Predictive and Preventive Maintenance

Course No: B02-008
Credit: 2 PDH

Daniel T. Daley, P.E. Emeritus

CED CANADA
engineering.ca
CPD FOR THE PROFESSIONAL

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.ca

Predictive and Preventive Maintenance

By

Daniel T. Daley

Introduction

Most people are familiar with some forms of predictive and preventive maintenance. Every time a person takes his car in to have the oil changed or the tires rotated, he is performing preventive maintenance. Whenever that person has the engine tuned based on a specific mileage rather than as a result of an operating problem, he is performing preventive maintenance. Every time a person uses the top of a penny to see if the tread depth passes the top of Lincoln's head, he is performing predictive maintenance.

In each of these cases, the person has chosen to behave in a proactive manner to avoid the cost and inconvenience associated with waiting for something to fail. When one waits for their actions to be stimulated by a failure, they have chosen to behave in a reactive manner. The adverse affects of that choice have been clearly exemplified by the thinly veiled threats contained in Mr. Goodwrench ads saying: "You can pay me now or you can pay me later." Implicit in that comment is the threat that the reactive maintenance performed later will be far more distasteful and costly.

While the comparisons between a specific proactive task and the reactive task (that will result if the proactive task is ignored) are a useful way to create an understanding of predictive and preventive maintenance, the issue is much larger. Most forward thinking enterprises have stated objectives to move from being reactive to being proactive. There is an implicit understanding that proactive behavior will yield results that are superior to those obtained from reactive behavior. As a result, they create programs and introduce initiatives that will assist the reactive-to-proactive transformation.

Maintenance is one area for which the reactive-to-proactive transformation is viewed as being quite commonplace. It is viewed as quite possible if not relatively simple to replace reactive tasks with proactive tasks. It is widely understood that predictive and preventive tasks will head off repair tasks. Based on that commonly held understanding, there is a belief that the transition from reactivity to proactivity can be easily accomplished.

While there are some examples where that is true, a word of warning is necessary. Many predictive and preventive tasks to not have the same close cause-and-effect relationship as does the oil change versus engine change example. When forms of predictive and preventive maintenance lacking that kind of close relationship are implemented, the price of maintenance goes up and the associated failures and reactive maintenance costs do not go down. It is important to identify predictive maintenance that is truly predictive and preventive maintenance that is truly preventive.

Background

While the choices concerning predictive and preventive maintenance typically seem to be discrete or occasional events, the choice to be proactive on the part of a capital intensive industry is an on-going or continuous affair. The balance between being proactive or being reactive is something that occurs on a day-in and day-out basis. Said another way, to be truly proactive all employees within a company or, at least, a single location must support the choice to behave in a proactive manner.

Before getting into describing both predictive and preventive maintenance in greater detail, we will discuss some of the background behind this subject.

As introduced above, maintenance can be done in one of two ways: it can be done in a proactive manner or it can be done in a reactive manner. Proactive maintenance is maintenance that is done without being caused by some form of failure. Proactive maintenance provides some form of prevention that identifies deterioration (so it can be acted upon) or eliminates deterioration so failures caused by that deterioration can be avoided. Proactive maintenance can take one of two forms: predictive maintenance or preventive maintenance.

- Predictive Maintenance is typically a non-invasive task intended to identify a specific condition of an asset. At the conclusion of a predictive task, the asset remains “good as old”. While the owner of the asset knows more about the condition of the asset, the condition of the asset has not been altered.
- Preventive maintenance is typically an invasive task intended to renew the asset and eliminate deterioration. When a preventive maintenance task is complete, the asset is “good as new”. Te deterioration has been eliminated and the asset has been restored to a “like-new” inherent reliability.

A shortened way of saying predictive and preventive maintenance is PM/PdM. PM stands for Preventive Maintenance. PdM stands for Predictive Maintenance.

On the other hand, reactive maintenance is a form of maintenance that has been precipitated by a failure. Reactive Maintenance has the following negative consequences:

- The asset utilization is typically impaired for a much longer time as a result of reactive maintenance.

