The Canary's Plan for Just-in-Time Replacement

David Albrice, May 24, 2015

"I try not to get involved in the business of prediction. It's a quick way to look like an idiot" - Warren Ellis.

Ever heard of the legend of miners bringing caged canaries into the coal mines?

Since canaries are highly sensitive to certain types of gases, they were ideal for detecting dangerous gas build-ups that were otherwise invisible. As long as the birds kept singing, the miners knew their air supply was safe.

And have you heard about the use of a bellwether?

Shepherds would place a bell around the neck of a ram while the flock of sheep were out of sight in the rolling hills of the misty English countryside. This would allow the shepherds to identify their flock through the fog.

What do these two simple, yet resourceful techniques have to do with asset management?

The **singing canary** and the **ringing bell** serve as simple metaphors for a variety of techniques that have been developed by different professions to assist in managing the uncertainties and

risks associated with future events. But these techniques are not the same…. there is a very important distinction between the canary and the bell:

- The miner's canary that **stops singing** serves to warn of immediate danger. It therefore represents the sudden and dramatic end of a course of events.
- The shepherd's bellwether that **starts ringing** provides a leading indicator of something coming up ahead that we cannot see from our current position. It therefore represents the start of a course of events.

Asset management requires both bells and canaries for managing risk.

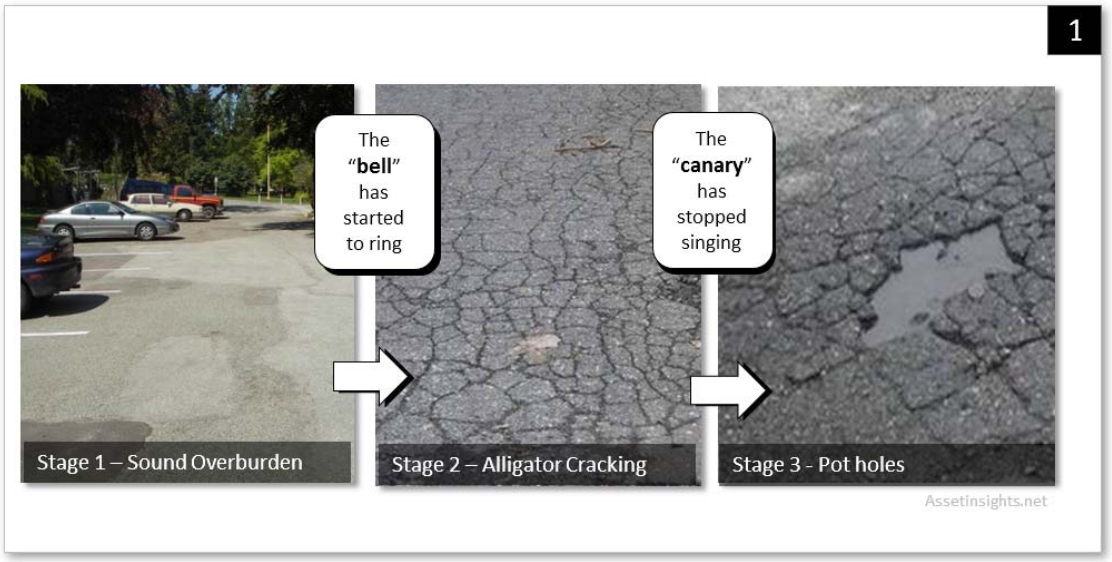
1. The Bells & Canaries for Asset Managers

When the replacement of an asset becomes necessary it is often a shock to the owners and managers as it represents a big ticket expenditures that suddenly needs to be funded from somewhere, disrupts the annual cash flow cycle and impacts on the regular operations on the property (or in the plant). In the case of buildings (*vertical assets*) it may be a leaking roof or an inoperable boiler; in the case of infrastructure (*linear assets*) it may be a burst underground water main; and in the case of equipment and fleet (*portable assets*) it may be a blown transmission.

