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Selecting Component Replacements to Improve Reliability

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Daniel T. Daley, P.E. Emeritus



Continuing Education and Development, Inc.

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

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Introduction

It seems that many people begin the process of improving reliability with the mind-set that all nuisance failures can and should be corrected by replacing the specific component that is causing the failures with one that is far more robust, thus providing a permanent solution. While that is a useful point of view when dealing with an asset while it is still under warranty, once the warranty period is over, it is often necessary to take a far more pragmatic approach.

That more pragmatic approach requires one to recognize that there are actually three alternatives available.

The first approach is the "do nothing" alternative or to simply live with the current situation. The second approach can best be called "immunity" or replacing the failing component with one that is immune to the form of deterioration that is causing the current component to fail. The third approach is best described as "prevention" in which a combination of predictive maintenance and preventive maintenance is used to allow intervention and component replacement to occur before failure.

When done in the most cost-effective manner, the choice of which alternative should be applied is based on lifecycle cost analysis and the least costly approach is selected.

For purposes of this course, it is my objective to describe the steps that should be taken when applying the Immunity alternative. In other words, these are the steps that should be used when selecting a component that is more robust and no longer experiences frequent nuisance failures.

When a current component is replaced by one that is thought to be more robust, a future for the asset is envisioned in which the specific component is replaced, the frequent failures stop, but nothing else happens. Frequently unintended consequences accompany the change of one component with another. Any time a component is replaced with a different one, some form of "management of change" should be applied to avoid those unintended consequences.

The first and least desired unintended consequence is that the new component does not improve the reliability of the asset. That consequence can be the result of several problems. The first problem is that the new component is not immune to the actual failure mechanism causing failures. In other words, you have failed to accurately identify the cause of failures. Another problem is that the replacement components are not actually immune to the properly identified failure mechanisms. In other words, you accurately identified the failure mechanism, but the new component being used is not capable. Whatever the situation, it is necessary to accurately identify the failure mechanism, then to find a component that is immune.

Another unintended consequence is that the solution that was selected introduces new and different problems. There are a variety of new problems that can be introduced when a replacement component

is installed including: 1) The replacement component is unable to fully perform the functions performed by the original component, 2) The replacement component is not immune to another failure mechanism that exists in the operating environment to which the original component was immune, or 3) The replacement component somehow changes the operating environment in an unexpected and undesired way.

Other unintended consequences can be the result of failing to provide adequate testing of the solution or failure to verify the veracity of your solution. A failure to verify the accuracy of your solution may become apparent when the long-term supply of replacement components does not match the apparent capabilities of the initially tested replacement components. This might be the result of having used a "cherry-picked" component during testing or the manufacturing or quality processes used to produce the replacement components being inadequate or unstable.

When improving reliability using "immunity" or replacing failing components with ones that are more robust, it is always important to affect as little as possible. Confining your changes to the failing component or sub-component rather than an entire equipment item will increase the likeliness that you will properly address the current defect while avoiding the introduction of new defects into the asset.

Isolating the Weakness

The first step in identifying the specific component or sub-component that is causing some form of failure your asset has been experiencing, is to isolate the specific form of weakness that is causing the failures. Keep in mind that in most instances, it is only one small component or sub-component that is the source of the failures. The greater accuracy with which the component or sub-component can be identified along with the specific reason it is failing, the simpler and more economical the solution will be.

When failures occur, it is helpful to make a practice of accurately identifying the malfunction report at the time of the failure then accurately identifying the failure mode at the conclusion of the repair. The malfunction report should identify the specific function that has been impaired. The failure mode should identify the specific component that was replaced when performing the repair and the condition of the failed component. Knowing the function performed by the component being replaced should provide a logical reason why the malfunction occurred. If the component that was replaced does not explain the reason why the malfunction occurred, it is likely that the wrong component was replaced and the failure will occur again in the future.

The combination of component and condition descriptions used to describe the failure mode should provide a clear path to the failure mechanism or deterioration mechanism that has produced the deterioration leading to the failure. When you know the specific component that has failed and the cause of the deterioration, it is then possible to begin the search for a component that will both perform all the functions being performed by the current component and be capable of withstanding the failure mechanism that is present in the operating environment without experiencing deterioration.

In exceptional cases, it may be necessary to perform Root Cause Failure Analysis or a Failure Analysis conducted in a laboratory to identify the specific failure mechanism. In this instance, it is typically best to involve the component manufacturer to ensure that he has not already performed the analysis and determined the solution. You are seldom alone in the problems you are experiencing. There is very little value in reinventing the wheel.