- The cost of reactive maintenance is much greater than a form or proactive maintenance that will provide an equivalent period of asset utilization.
- The event that stimulates reactive maintenance is outside the direct control of any person. As a result, rather than being confined to a limited impact, the failure can precipitate much further ranging events. Rather than simply a failed mechanical pump seal, the event can turn into a refinery fire with untold consequences.

Obviously, there is an incentive to convert from reactive maintenance to proactive maintenance.

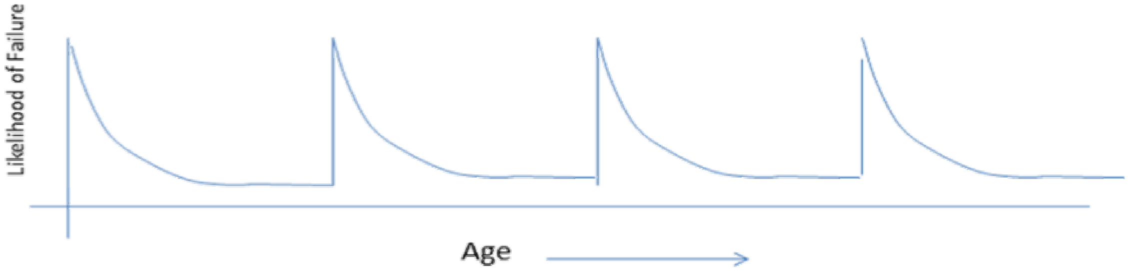
The objective of any form of maintenance is to “buy” the reliable utilization of an asset for some period of time. In achieving that objective, there are several goals:

1. The first goal is to ensure the reliability of the asset is as high as possible for the entire period of utilization.
2. The second goal is to pay as little as possible for each period of utilization.

When considering the reliability goal described above, achieving the utilization using proactive maintenance as the mechanism of choice is likely to lead to higher reliability. Several reasons make that statement true.

- The reliability of an asset being maintained using some form of proactive maintenance has already been established through its on-going operation. Proactive maintenance tasks have a controlled and limited impact so there is little likely that elements affecting the asset reliability will be adversely affected.
- Reactive maintenance typically involves some invasive step that includes the exchange or renewal of one or more components.
    - Any invasive activity has some likelihood of leaving failure causing defects behind.
    - All new components have some likelihood of infant mortality or early failure. When integrated over the entire life of an asset, this infant mortality can introduce a substantial likelihood of one or more additional failure events.

Lifetime Likelihood of Failure using Proactive Maintenance



Lifetime Likelihood of Failure using Reactive Maintenance

As a result, a proactive system of maintenance ultimately produces a higher level of reliability.

The second important issue is cost. People who choose to regularly change the oil in their automotive engines understand the economic differences between changing oil and changing engines. While this example clearly portrays the dramatic economic differences between a relatively simple preventive task and a fairly complex and costly reactive task, many choices do not present this same level of contrast or simplicity.

Suppose that the total cost of the proactive over the life of an asset is equally costly as the avoided reactive repair. Or what if the proactive task is only partially effective? Or what if the planned life of the asset is relatively short and the full value of a comprehensive program of PM/PdM may not be recouped?

Obviously, the choice between proactive maintenance and reactive maintenance is not always as clear as it is in the oil change / engine change case. On the other hand, the choice to be proactive and behave in a proactive manner all the time is something employees of a large enterprise can understand and embrace. They can also understand the choice to be highly reactive and accept asset failures. What employees have difficulty understanding is the choice to be proactive some of the time and to be reactive at others. In that situation, the choices appear somewhat subjective and the result of convenience or politics.

The point to keep in mind is that assuming a proactive stance on maintenance is likely to be most cost effective the vast majority of situations. As a result, it is best to adopt "prevention" as a guiding principal. If it is possible to identify effective and efficient predictive or preventive tasks, it should be assumed they will be adopted and applied.

For a predictive or preventive task to be effective, it is important to understand the Failure Mode or Failure Modes that produce failures and the Failure Mechanisms that produce the deterioration resulting in the Failure Mode. Lacking that knowledge, it is possible to create predictive and preventive tasks, but there is no guarantee that the identified tasks will have any net positive outcome.