People then ask: *Why did we not know this was going to happen? Could we have anticipated this problem and prepared ourselves?* **Angry meetings are called** and lots of finger pointing goes on.

But asset managers do have a choice… they can decide whether to spend more on the mindful anticipation and averting of failures or, instead, on recovering from the consequences of failure and face the music at angry meetings.

So what does the choice to avert failures look like in the real world? Asphalt paving provides a great example.



When asphalt paving is first installed it is in good condition. After a few years of exposure and use, minor cracks form. Eventually, potholes and subsidence will occur. The ***bell started to ring*** when the first cracks in the roadway appeared and the ***canary stopped singing*** when the potholes appeared.

In the domain of asset management, this means that we should be listening closely for ringing bells and watching for silent canaries. Those bells signal changing maintenance requirements whereas the poor lifeless canaries mean that replacement is necessary.

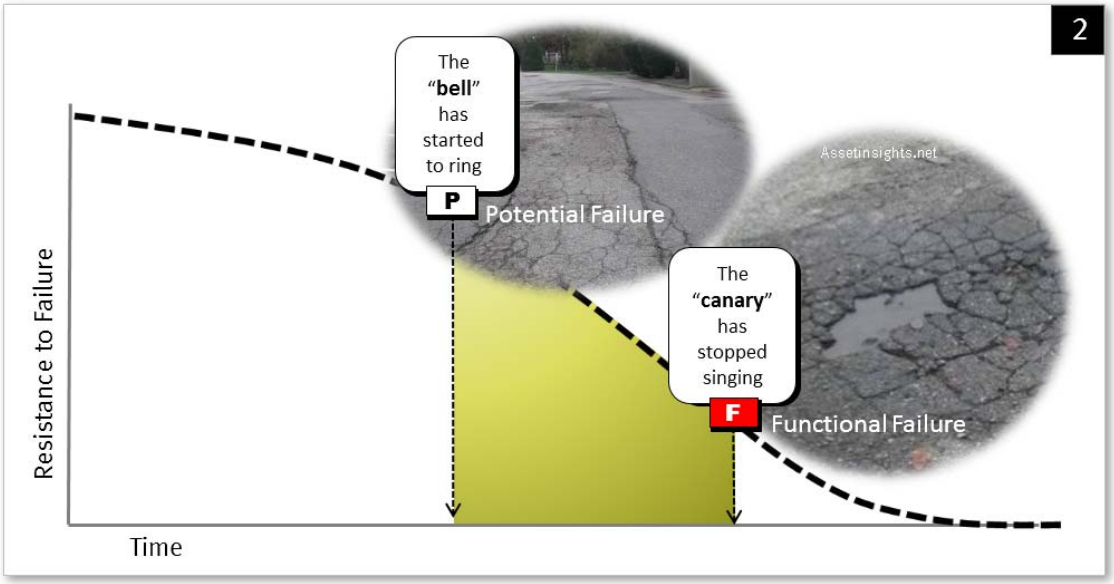
These are two significant thresholds along the life of an asset and the interval between these points are of tremendous value to effective asset management.

