frequency of breakdowns. The data showed that **corrective maintenance comprised the majority (≈60%) of its maintenance**. The pump's unplanned failures not only drove up repair costs but also caused extended downtime in the process unit whenever the pump failed unexpectedly.

In essence, this was the opposite scenario of Case A – here **too little preventive maintenance** was being performed. The expectation was that running to failure would maximize run time, but in reality it resulted in **frequent sudden failures and costly interruptions**, far outweighing the saved effort from deferring maintenance.

Figure 2

Analysis:

Reliability analysis of the centrifugal pump's failure history indicated a classic **wear-out pattern**. The Weibull distribution fitted to this pump's time-to-failure data showed a **shape factor β greater than 1**, meaning failure rate increases with time in service.

In practical terms,

components like bearings, bushings, and impellers in the pump were subject to cumulative wear and aging. As the pump operated over months and years, the probability of failure grew – especially once past a certain age (the **scale factor η** of the Weibull model gives the characteristic life by which ~63% of units would fail). With **β** > 1, **age was a real driver of failure**: this pump would predictably fail if left running long enough without overhaul. Such wear-out behavior is exactly when **time-based maintenance can be highly effective** – by scheduling an overhaul or critical part replacement at a fixed interval **before** the steep increase in failure probability, one can avert a large portion of unplanned outages.

No. of Failures	CM	TBM	CBM	MTBF(Months)	Months/PM
122	138	56	40	2.521008403	5.454545455
	59%	24%	17%		

Contrast between Case A & B

In Case B, the maintenance strategy was not keeping up with the asset's inherent life cycle. The result was analogous to **operating beyond the asset's reliable life**, leading to breakdowns. A better PMO approach for this pump is to introduce a **scheduled maintenance plan or enhanced condition monitoring**.

For example, based on failure data (and possibly OEM recommendations), the refinery could establish a **periodic overhaul interval** aligned with the pump's wear-out age – this is often guided by statistical analysis or standards and best practices for similar pumps.

Even implementing basic **predicted maintenance** tasks (like routine vibration analysis, Ultrasound or inspections at set intervals) could detect early signs of wear so maintenance can be performed proactively. Industry standards emphasize that **time-based (predetermined) maintenance is justified when there is a clear age-related failure pattern**.

In this case, applying such standards would mean recognizing the pump's limited useful life and intervening on schedule. Had a proper time-based preventive maintenance been in place, the high percentage of reactive maintenance in Case B could have been significantly reduced, improving overall uptime.

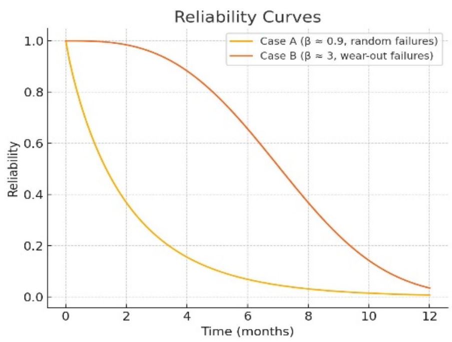
Reliability Modeling and Optimization of Maintenance Strategy

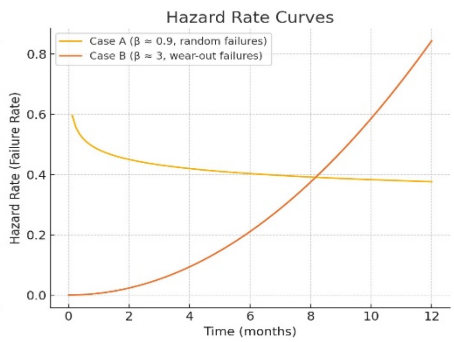
The contrast between Case A and Case B highlights a fundamental principle of reliability engineering: **maintenance strategies must match the failure distribution of the equipment**. A tool commonly used to model failure behavior is the **Weibull distribution**, which is characterized by two parameters – **shape (β)** and **scale (η)**. The shape parameter **β** is especially informative:

In implementing a PMO program, it is also important to consider the **consequences of failure and the cost of maintenance**. High-criticality assets (e.g. a compressor in a refinery) might warrant even proactive part replacements regardless of **β**, simply because any failure is intolerable. In contrast, low-criticality equipment might be run to failure even if $\beta > 1$, if the consequence is minor and repairs are cheap. Modern maintenance management aligns with **risk-based and condition-based strategies**:

many companies are **shifting from purely time-based schedules to condition-based maintenance to avoid unnecessary interventions**. This trend is supported by the advent of IIoT sensors and predictive analytics that can track equipment health in real time, enabling maintenance "**only when truly needed**". Still, time-based maintenance remains vital for equipment with known life limits or when condition monitoring is impractical.

The **optimal strategy is often a mix**: apply **time-based (scheduled) maintenance** for wear-out dominated items, and **condition/predictive maintenance** for random failure dominated items – all under a framework of continuous improvement. This aligns with the guidance of standards like **ISO 14224:2016**, which provides a framework for classifying maintenance types and stresses tailoring the strategy to the asset's failure characteristics.





CONCLUSION

The two case studies from the refinery's PMO program demonstrate that **preventive maintenance must be optimized, not maximized**. In Case A, a reciprocating plunger pump was essentially "over-maintained" with frequent time-based service, yielding no reduction in failures – a scenario attributable to the pump's random failure pattern and infant mortality issues. More PM in that case did not equate to higher reliability; instead, it added cost and downtime. In Case B, a vertical multistage pump suffered the opposite problem: under-maintenance in the face of an age-related failure pattern led to excessive corrective repairs. The lack of scheduled overhauls meant the pump was run into the wear-out phase, resulting in repeated breakdowns.

These examples reinforce a key reliability lesson: **the relationship between preventive maintenance and failure reduction is not one-size-fits-all**. It depends on the asset's failure distribution (e.g. the Weibull **β** factor) and the nature of its failure modes.

An effective PMO program uses data-driven analysis to find the "sweet spot" for each asset – identifying which equipment will benefit from regular overhauls and which are better served with condition monitoring or design improvements. Reputable frameworks and studies like **Reliability-Centered Maintenance (RCM)** provide criteria for this decision process, ensuring that each preventive task is justified by a real failure prevention benefit.

Additionally, standards and guidelines (ISO 14224, SAE JA1011 for RCM, etc.) encourage organizations to focus preventive efforts where they pay off, and avoid indiscriminate maintenance that doesn't reduce failures. By aligning maintenance strategies with the actual reliability characteristics of equipment, refineries and other industries can **increase uptime, reduce maintenance costs, and improve safety**.

The ultimate goal of PMO is to move from a "more maintenance is better" mindset to a **"smarter maintenance is better"** approach – where every maintenance dollar and hour is spent in the most effective way possible to ensure reliability.

Through cases like these, it becomes clear that understanding an asset's failure behavior is the cornerstone of optimizing preventive maintenance and achieving world-class reliability performance in any plant.