Predictive maintenance activities typically measure the amount of deterioration that has occurred. Frequently the deterioration is inferred by some other measurable characteristic. For instance, assume that the failure mechanism is corrosion and the ultimate Failure Mode will be a deteriorated impeller in a pump, the amount of deterioration might be measured by the amount of vibration the pump is experiencing or the reduction in discharge pressure. While neither are direct measures of deterioration, both infer that deterioration has occurred. The loss of discharge pressure is probably a better measure because it more directly points to the deteriorated impeller and there are other problems that can cause increased vibration.

In either case, it is important to understand that "impeller – damage by corrosion" is a typical, if not dominant, failure mode. Once that fact is understood, it is then possible to identify a suitable predictive task that will help understand the rate of deterioration and the current condition.

Preventive activities typically repair or replace a deteriorated component with one that fulfills the characteristics of a new component. In the case of the impeller described above, a deteriorated impeller might have a reduced diameter or have lost metal in certain critical locations. To restore both the pumping capabilities of the system and the reliability and usable life, it is necessary to either build-up the areas of metal loss on the old impeller to like new conditions or to replace the impeller with a new one.

Clearly, one does not want to replace the impeller before the time all its value has been consumed. On the other hand, one does not want to ignore an opportunity to change the impeller that has no associated loss in profitability without seizing that opportunity. The value of the lost usable life for the impeller is typically far exceeded by the cost of lost production if the pump maintenance requires an outage or reduction in production.

Definition – Predictive Maintenance

It is helpful to have a clear definition of predictive maintenance in mind when developing a comprehensive proactive maintenance program. As suggested earlier, predictive maintenance is some form of activity aimed at identifying the presence of deterioration or defining the extent of deterioration that already exists. At the end of a predictive task, the person performing the predictive task knows more about the asset, but the condition of the asset has not been changed. Well defined predictive maintenance will provide a clear indication if further action is currently needed.

Predictive maintenance can take a number of forms. For any of the forms to be effective, they must focus on a form of deterioration that actually exists in the asset being maintained. For instance:

- If some form of PdM that is sensitive to corrosion is being applied and the asset is not subject to corrosion, the PdM has no value.
- Conversely, if some component within the asset is being subjected to erosion and there is no PdM focusing on identifying the presence or extent of erosion, the likelihood of a failure will not be reduced.

While the point being made above may seem obvious, it is common for PdM programs to include lots of activities that were recommended by the OEM and are effective in other applications but have no value in the current service. The unfortunate aspect of providing ineffective PdM while ignoring the forms of deterioration that actually exist is that asset owners feel secure when there is no reason for their security.

Another important characteristic of predictive maintenance is that it is typically non-invasive or non-intrusive. That means it is unnecessary to disassemble the affected asset to perform PdM. This has the benefit of avoiding the possibility of introducing new defects as a result of the predictive maintenance activity. The example of using a penny to measure tire tread depth is a good example of non-invasive PdM. There is no chance of leaving a defect as a result of performing the test and the owner has a good idea of tire condition (as it relates to tread depth) at the conclusion of the test.

In this case the device being used to perform the PdM is inexpensive and readily available. The test procedure is easy to understand and it is easy to interpret the results of the test.

In addition, the simple tread-depth test has the side benefit of getting the person performing the test in close proximity with the tires being tested. In this case, there is some possibility that the person performing the test will notice: 1) If there has been damage to the side-wall of the tire, 2). If the tire pressure is low, and 3) If, at least, some portion of the tire has picked up a nail penetration. Many smart forms of PdM have similar side-benefits, if individuals performing the PdM are alert and know what to look for.

In order for PdM to be effective it is important for asset owners to understand:

- The Failure Modes that result in the failure of components
- The Failure Mechanisms that result in the deterioration leading to the Failure Mode

If the asset (or similar assets) has been in existence for quite some time and if the owners have maintained good records of failures, it is possible that they know both the Failure Modes and the Failure Mechanisms present in the environment where the asset exists. On the other hand, if the asset is new or new to the operating environment where it is being used, it may be possible to identify only the Failure Mechanisms that are likely to affect the asset.