Keep in mind the analogy that if you own a vehicle that experiences a water leak, it is possible to solve the problem by replacing the vehicle. Or the problem can be solved by replacing the water pump. Or the problem can be solved by replacing the pump seal. Or you can solve the problem by properly aligning the pump and replacing the seal faces. In the end, it is only the seal faces or their alignment that has caused the failure. When you choose a solution using a shotgun blast rather than a rifle shot, it is far more costly and creates the possibility of introducing far more new defects.

What If Your Failure Mapping Points to More than One Failure Mechanism

It is always possible that when you review past failures looking for the link between the Malfunction Report and the Failure Mode, you find that there is not a single Dominant Failure Mode, but instead, two or more Failure Modes have been identified in the various repair descriptions.

This is a situation that is possible if there are several Failure Mechanisms in the operating environment and the race to the ultimate Failure Mode is so competitive that sometimes one Failure Mechanism reaches the finish line first and sometimes the other Failure Mechanism finishes first and produces the failure mode. In this case, there should have been evidence of both Failure Mechanisms at work during all of the failure analysis that have been conducted. For instance, if a rotating shaft ultimately failed due to fatigue, there should be signs of corrosion or corrosion products if that was the second Failure Mechanism that was present.

Unless you can confidently exclude the presence of the second Failure Mechanism due to misidentification or identification without any form of failure analysis, it will be necessary to implement a solution that addresses both Failure Mechanism. For instance, in the case described above, it may be necessary to take steps to correct imbalance and eliminate misalignment to prevent fatigue and to find some way to eliminate corrosion by using a superior material or a coating system.

The "Light Switch" Test

There are a number of situations in which the solution being introduced is the result of the maintenance activity being performed rather than the new component that was installed. A good example of this is when an electrical or electronic system fails due to loose or corroded connections. In this case, when the selected part is replaced, the connections are cleaned and tightened and functionality resumes. Everyone is happy because the repair is successful.

In the case of a single repair, it may be reasonable to accept the repair and go on to the next job. But in the case of fleet maintenance where a number of the components will be replaced, it is important to

confirm that the component that was replaced is, in fact, the culprit. Do this using a "light switch" test in which you are trying to turn the problem off, then on again, then off again.

Do this by performing the initial repair and checking that functionality has returned. Next, remove the new component and re-install the old component. Again, perform a function test. If the system again fails to function, you have confirmed that the replaced component is bad. But if the system continues to function properly with the suspect component installed, the maintenance activity repaired the problem and not the replaced component. In this case, it will be necessary to identify the issue causing loosening or inadequate contact due to corrosion.

A final step is to re-install the new component to ensure that functionality is again restored. While functionality is restored in 99% of the instances, there are cases when the system no longer operates even with the new component. In this case, it is important to continue troubleshooting the system until the entire problem is understood.

The kind of issue described in this section is particularly common when using electronic "black boxes" with which there is no clear external symptoms of failure. In these instances, temperature or electrical input might be causing intermittency or improper response, so it can be difficult to be certain if a failure has occurred even using the "light switch" test. In this case, it is best to return the device to the manufacturer for bench-testing before setting out on a program that involves the replacement of a large number of components that are thought to be defective.

You Cannot Change Just One Thing - So Alter as Little as Possible

There is an old saying: You cannot change just one thing. As suggested above, it is important to keep that thought in mind when solving a reliability problem by replacing a component or sub-component with one that is more robust. The refining and process industry is guided by "management of change" regulations that create a requirement that sufficient analysis be done to ensure that unintended consequences do not occur. But other industries have no similar requirements in place so it is up to the engineer to see that unintended consequences are avoided.

One thing that is certain is that the more that is changed when solving a problem, the greater the possibility of introducing new defects. In the case of the leaky pump above, if all the components are kept the same and only the procedure used to ensure proper alignment is improved, there is very little possibility of introducing a new defect. Or if the seal design and geometry remain the same and only the material used in making the seal faces is changes, again, there is little room for new defects to be introduced.

On the other hand, if a wholly new seal or a wholly new pump is installed, the possibility of a variety of new problems is introduced. Clearly, there are cases in which elements beyond the specific components that are failing are marginal and those cases may justify more extensive improvements. But in those instances, it is important to be certain that engineering analysis is applied to the full extent of changed components and not just the component that has been troublesome in the past.

