RELIABILITY CENTERED MAINTENANCE: 9 PRINCIPLES OF MODERN MAINTENANCE

In this article I provide a brief history of the development of Reliability Centered Maintenance (RCM). And from there we explore ***9 Modern Maintenance Principles****. As a maintenance & reliability practitioner, you should know these principles and live by them.*

FIX IT WHEN IT BREAKS

For most of human history, we've had a very simple approach to maintenance: we fixed things as they broke. This served us well from our early days huddled around campfires until about World War II.

In those days, industry was not very complex or highly mechanized. Downtime was not a major issue and preventing failures wasn't a concern. At the same time most equipment in use was simple and more importantly, it was over-designed. This made equipment reliable and easy to repair. And most plants operated without any preventive maintenance in place. Maybe some cleaning, minor servicing and lubrication, but that was about it.

This simple 'fix it when it breaks' approach to maintenance is often referred to as First Generation Maintenance.

THINGS CHANGED DURING WORLD WAR II.

Wartime increased the demand for many, diverse products. Yet at the same time, the supply of industrial labour dropped. Productivity became a focus. Mechanization increased.

By the 1950's more and more complex machines were in use across almost all industries. Industry as a whole had come to depend on machines.

And as this dependence grew, it become more important to reduce equipment downtime. 'Fix it when it's broken' no longer suited industry. A focus on preventing equipment failures emerged. And the idea took hold that failures could be prevented with the right maintenance at the right time. In other words, the industry moved from breakdown maintenance to time-based preventive maintenance. Fixed interval overhauls or replacements to prevent failures became the norm.

This approach to preventive maintenance is known as Second Generation Maintenance.

MORE MAINTENANCE, MORE FAILURES

Between the 1950s and 1970s a third generation of maintenance was born in the aviation industry.

After World War II air travel became widely accessible. And passenger numbers grew fast. By 1958 the Federal Aviation Administration (FAA) had become concerned about reliability. And passenger safety.

At the time, the dominant thinking was that components had a specific life. That components would fail after reaching a certain "age". Replacing components before they reached that age would thus prevent failure. That was how you ensured reliability and passenger safety.

In the 1950's and 1960's the typical aircraft engine overhaul was every 8,000 hours. So when the industry was faced with an increasing number of failures, the conclusion was easy. Obviously, component age must be less than the 8,000 hours that was being assumed. So maintenance was done sooner. The time between overhauls reduced.

Easy, right?

But increasing the amount of preventive maintenance had three very unexpected outcomes. Outcomes that eventually turned the maintenance world upside down.

First of all, the occurrence of some failures decreased. That was exactly what everybody expected to happen. All good.

The second outcome was that a larger number of failures occurred just as often as before. That was not expected and slightly confusing.

The third outcome was that most failures occurred more frequently. In other words, more maintenance lead to more failures. That was counter-intuitive. And a shock to the system.

THE BIRTH OF RELIABILITY CENTERED MAINTENANCE (RCM)

To say that the results frustrated both the FAA and the airlines would be an understatement. The FAA worried that reliability had not improved. And the airlines worried about the ever increasing maintenance burden.

So during the 1960's the airlines and the FAA established a joint task force to find out what was going on. After analysing 12 years of data the task force concluded that overhauls had little or no effect on overall reliability or safety.

For many years, engineers had thought that all equipment had some form of wear out pattern. In other words, that as equipment aged the likelihood of failure increased. But the study found this universally accepted concept did not hold true.

Instead, the taskforce found six patterns describing the relationship between age and failure. And that the majority of failures occur randomly rather than based on age.

The taskforce findings were used to develop a series of guidelines for airlines and airplane manufacturers on the development of reliable maintenance schedules for airplanes.

The first guideline titled "Maintenance Evaluation and Program Development" came out in 1968. The guide is often referred to as MSG-1 and was specifically written for the Boeing 747-100.

The maintenance schedule for the 747-100 was the first to apply Reliability Centered Maintenance concepts using MSG-1. And it achieved a 25% to 35% reduction in maintenance costs compared to prior practices. As a result, the airlines lobbied to remove all the 747-100 terminology from MSG-1. They wanted the maintenance schedules for all new commercial planes designed using the same process.

The result was MSG-2, released in 1970 titled "Airline/Manufacturer Maintenance Program Planning."

AMAZING RESULTS FROM THE FIRST APPLICATIONS OF RELIABILITY CENTERED MAINTENANCE (RCM)

The move to 3rd Generation or Reliability Centered Maintenance as outlined MSG-1 and MSG-2 was dramatic.

The DC-8's maintenance schedule used traditional, 2nd Generation Maintenance concepts. It required the overhaul of 339 components and called for more than 4,000,000 labour hours before reaching 20,000 operating hours.