For instance, if an asset is installed somewhere in a dry desert, it is less likely the asset will experience forms of corrosion associated with the presence of atmospheric moisture. On the other hand, if the same asset is applied in a location close to the Gulf Coast of the United States, it is likely to be exposed to that form of corrosion resulting from atmospheric moisture. In the first case, PdM that monitors for moisture based corrosion (uniform corrosion) is a waste of resources. In the second, that form of PdM would result in resources well spent.

Definition – Preventive Maintenance

As is the case with predictive maintenance, there is value in clearly understanding preventive maintenance when developing an effective maintenance program. Unlike predictive maintenance, preventive maintenance:

- Is typically invasive
- Does change the condition of the asset leaving it “good as new” when completed in a proper manner
- Can introduce new defects when improperly done

Very much the same as predictive maintenance, for preventive maintenance to be effective, it is important to know the Failure Mode and Failure Mechanism being addressed by the PM. In most (but not all) instances when PM is performed, the deterioration should be apparent in the component being repaired or replaced. A corroded component should show signs of rust or other oxidation. An overloaded component might show signs of distortion or overheating. (Components exposed to fatigue should be changed before signs of impending failure are evident. A component exposed to fatigue that will experience several billion cycles before failure, should be changed with sufficient life remaining to clearly avoid failure. If one waits for fatigue cracks to become evident, it will likely be too late to intervene before failure.)

One advantage associated with preventive maintenance is that deterioration and even the formation of the defect is not simultaneous with the precise time of the failure. For instance, a pipeline may corrode for a long time before a leak-causing defect appears. It is also possible that a defect (thinning below the minimum wall thickness) can form in a piping system, but the operating pressure is not currently at the maximum operating pressure. In that case, a defect that would allow a burst or leak at maximum conditions may not allow a leak at current conditions. This all leads to additional time and opportunities to find and address the issue before a failure occurs.

In performing preventive maintenance, typically one of the components is replaced. Components have two characteristics that are important when creating and performing preventive maintenance.

- The cost of the component
- The characteristic life of the asset

While the objective of any form of preventive maintenance is to intervene before a failure occurs, it is also important to “harvest” all the usable life from each and every component. While the cost of the component remains constant, the life that has been harvested can vary. It is best to delay preventive maintenance as long as possible. The timing of the PM should optimize the balance between harvesting the maximum usable life while still avoiding failures or incurring too much risk.

As a result, various forms of predictive maintenance and preventive maintenance activities tend to go hand in hand. It is frequently best to precede a preventive task with a predictive task to determine if end-of-life conditions are, indeed, soon approaching or there is time to wait. As described above, it is important to understand the Failure Mode that will result in the end-of-life for each component, and it is important to understand the Failure Mechanism that is causing the deterioration leading to the end-of-life.

Identifying Appropriate PM/PdM

Effective Predictive Maintenance has several important characteristics:

- It is directly related to the Failure Mode and Failure Mechanism of the component in question and the operating environment.
- It measures some apparent characteristic that is directly related to the specific form of deterioration.

- It is cost effective and relatively easy to perform.
- The results can be accurately interpreted without multiple or wide differences in opinion.
- Effective PdM provides a clear signal of what steps should follow.

Effective Preventive Maintenance also has several characteristics:

- Preventive Maintenance tasks should pass the tests for maintainability.
    - PM tasks should restore the inherent reliability of the asset being maintained.
    - PM tasks should be accomplished in a ratable period of time.
- Preventive Maintenance tasks should be cost effective.
- Effective PM tasks should balance the objective of harvesting all the usable life of each component with increasing risk of failure and other economic considerations (like early opportunities).