The Alternatives for Reliability Improvement

When making changes that will improve the reliability of an asset, it is useful to thoroughly understand the alternatives and to analyze those alternatives in a realistic and rational manner.

One of the first jobs I was assigned when I began my career in engineering was the replacement of a pump that had experienced a complete bearing failure. The work order to repair the pump came with a comment by the operating organization that the pump should be replaced, it was troublesome. The first thing I noticed was that the pump had a three-number designation (e.g. P-123) in a plant where new pumps were being assigned five number designations (e.g. P-12345). This suggested that the pump was very old and had been in service a long time. It turned out that the pump was more than fifty years old and, for most of that time, had been very reliable.

To make a long story short, it turned out that a number of remote pumps like this one had begun to fail recently since the operation had changed, moving operators to a remote-control room and depending on remote control systems. Pumps were being started and operated for long periods against closed discharge valves because operators were no longer expected to "line up" pumps in person when placing them in service. The operators no longer checked oil level and oil color frequently. And operators seldom came in close contact with equipment so they could place their hands-on bearing housings to sense overheating or listen for cavitation.

Reviewing the three alternatives (do nothing, immunity and prevention) in this situation, it is likely that none of the three would significantly improve reliability without taking some additional steps. It would be possible to return performance to what it had once been by returning the operator interface with equipment to what it had been in the past. It would have been possible to replace the frequent operator contact with increased contact by maintenance personnel. It would have been possible to enhance the remote sensing of aberrant conditions. Or it would have been possible to use some combination of changes combined with the more robust equipment that the operating department was convinced they needed.

Ultimately, it is important to envision how any of the three alternatives will function in any future scenario. Independent of the choice (do nothing, immunity by improved robustness, or prevention using predictive and preventive maintenance) it would be important to envision all the situations that might cause deterioration leading to the various failure modes then identify how and what will prevent those future failures from occurring.

In the case of replacing the fifty-year-old pump described above, even the best and most current pump would be unlikely to survive with the discharge blocked, low oil level or dirty oil. As a result, some further form of accommodation will need to be included with any solution to produce a reliable system.

Retaining Form, Fit and Function

The terminology that has been historically applied to the selection of replacement components or equipment are contained in the three words: form, fit and function. While those terms do not adequately address reliability and useful life requirements, they still need to be appropriately addressed.

Form is used as a way of saying that the replacement device must share the same general appearances, dimensions, weight and other physical characteristics as the component being replaced.

Fit is used as a way of saying that the replacement component must be able to be installed using the current connections like the bolting patterns, flange connection dimensions and the like.

Function is used to say that the replacement component must perform the same activities as the component being replaced. For instance, an on-off switch must not only turn a circuit on and off, it must do so for a circuit operating at a specific voltage and current level.

If the form, fit and function of a replacement component remains the same as the component it is replacing, then the same part number (or a part number modified only by adding an additional version designation) can be applied.

If the form, fit, or function is changed, the part number must be changed, and the physical installation must be accommodated by making some other physical changes to the system where it is being installed.

Again, a change in form, fit or function opens the door to unintended consequences and the introduction of new defects. This fact suggests that the first approach at increasing the robustness of any component should be to go back to the current manufacture and request that they make the changes to the current component to allow it to provide the required reliability and useful life.

The Improved Characteristics

I recall another situation when the bags used to package and transport a moisture sensitive product started allowing moisture to enter and the contained product to deteriorate before being used by the customer. After going through months of the change management process and repeatedly asking the manufacturer what changes had been made and having him repeatedly respond, "We haven't changed anything.", the bag manufacturer finally said, "We haven't changed anything, but we have improved the adhesive used to seal the bag closed." This revelation finally provided the insight needed to solve the problem. The adhesive was, in fact, a better adhesive for almost any product except the one that we were packaging. In our case the adhesive provided a seal for a limited amount of time, then began to deteriorate allowing moisture to enter.

When upgrading a component or sub-component to be immune to a current failure mechanism, it is important to be certain that the new characteristics are also immune to other failure modes that may be present. While the term "improvement" does suggest improved results, it also identifies the presence of a change and changes can be both an opportunity and a threat.

For instance, stainless steel is typically an upgrade from carbon steel, but 400 grade stainless steel is actually a downgrade from carbon steel when used in the presence of hydrochloric acid. High alloy materials frequently provide resistance to various forms of chemical attack, but they also may not have the physical strength of plain old carbon steel. That is why clad composites are frequently used to provide both the required resistance to chemical degradation and physical strength and toughness.