Compare that to the maintenance schedule for the Boeing 747-100, developed using MSG-1. It required just 66,000 labour hours before reaching the same 20,000 operating hours!

Another interesting comparison is to compare the number of items requiring fixed-time overhauls. The maintenance for the DC-10 was developed using MSG-2 and required the overhaul of just 7 items versus the 339 on the DC-8. And both the DC-10 and Boeing 747-100 were larger and more complex than the DC-8.

Impressive results, and the US Department of Defence (DoD) thought so too.

THE US DEPARTMENT OF DEFENSE GETS INVOLVED

So, in 1974 the DoD asked United Airlines to write a report on the processes used to write reliable maintenance programs for civilian aircraft. And in 1978 Stan Nowlan and Howard Heap published their report. It was titled "Reliability Centered Maintenance".

Since then a lot more work was done to progress the cause of Reliability Centered Maintenance. The airline industry has moved to MSG-3. John Moubray published his book RCM2 in the 1990's introducing Reliability Centered Maintenance concepts to industry at large.

Nowadays, RCM maintenance is defined through international standards. But it's the work done in the 60's and 70's that culminated in the Knowlan & Heap report in 1978 that all modern day RCM maintenance approaches can be traced back to.

That's now more than 40 years ago. So any Maintenance & Reliability professional should be familiar with it by now. It's been around long enough. It's well documented. And widely available.

Unfortunately, we find that's not the case. The principles of modern maintenance as developed in the journey to Reliability Centered Maintenance are not always known or understood. Let alone applied.

The rest of this article will outline those principles. They should underpin any sound maintenance program.

One of the best summaries of these principles can be found in the NAVSEA RCM Handbook. I would highly recommend reading it. It is well written and easy to understand. And the following Principles of Modern Maintenance are very much built on the 'Fundamentals of Maintenance Engineering' as described in the NAVSEA manual.

9 PRINCIPLES OF MODERN MAINTENANCE

Whether you are developing a new maintenance program. Or improving the maintenance program for an existing plant. All reliable maintenance programs should be based on the following Principles of Modern Maintenance:

Principle #1: Accept Failures

Principle #2: Most Failures Are Not Age Related

Principle #3: Some Failures Matter More Than Others

Principle #4: Parts Might Wear Out, But Your Equipment Breaks Down

Principle #5: Hidden Failures Must Be Found

Principle #6: Identical Equipment Does Not Mean Identical Maintenance

Principle #7: "You Can't Maintain Your Way To Reliability" [5]

Principle #8: Good Maintenance Programs Don't Waste Your Resources

Principle #9: Good Maintenance Programs Become Better Maintenance Programs

As a Maintenance & Reliability professional, you must understand these principles.

You must practice them.

You must live by them.

PRINCIPLE #1: ACCEPT FAILURES

Not all failures can be prevented by maintenance. Some failures are the result of events outside our control. Think lightning strikes or flooding. For events like these, more or better maintenance makes no difference. Instead, the consequences of events like these should be mitigated through design.

And maintenance can do little about failures that are the result of poor design, lousy construction or bad procurement decisions.

In other cases the impact of the failure is low so you simply accept a failure (think general area lighting).

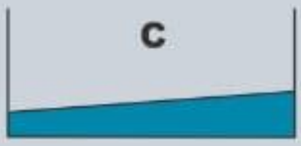
So, good maintenance programs do not try to prevent all failures. Good maintenance plans and programs accept some level of failures and are prepared to deal with the failures they accept (and deem credible).

PRINCIPLE #2: MOST FAILURES ARE NOT AGE RELATED

As explained above the research by the airline industry has shown that 70% – 90% of failure modes are not age-related. Instead, for most failure modes the likelihood of occurrence is random. Later research by the United States Navy and others found very similar results.

This research is summarised in the six different failure patterns shown below:

Failure Patterns & Distributions

Failure Pattern		Distribution				Description
		UAL 1968	Broberg 1973	MSP 1982	SUBMEPP 2001	
Age Related	A 	4%	3%	3%	2%	An initial failure period, followed by the main lifespan of the item, which shows a constant probability of failure. This is followed by a wear-out zone in which the probability of failure increases dramatically.
	B 	2%	1%	17%	10%	As "A" but without the initial early failure period.
	C 	5%	4%	3%	17%	The probability of failure increases gradually, but there is no clearly identifiable average lifespan of the equipment.
Random	D 	7%	11%	6%	9%	The equipment is satisfactory when new, but the failure probability increases rapidly up to a level, which remains constant.
	E 	14%	15%	42%	56%	This type of equipment shows a random failure pattern and again has no identifiable lifespan.
	F 	68%	66%	29%	6%	A high infant mortality is superseded by a rapid drop in failure probability, which then remains constant or increases very gradually.
Age Related		**11%**	**8%**	**23%**	**29%**	
Random		**89%**	**92%**	**77%**	**71%**	

UAL refers to the original United Airlines research, which lead to the development of Reliability Centred Maintenance (RCM). The 1973 Broberg study also relates to airlines. 1982 MSP is a US navy study and the 2001 SUBMEPP study refers to a study on US submarines. The relatively high percentage of items showing wear out in the US Navy and Submarine study have been attributed to their corrosive environment, whereas the relatively low proportion of failures exhibiting infant mortality has been put down to the extensive testing before equipment is put into service.