Experience shows that all too frequently, rather than the characteristics described above, predictive and preventive maintenance has one or more of the following characteristics:

- The maintenance being applied was selected from a number of activities that were recommended by the manufacturer for all such systems in any and all applications. In this case, the maintenance may or may not be applicable. The example provided above that described the difference in corrosion between arid deserts and humid Gulf Coast regions provides a useful comparison. Typically vendor recommendations ignore the differences resulting from where their product is sold and prescribe the same PM/PdM maintenance program for all applications.
- The maintenance being applied is a task or technique that the owner understands. This is in contrast to a procedure that may require some learning but is directly applicable to the specific application and form of deterioration.
- The maintenance being applied makes the owner “feel better” by doing something rather than nothing. Occasionally, some form of deterioration is known or suspected but the owner has no direct knowledge of how best to deal with it. In these situations, it is not uncommon to find a form of proactive maintenance being used that does not apply. The only rationale that can be identified is that the task “makes the owner feel better” because he is doing something rather than idling by while the asset deteriorates.

While the characteristics described above provide the student with some useful things to consider when selecting the predictive and preventive tasks to address a specific Failure Mechanism and Failure Mode, they provide little assistance in identifying specific tasks. There is an increasingly broad array of predictive maintenance tools that are available in the marketplace. Occasionally the individuals representing those tools in the marketplace like to portray their products as being more capable than they really are. Unfortunately, many of the tools can be made to detect defects during a sales pitch but cannot perform nearly as well in the actual workplace.

For example, ultrasonic listening devices are able to detect astounding noise levels in a controlled environment. Many are actually very useful for a wide variety of applications when in the hands of trained technicians. On the other hand, when the tool is placed in the hands of an untrained individual in an uncontrolled environment, the results are far less reliable or repeatable. In this case, it is best to “pilot” the use of the chosen tool in the actual workplace by the actual individuals who will use it on a day-to-day basis to ensure that the results are as-expected.

Typically, identifying effective predictive tasks are more challenging than preventive tasks because so many of them are dependent on special tools and special skills. But there are cases when the effectiveness of preventive maintenance is equally challenging. For example, if a preventive task that is commonly done in a shop must be done in an outdoor setting, the results may not be the same. For instance if a repair process entails soldering, the results of the repair may not be as robust when conducted in outdoor locations where wind, rain or other source of instability exists.

As with predictive maintenance, it is typically best to “pilot” each preventive activity in the specific working environment where it will be conducted using the skills of those who will actually perform the work on a day-to-day basis. If the real-life application is too much different from the application when being done under controlled conditions, the results may be inadequate.

Timing PM/PdM

There is a saying that “A dollar today is not a dollar tomorrow”. This is a reminder that there is an on-going relationship between time and money. This is particularly true when it comes to predictive and preventive maintenance. The following describes some of the time and cost related elements that must be considered:

- When preventive maintenance is scheduled to occur too early, some portion of the usable life of a component will be wasted.
- When predictive maintenance is scheduled to be conducted on a continuous basis, some amount of work will be done when there is little or no risk of failure, and therefore little value.

It is important to understand that all the information needed to evaluate timing issues may not be available from the very start of a predictive or preventive maintenance program. While you may know that a component is subject to the deterioration resulting from a specific Failure Mechanism, you may not know specifically when the deterioration starts or when it reaches a point of impending failure.

Ultimately, it might be necessary to use the results that are collected during early predictive or preventive maintenance activities to adjust the timing of future PM/PdM. For instance, if an anti-friction bearing is changed at a specific time based on the manufacturers B-10 rating, it is possible to inspect the removed bearing and make the following recommendations for the future:

- Roll the inner race against the outer race of the bearing to determine if the bearing is running roughly or smoothly. Also determine if the two races have loosened relative to each other. First assume the bearing shows no deterioration whatsoever. In this case, gradually increase the interval between PM tasks to harvest a larger portion of the usable life.
- Now assume that the bearing has been found to show some amount of deterioration but no other element in the equipment item has been damaged. In this case, the PM has been scheduled at the correct interval so it should be left as is.
- Finally, assume that the bearing shows marked deterioration and the bearing failure has caused damage to some other components (like the shaft). In this case, the PM interval should be shortened to the point when only the bearing has failed.

While this example is useful in understanding why one may choose to adjust PM intervals, it has some limitations. Obviously an astute engineer would probably introduce some form of predictive maintenance ahead of the preventive maintenance. If either vibration analysis or ultrasonic analysis were applied, it would be possible to identify bearing deterioration when it first occurs. Then the preventive maintenance could be scheduled in an optimum manner; harvesting all the usable life from the bearing while avoiding collateral damage to other components.