When making an improvement, make certain the solution is truly an improvement for the intended life-cycle and for all environments and operating situations the component will face.

Verifying the Improved Characteristics

When you find that a component or subcomponent is failing to deliver the expected reliability or useful life, that knowledge should be taken as a sign that the component has not been tested or proven in the operating conditions to which it is currently being exposed over its lifetime.

It is possible that the manufacturer never performed the accelerated testing or did perform testing but not under conditions that adequately represented the environment where the component is being used.

Or, it is possible that you are using the component in a way that was never intended. For instance, mobile equipment is frequently used in conditions far warmer or colder than was included in the Highly Accelerated Stress Testing (HALT). Lubricants are frequently used for longer periods without being replaced, thus allowing the effectiveness of additive packages to deteriorate below acceptable limits. Filters become filled to the point of break-through without being changed. An entire variety of unanticipated extremes in usage are possible.

Applying this knowledge to your own situation, it is important to thoroughly understand the severity of conditions to which your failing component is being exposed. By doing this, you may find that the currently installed component would be perfectly adequate if only you were to make some subtle change to the way it is being used or applied.

If that is not the case, then at least you will understand the actual conditions to which the proposed replacement component must be tested in order to ensure it will perform as expected and desired.

The characteristics that must be part of the testing should include:

- The full range of operating temperature
- The full range of operating pressure
- The full range of weather conditions, including:
 - Rain and blowing rain
 - Snow and icing
 - Blowing dust and debris
 - Stress loading
 - Vibration
 - The full range of chemicals to which the component will be exposed
 - The full range of pH

- Exposure to direct sunlight
- The number of operating cycles needed to represent the desired useful life
- Unusual conditions that may be presented by extremes in the manner in which the asset of operated or maintained
- Typical operating positions

While the entire range of tests needed to fully ensure the capabilities of a component may seem staggering, it is important to realize that these tests will be performed either by the manufacturer, by you in a laboratory setting, or by you when the component is installed and operating as a part of your business. The third choice is the one that is often selected by default and results in the marginal reliability and losses in the income upon which your business depends.

In most instances you will find that promises made by manufacturers are limited to:

- A specific useful life (possibly a few years)
- Specific operating ranges of pressure and temperature
- Usage under a specific set of conditions that provide protection for the component
- Other limitations

By thoroughly understanding these limitations you may ultimately determine that the solution to your reliability problems may simply result in providing some form or forms of accommodation for your current component rather than replacing the current component with one that appears to be more robust, but may in reality be subject to the same limitations as your current component.

Verifying Long Term Capabilities of the Manufacturing and Quality Processes

When selecting a component that will be installed in a new asset, a fleet of new assets or a manufacturing run of new products, there are a number of steps taken to ensure that the components being used will continue to provide the desired characteristics for the long term. It is frequently possible to find a part or component that will work once or for a short duration but will not provide the same level of service over the long-term or for multiple copies of the same component.

To assure that all future products retain the same degree of quality and performance as was exhibited by the original article, manufacturers apply the following steps either directly or through the manufacturer who is supplying the component to them:

- Highly Accelerated Life Testing (HALT) - to ensure each and every component is capable of performing the desired function over the desired lifespan and with the desired degree of reliability.
- Application of ISO procedures to the manufacturing process to ensure that the critical steps in the manufacturing process are being conducted (and will always be conducted) in a manner that ensures the appropriate quality and life-cycle performance.

- Statistical Process Control (SPC) to monitor critical results within the manufacturing process to identify instances that are either out of control or on the way to being out of control so products that do not meet requirements can be avoided.
- Highly Accelerated Stress Screening (HASS) at the end of the manufacturing process to ensure that critical elements of the manufacturing process have not gone astray leading to a quality spill of some kind.
- A clear understanding of the Lot Tolerance Percent Defects (LTPD) of products being delivered to customers as a way of understanding the maximum number of defective components that might slip through all the steps above and reach their customers.

When attempting to provide some level of assurance that the parts and components being used will always perform as desired, the asset manufacturer or integrator will audit their suppliers to ensure that their manufacturing process include the elements described above.

When you decide to replace one of the original equipment components with a different component, it will be equally important for you to provide the same level of long-term assurance by verifying that the manufacturer of the replacement component has the same capabilities in place.