2. From Canaries & Bells to the P-F Curve

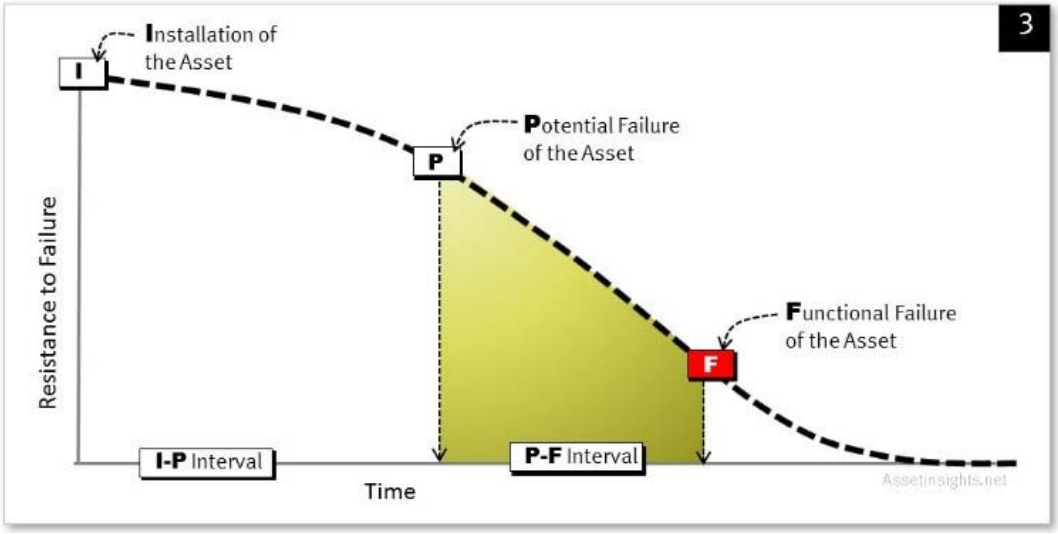
The P-F Curve was developed by Moubray (1997) and has been extensively referenced in the reliability engineering and facility management literature.

- **"P"** refers to "potential failure" -- the bells start ringing
- **"F"** refers to "functional failure" -- the canary stops singing

Returning to the example of asphalt paving, the figure below presents the relationships between potential failure and functional failure.



The PF interval is the failure development period from potential failure ('P') to functional failure ('F') where the asset manager has the opportunity to take action to monitor performance through techniques such as failure-modes-and-effects-analysis (FMEA), root cause analysis (RCA), and thereby anticipate and avert the **consequences of failure**.



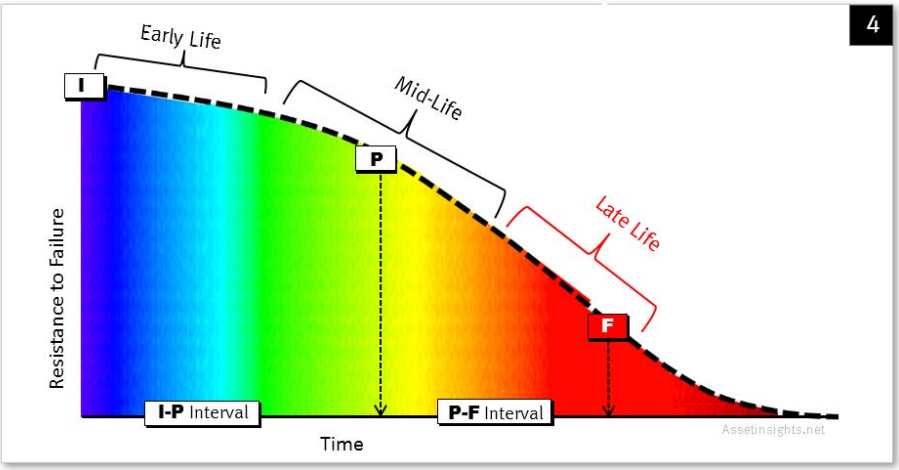
- ***Potential Failure*** - The point in the deterioration process when it is first possible to detect whether a "failure" is occurring, or is about to occur. This will depend on the quality of the diagnostic technologies, such as infrared thermography or the testing protocols such as pull adhesion test. Potential failures do not signal that an asset must be replaced. Rather, they are leading indicators of the months, years or decades before the end of life of the asset.
- ***Functional Failure*** – The point in the deterioration process when the density of deficiencies (and/or significance of deficiencies) has exceeded an acceptable level,

where acceptable is defined by the owners and/or industry standards. The asset is essentially beyond economic repair.

The P-F curve has tremendous value as a forecasting tool and can be used for risk management, maintenance management and renewal planning for assets.

3. Risk Management Along the P-F Curve

With an understanding of the gradual deterioration of an asset and the two major risk thresholds of P and F, the following graph provides a risk profile. The types of risk and their severity are different during the I-P and P-F intervals.