Forms of Prediction

The introduction of sophisticated electronics and microprocessor based devices has led to an ever increasing number of predictive tools. The same capabilities that used to require carrying a suitcase sized vibration analysis tool to an ailing piece or equipment can now be packed into a pen sized device that one can carry in his shirt pocket.

With the difficulty of carrying the suitcase sized device back and forth came the commitment to analyze and apply the information coming from the measurement. Unfortunately, when the effort to gather the data became less, so did the discipline in using and applying the resultant information. It is important to:

- Clearly understand the anticipated forms of deterioration.
- Select a tool that can accurately assess the current stage of the deterioration.
- Create the discipline to analyze the information being produced.
- Create the discipline to act when unacceptable level of deterioration or incipient failure is detected.

While there are a wide variety of forms of prediction, not all forms of prediction can be successfully applied in the manner described above. With some forms of prediction, either the trustworthiness of the results or the lack of clarity of the results may lead to little or no response.

In manufacturing there is a device called a “go/no-go” gauge. It is used to measure a product and quickly decide if the product is good (go) or does not meet the requirements (no-go). The predictive tools chosen to assess the current status of deterioration must have the same qualities as a “go/no-go” gauge. Once measures meet a specific condition, it should be clear that it is time to take the next step.

Examples of tools that provide the kinds of results that can be used in a go/no-go manner include:

- Vibration analysis (that have predetermined limits)
- Ultrasonic analysis of airborne sounds (that have predetermined limits)
- Ultrasonic analysis of metal thickness (that have predetermined limits)
- Oil analysis (that have predetermined condemnation limits)
- Shock pulse analysis
- Simple temperature measurements
- Simple pressure measurements

Examples of tools that require interpretation and are of limited use in day-to-day predictive analysis are:

- X-ray
- Shear wave
- Vibration analysis where condemnation limits have not been determined
- Airborne ultrasonic analysis where condemnation or action limits have not been determined

The fact these tools are of limited use in day-to-day PdM does not exclude their value in more sophisticated non-routine analysis. The difference between non-routine analysis and routine PdM is that non-routine analysis typically has high visibility and enough analytical attention to cause a decision to be made in a timely manner. Without high visibility and a system for forcing decisions to be made, the information coming from PdM simply gets filed until there is a major problem. Then investigators obtain the data and ask, “Why didn’t you act? You had the data telling you there was a problem.”

Forms of Prevention

As described above, prevention or preventive maintenance typically takes the form of an invasive activity in which a deteriorated or defective component is replaced. As such, the preventive maintenance task takes the form of a small project that has a set group of steps, a set group of tools and materials and well-understood results.

The fact that preventive maintenance takes on such concrete characteristics makes it an activity that can be easily evaluated. Each preventive task should be evaluated for its “maintainability”. Maintainability is defined as the ability to restore the inherent reliability of an asset in a ratable period of time. Based on that definition, there are three characteristics against which any PM task can be measured:

1. First, will the PM task restore the Inherent Reliability (or like-new reliability) of the asset?
2. Second, can the PM task be done in a ratable or repeatable period of time?
3. Finally, is it likely that the PM task will introduce new defects?

Each of these characteristics is best measured by its degree of uncertainty. For instance, if a PM task includes the installation of a component that is of uncertain quality or if a step in the PM task has uncertain results (like a step performed in a blind location), then it is uncertain if the PM will restore the Inherent Reliability of the asset.

Also, if the PM task includes steps that require an uncertain duration to complete, the task is not ratable or repeatable. In this case, it will be impossible to say how long it will take to complete.

Finally, if the task is done in a manner that may or may not introduce new defects into the system, there is another degree of uncertainty. If a task requiring almost surgical cleanliness is expected to be accomplished out in a corn field, one might expect an unacceptable level of uncertainty concerning the resulting products.

In any of these cases, the proposed PM is not truly “maintainable” and should be replaced with a task that provides “certain” results.

Another element associated with creating an optimum PM activity is the life of the component being maintained. In some situations, the usable life is well-known or well-established. In other cases, the form of deterioration leading to end-of-life conditions may be understood but the actual timing is not well known.