While this may seem to be a detailed and cumbersome process, it is important to at least ask questions of the new supplier to see how far they are from being able to provide the desired level of assurance. If it is impossible for a supplier to promise that the components they supply in the future will be capable of providing the desired reliability and useful life, you might find yourself dealing with the same problem again in a relatively short amount of time.

Initial Monitoring

When a component is replaced by one that is expected to provide improved reliability performance, the most prudent approach is to provide continued vigilance until the new component proves its capabilities. If present, most of the unanticipated issues will expose themselves in the early days of operation. If not caught and dealt with early-on, it is possible that the new problem will simply blend into the background of on-going problems without exceptional level of concern or corrective action.

The point being made is that if you have been working on a specific reliability problem for some time and you have selected a solution you think will work and if that solution does not work, you are better off using the data while it is still fresh in your mind to continue searching for the correct solution. When you put a problem behind you, it is best to be certain the solution is providing the performance that was expected by you and promised to your organization.

Your own credibility as well as the technical and economic performance of your company depends on performance promises being kept.

Long Term Monitoring

If your objective in replacing a component is to extend the Mean Time Between Failure (MTBF) of the component from two years to four years, you will not realize the initial benefit of the replacement until

after the prior two year life has been exceeded and you will not know if your ultimate objective has been achieved until the four year objective has been met or exceeded. Obviously, the chore of determining if your efforts have been successful is one that requires long-term monitoring.

Keep in mind that the decision to select one alternative over others is typically made based largely on economic considerations, so the promised useful life is important to achieving the desired economic performance of the enterprise in which you are involved. As a result, it is important to keep track of promises that are kept and those that have failed to deliver.

Rather than viewing the measure of promises kept and promises failed from an individual basis, it is most useful to view this balance from a broader perspective. For instance:

- Are the engineering processes and practices being used actually performing well or should they somehow be improved?
- Do specific suppliers make good on their promises or are their promises hollow?
- Does your economic analysis, and the resulting ways money is being used, lead your company in the most cost-effective direction?
- Had you simply selected the "do nothing" alternative, would the results have been much the same as they turned out?

The fourth question being asked may seem like an unusual one, but it is an important question to consider. I have experienced situations in which a facility was being used as a laboratory or testing ground for an engineer's ideas. In one case, the head of the rotating equipment group had many ideas that, based on his beliefs, should have worked to significantly improve the performance of pumps, compressors, turbines and motors.

Over a long career, the influence of this person resulted in a significant number of "customized" solutions being installed. Unfortunately, when one of the customized equipment items failed, it was necessary to manufacture custom parts before the equipment item could be repaired. This significantly increased the time needed for repairs over the time that would have been needed if Original Equipment Manufacturer (OEM) components had either been held in stock or ordered upon failure.

Over the long-term, despite the fact that the custom solution might have marginally improved the reliability of the equipment item, it significantly reduced its availability. When the person who implemented all the custom solutions retired, it was the responsibility of the next person in that role to return all those modified equipment items to their original condition using OEM components.

In addition to providing a warning against highly customized solutions, this cautionary tale is intended to provide some thoughts concerning the importance of sourcing components from a stable and reliable supplier rather than a custom supplier.

Conclusion

If I attempted to highly summarize the lessons contained in this course, I would do so using the terms "certainty and uncertainty".

While the ultimate objective of improving reliability by replacing components with ones that are more robust is in itself a process leading to an objective that increases certainty, doing so in an effective manner requires that you focus on certainty at every twist and turn through the process.

The issue causing marginal reliability with which you are dealing is the result of your asset being designed and constructed with an unacceptable level of certainty pertaining to various components. If you are planning to improve that performance, you must do so by decreasing the uncertainty that the component manufacturer, the asset designer, or the asset builder chose to accept.

Starting by knowing "with certainty" which component or sub-component is causing the failures, then knowing "with certainty" why that component is failing and then moving on to "being certain" that your solution will eliminate the problem being experienced and do so without creating some other problem(s), it is possible to develop a high degree of confidence in your solution and the promised improvement.

Next, being certain that the component or sub-component being replaced will achieve the promises being made by the manufacturer and that the manufacturer has the capability of delivering products that perform as promised over the long-term, will ensure expectations are met well into the future.

The process of improving the reliability of an asset is one that must be built upon a high level of certainty and integrity. It is not just a matter of making things better for the short term. It is important to provide a credible long-term solution.