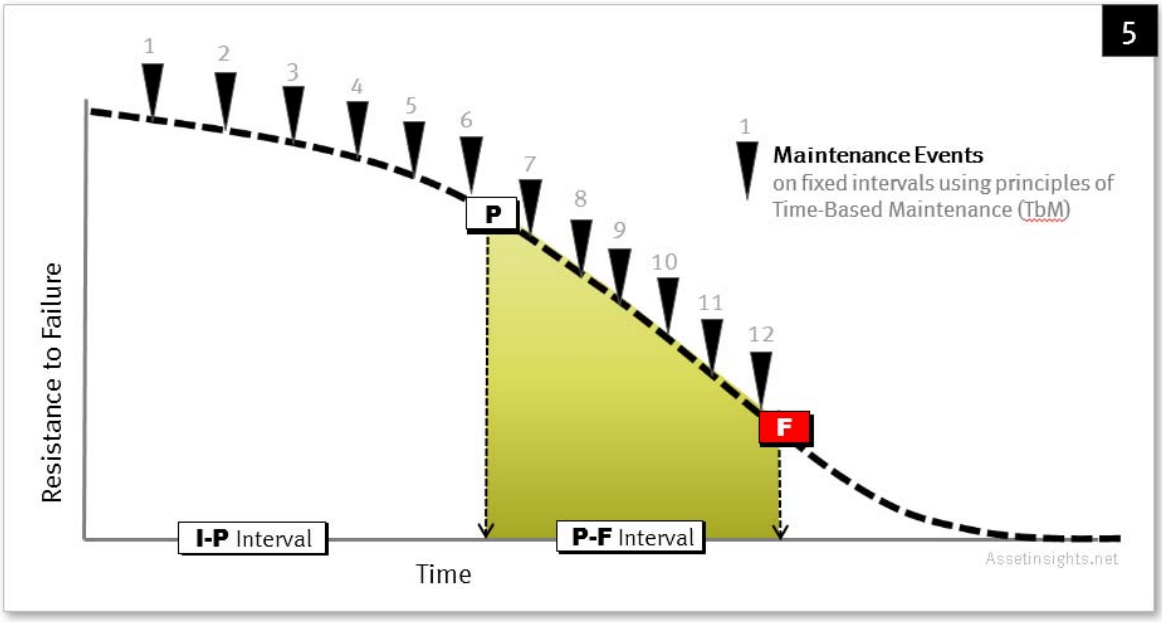
With an understanding of the varying risks at different stages in the life of an asset, the asset manager can start to make preparations for appropriate maintenance strategies to mitigate that risk by averting failures.

4. Maintenance Management Along the P-F Curve

Maintenance can be classified in a variety of different ways. When considering the P-F curve, however, one of the most relevant methods is to consider that all maintenance activities can fall into one of two main classes:

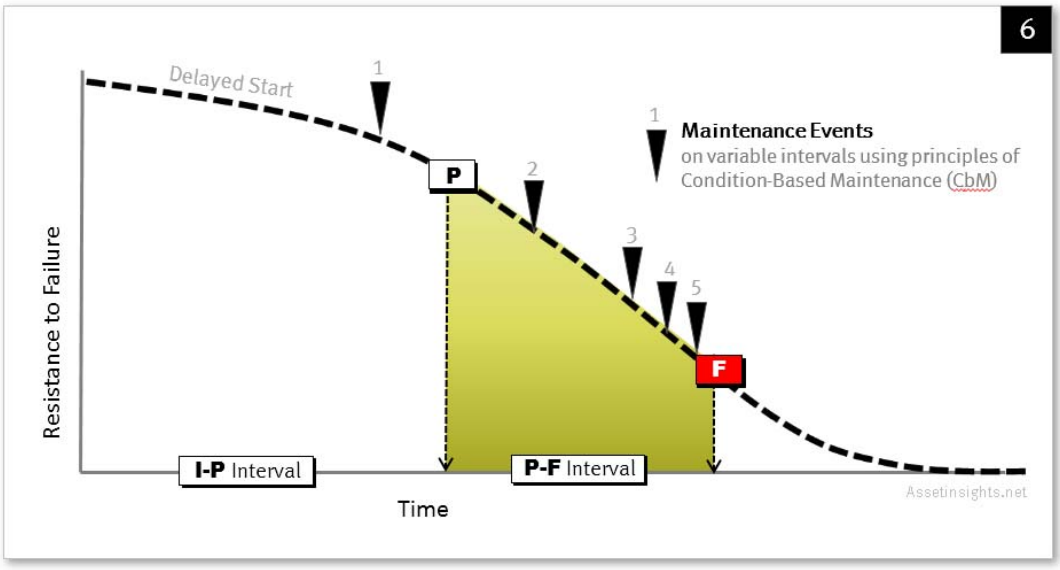
- ***Time-based Maintenance (TbM)*** - This carries out work on fixed intervals of time, consistently over the service life of an asset regardless of its age, For example: perform task "x" every two years.
- ***Condition-based Maintenance (CbM)*** - This is dependent, in part, on the emergence of distress-metrics that are empirically measurable at different life stages. CbM contemplates age and exposure conditions, is variable in its intervals and conditional in its implementation. For example: perform task "x" if condition "y" arises.

The first figure (#5) below illustrates fixed interval maintenance along the P-F curve where maintenance intervals do not change at any time over the life of the asset.



Regardless of the age of the asset, maintenance occurs at the same frequency in both the I-P Interval and the P-F interval. This type of maintenance is appropriate for certain kinds of assets, such as fire safety and life safety equipment which must be maintained in accordance to strict prescriptive requirements.

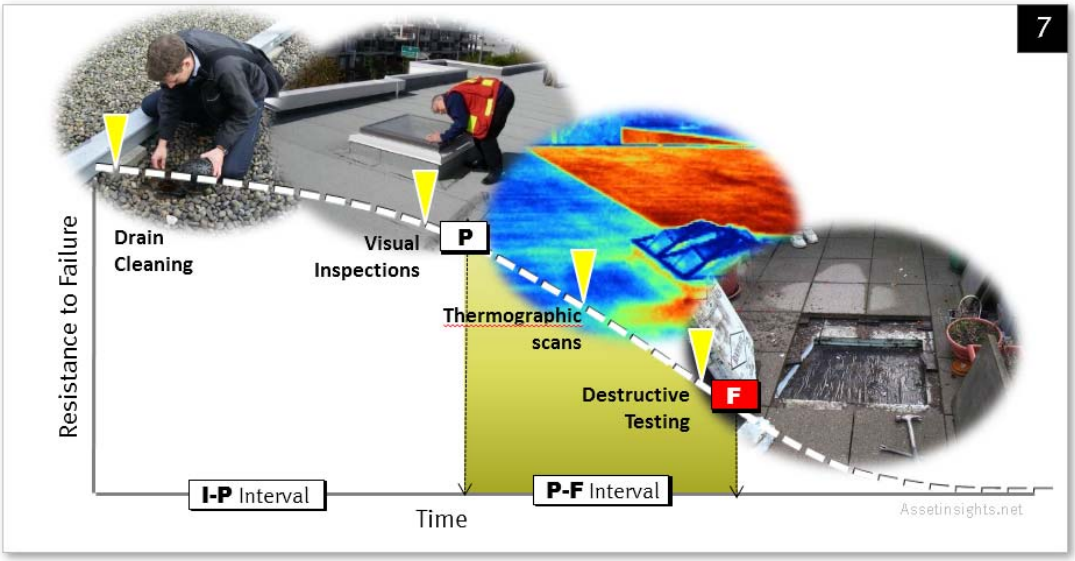
The next figure (#6) illustrates condition-based maintenance (CbM) along the P-F Curve. Note that the black arrows are not equally spaced and their frequency increases as the asset approaches functional failure. In other words, maintenance occurs more frequently in the P-F interval than in the I-P interval.



CbM is more appropriate for assets that do not have predictable wear out patterns and they are stochastic in nature.