The following descriptions will help the student better understand this issue.

- **Known Life Based**

Typically, man rather than Mother Nature determines the timing of PM in cases where there is a known usable life.

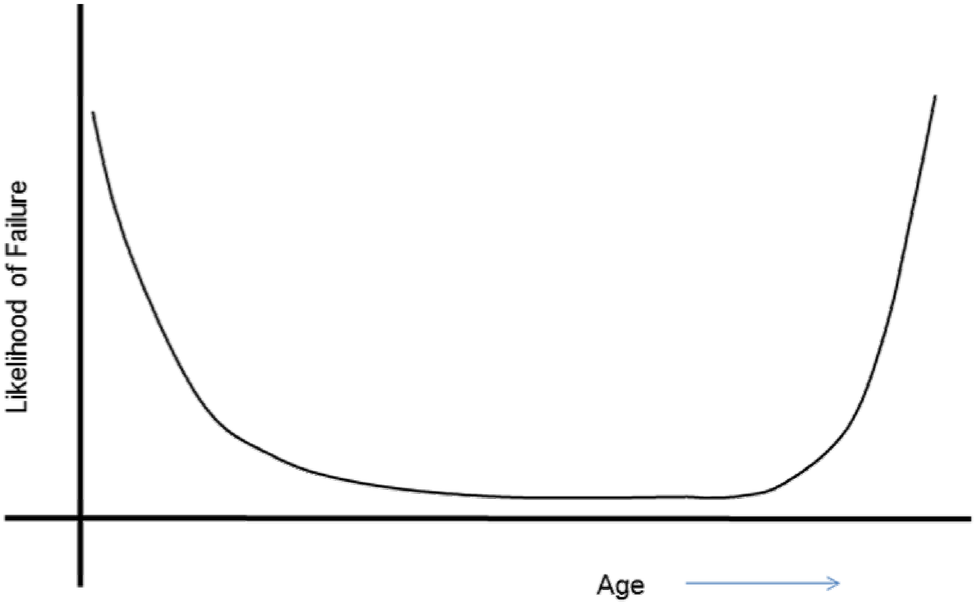
One example is fatigue in energized devices. For instance, if a large and heavy rotating fan is experiencing fatigue, the useable life is typically set by man. Mother Nature has created the Failure Mechanism called fatigue. Based on speed, geometry and stress level, the fan blades are likely to fail at some point in time. The geometry and strength of protective devices around the fan determines the degree of hazard that exists in the area around the fan. If the hazard created by a fan failure is high, then it is only prudent to change the fan blades at a point in time long before fatigue cracks start to form. Man rather than nature will set the timing of the PM to limit risk.

Another situation involves circumstances where an opportunity to perform the PM at minimal cost exists at some time before the expected failure. An example is the situation where a bearing or other component is expected to live past the next outage or turnaround but not through the one after that. In this case, while usable life might be wasted, the cost of the PM is minimized by avoiding an unnecessary outage.

In both these cases, logic and economics rather than the well-defined progress of some form of deterioration forms the known life basis for timing a PM event. There are other examples like the slow but regular thinning of pipe thickness due to uniform internal corrosion. These examples have a known timing for the end of the useful life but typically the actual timing of the PM is based on business or other considerations.

- **Unknown Life Based**

The bathtub curve shown below provides a useful mental picture of the likelihood of failure over the life of an asset. Much like the life of a typical human being, there is a greater likelihood of failure (death) at the beginning of life. This is called Infant Mortality. After the period of infant mortality has passed, there is a long period during which the likelihood of failure is relatively low but constant. As the asset ages, the likelihood of failure increases.



Bathtub Curve

While the bathtub curve provides a useful mental model of the likelihood of failure over the life of an asset, it is also somewhat misleading. While life generally takes the form shown on the diagram, it includes the simplifying assumption that we actually have a good idea of when the end of life will occur. That is typically not the case.

More frequently, we have a general idea of when the end of life will occur but the manner in which an asset is used will affect when the end of life will occur. (The diagram below includes a dashed portion to portray this period of uncertainty.)