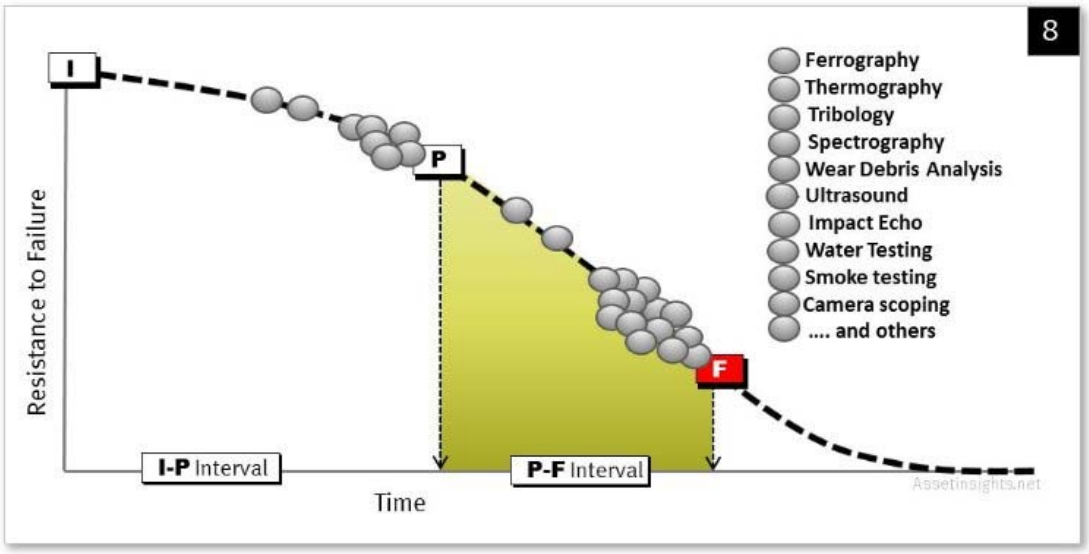
A good maintenance program will contain an appropriate mix of TbM and CbM activities for different assets. The maintenance mix is the term used to describe the aggregate of the different types of TbM and CbM applied to all the assets of a building or infrastructure network.

The next figure (#7) provides a visual illustration of different types of maintenance events occurring along the P-F curve. Generally, the more sophisticated condition-based maintenance (CbM) activities occur in the P-F interval than during the earlier I-P interval.



The ratio of TbM to CbM should be aligned to individual assets and also adjusted at different stages over their respective service lives.

The final graph (#8) provides a list of some of the more common predictive maintenance (PdM) techniques are used to identify potential failure ("P") and functional failure ("F").



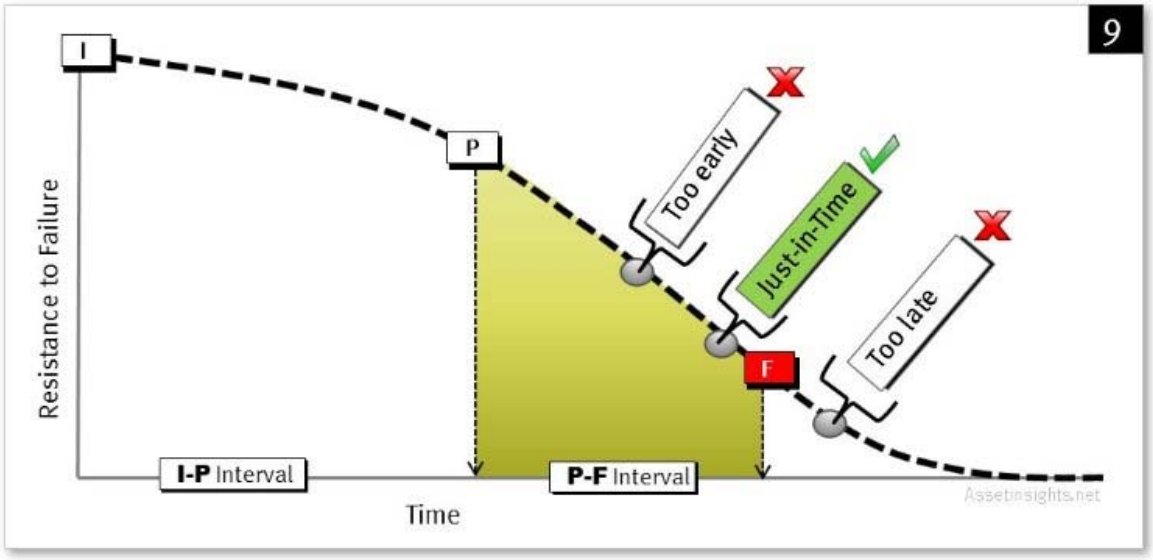
These technologies are all intended to help the asset manager hear the ringing bells as early as possible. For example, thermographic scans on panelboards, pumps and roofs will reveal concealed conditions that are not evident to the naked eye. An earlier article provided more details on detecting things that are hiding from view.

Eventually, the maintenance program for each asset reaches a point of diminishing returns and it no longer makes economic sense to continue to maintain an asset. Once the asset is beyond economic repair, the asset manager must plan for its replacement.

5. Renewals Management Along the P-F Curve

There are difficult problems of uncertainty surrounding the final stages in the life of assets and the PF Curve offers some useful principles to help the asset manager as an asset passes through certain critical life thresholds.

The first graph in this series (#9) indicates whether a renewal project may be considered to occur too early (premature), just-in-time (optimal) or too late (dangerous). The asset manager's goals is to find that “sweet spot” and replace assets just-in-time before they reach functional failure so that the maximum life is extracted from the asset.

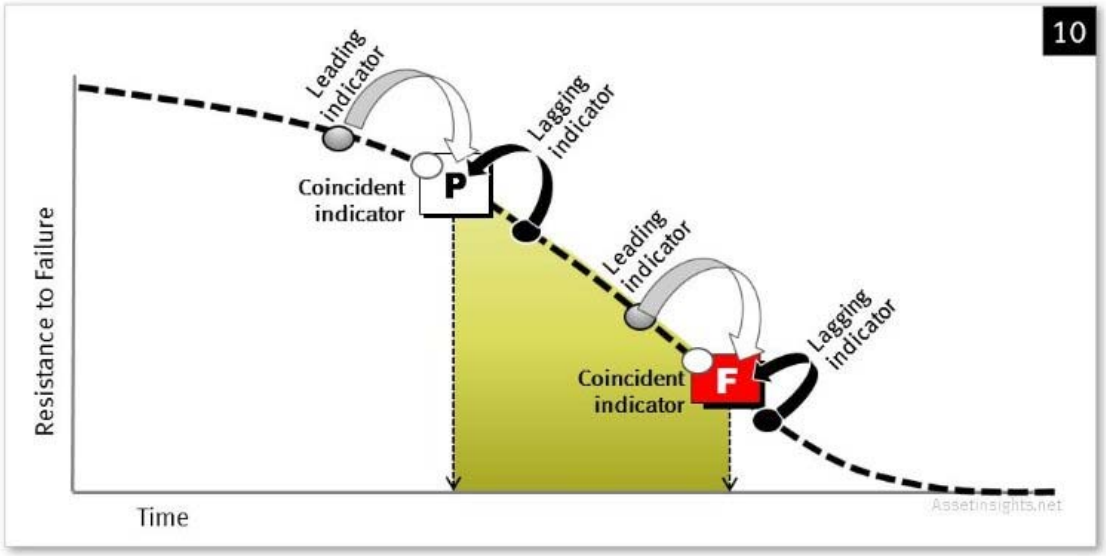


The Just-in-Time asset replacement strategy is both an art and a science. A renewal project that occurs too early in the PF interval does not have adequate proximity to functional failure. The asset manager has failed to extract the full useful life from the asset. The only legitimate cases where this may occur are the early replacement of an asset to meet some form of obsolescence - typically economic obsolescence (such as energy efficiency measures) or legal obsolescence (new codes or product recall). A deeper discussion on there early renewal cycles are address in the article on whether assets are fading or degrading.