An example of this situation is the B-10 life of an anti-friction (or roller) bearing. Of all the components used in engineering, the anti-friction bearing is one that has its useful life most clearly displayed in supplier data. The advertised B-10 life is the time at which 10% of the bearing population will have failed.

Unfortunately, the B-10 life of a bearing is based on several assumptions:

- Bearing loading
- Bearing rotating speed
- Bearing temperature
- Bearing lubrication

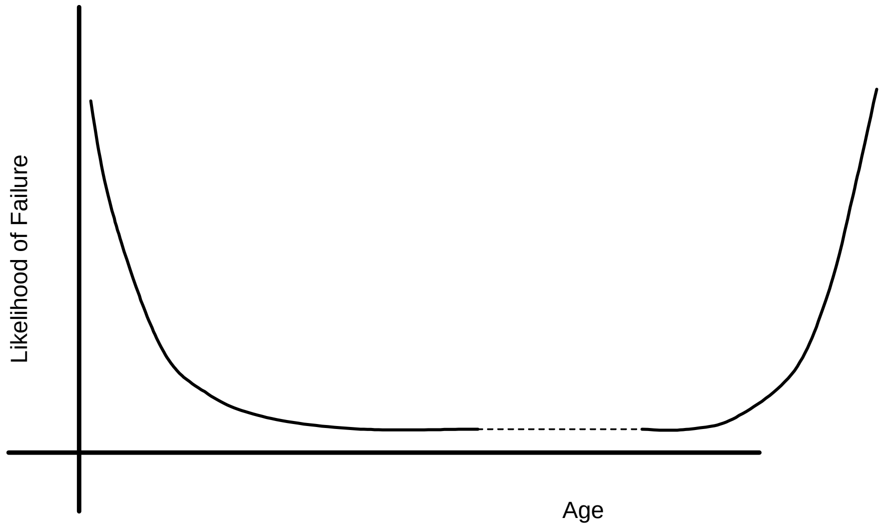
When a designer applies a B-10 bearing, the actual conditions for each of those characteristics are typically different than the values used by the manufacturer in determining the B-10 life. An equipment designer selects a bearing for "worst case" conditions and the bearing only seldom operates at those extreme conditions. For instance, a pump designer selects a bearing for a pump operating at the limit of its curve at maximum temperature and loading. When a plant designer selects a pump, he typically chooses one that has more capacity than is actually needed. As a result, the bearing is underloaded for most of its life. In some cases, like operating speed, the impact on usable life is a factor of the characteristic squared. Underloading or underutilization leads to much longer usable lives than expected based on the B-10 life data.

As a result, rather than performing the preventive maintenance at the assumed end-of-life condition, it is preferable to begin performing some form of predictive maintenance that is effective in identifying the true end-of-life condition. In the case of a bearing, vibration analysis or ultrasonic measurements can be taken at the assumed end of life and the invasive form of PM deferred until end-of-life conditions are confirmed.

The anti-friction bearing case provides a useful example of a situation where PdM should be applied before PM is used, but it portrays a philosophy that is important to all PM/PdM programs.

PdM should be used first because:

- It costs less.
- It does not introduce new defects.
- It allows the owner to harvest all the available values from assets.



Bathtub Curve – Unknown End-of-Life

In the example described above, predictive maintenance works hand-in-hand with some form of preventive maintenance to limit the risk of failure while allowing the maximum amount of usable life of an asset to be harvested.

Conclusion

The objective of converting from a reactive form of maintenance to a proactive form of maintenance is important to most, if not all, capital intensive businesses. In turn, creating an effective program of proactive maintenance requires the thorough understanding of Failure Modes, Failure Mechanisms, the forms of deterioration and the rates of deterioration.

In addition, for predictive maintenance to be effective, the predictive tools being used must be able to clearly and accurately measure deterioration. PdM must be understood and trusted to be effective so timely decisions can be made. Preventive Maintenance must provide tasks that are truly maintainable. They must be of a “certain” duration and they must provide “certain” results.

PdM and PM can be employed together in a manner that may minimize risk of failure while harvesting all the usable life from an asset.