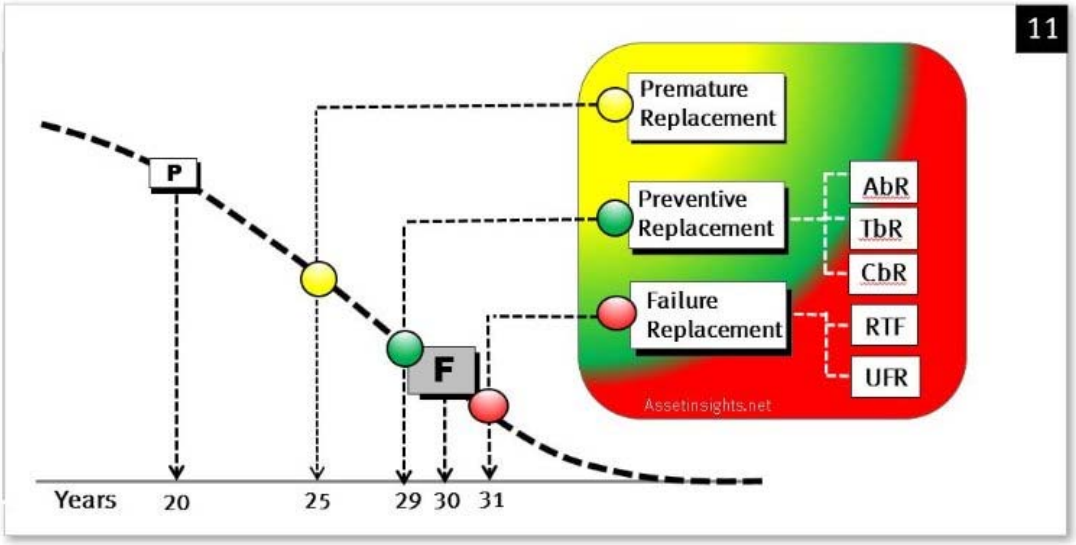
In order to find the optimal renewal interval, the asset manager needs to be familiar with three types of indicators of distress associated with potential failure and functional failure.

- A ***leading indicator*** is a telltale sign of an emerging future condition. It manifests before the failure has occurred and is equivalent to a ringing bell.
- A ***lagging indicator*** arises after the failure condition has arrived as it emerges as a downstream consequence. It manifests after the failure and is equivalent to a dead canary (rather than a silent canary).
- A ***coincident indicator*** occurs at approximately the same time as the conditions it signifies and is equivalent to the simultaneous ringing of the bell and dead canary.

The following graph (#10) provides a conceptual illustration of these three classes of indicators relative to potential failure ("P") and functional failure ("F")



The final figure (#11) illustrates the different types of asset replacement strategies in relation to functional failure.



An earlier article introduced 5-different types of replacement strategies under the [Grasshopper's Lesson on Asset Management].

- **AbR** = Age-based Replacement
- **TbR** = Time-based Replacement
- **CbR** = Condition-based Replacement
- **RTF** = Run to Failure
- **UFR** = Unintended Failure Replacement

Just as the maintenance mix provides the ratio of assets that are preserved using a combination of time-based and condition-based maintenance, so to does the renewals mix provide a variety

of strategies for replacement of each asset. For example, some assets may best candidates for age-based replacement whereas others should be subject to a policy of condition-based replacement.

Closing questions: ***Do so many canaries need to die every day in plants and buildings around the world. Can we find ways to get them out of the way of harm so that they don't need to stop singing?***

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David Albrice is a Senior Asset Management Specialist at RDH Building Engineering Ltd. His experience with the P-F curve comes from his work on facility condition assessments and life cycle audits. David can be followed on Twitter and additional asset management articles can be read on LinkedIn.