Apart from showing that most failure modes occur randomly. These failure patterns also highlight that infant mortality is common. And that it typically persists. That means that the probability of failure only becomes constant after a significant amount of time in service.

Don't interpret Curves D, E, and F to mean that (some) items never degrade or wear out. Everything degrades with time, that's life. But many items degrade so slowly that wear out is not a practical concern. These items do not reach wear out zone in normal operating life.

So what do these patterns tell us about our reliable maintenance programs?

Historically maintenance was done in the belief that the likelihood of failure increased over time (first generation maintenance thinking). It was thought that well timed maintenance could reduce the likelihood of failure. Turns out that for at least 70% of equipment this simply is not the case.

For the 70% of equipment which has a constant probability of failure there is no point in doing time-based life-renewal tasks like servicing or replacement.

It makes no sense to spend maintenance resources to service or replace an item whose reliability has not degraded. Or whose reliability cannot be improved by that maintenance task.

In practice this means that 70% – 90% of equipment would benefit from some form of condition monitoring. And only 10% – 30% can be effectively managed by time based replacement or overhaul.

Yet most of our PM programs are full of time based replacements and overhauls.

PRINCIPLE #3: SOME FAILURES MATTER MORE THAN OTHERS

When deciding on whether to do a maintenance task consider the consequence of not doing it. What would be the consequence of letting that specific failure mode occur?

Avoiding that consequence is the benefit of your maintenance.

The return on your investment.

And that is exactly how maintenance should be seen: as an investment. You incur a maintenance cost in return for a benefit in sustained safety and reliability. And as with all good investments the benefit should outweigh the original investment.

So, understanding the consequences of failures is key to developing a good maintenance program. One with a good return on investment.

Just as not all failures have the same probability, not all failures have the same consequence.

Even if it relates to the same type of equipment.

Consider a leaking tank. The consequence of a leaking tank is severe if the tank contains a highly flammable liquid. But if the tank is full of potable water the consequence might not be of great concern.

Easy, right?

But what if the water is required for fire fighting?

Same tank, same failure but now we might be more concerned. We would not want to end up in a scenario of not being able to fight a fire because we had an empty tank due to a leak.

Apart from the consequence of a failure you also need think about the likelihood of the failure actually occurring.

Maintenance tasks should be developed for dominant failure modes only. Those failures that occur frequently and those that have serious consequences but are less frequent to rare. Avoid assigning maintenance to non-credible failure modes. And avoid analyzing non-credible failure modes. It eats up your scarce resources for no return.

A maintenance program should consider both the consequence and the likelihood of failures. And since Risk = Likelihood x Consequence we can conclude that good maintenance programs are risk based.

Good maintenance programs use the concept of risk to assess where to use our scare resources to get the greatest benefit. The biggest return on our investment.

PRINCIPLE #4: PARTS MIGHT WEAR OUT, BUT YOUR EQUIPMENT BREAKS DOWN

A ‘part’ is usually a simple component, something that has relatively few failure modes. Some examples are the timing belt in a car, the roller bearing on a drive shaft, the cable on a crane.

Simple items often provide early signals of potential failure, if you know where to look. And so we can often design a task to detect potential failure early on and take action prior to failure.

For those simple items which do “wear out” there will be a strong increase in the probability of failure past a certain age. If we know the typical wear out age for a component, we can schedule a time-based task to replace it before failure.

When it comes to complex items made of of many “simple” components, things are different.

All those simple components have their own failure modes with its own failure pattern. Because complex items have so many, varied failure modes, they typically do not exhibit a wear out age. Their failures do not tend to be a function of age, but occur randomly. Their probability of failure is generally constant as represented by curves E and F.

Most modern machinery consists of many components and should be treated as complex items. That means no clear wear out age. And without a clear wear out age performing time based overhauls is ineffective. And wasteful of our scarce resources.

Only where we can prove that an item has a wear out age does performing a time based overhaul or component replacement make sense.

PRINCIPLE #5: HIDDEN FAILURES MUST BE FOUND

Hidden failures are failures that remain undetected during normal operation. They only become evident when you need the item to work (failure on demand). Or when you conduct a test to reveal the failure – a failure finding task.

Hidden failures are often associated with equipment with protective functions. Something like a high-high pressure trip. Protective functions like these are not normally active. They are only required to function by exception to protect your people from injury or death. To protect the environment from a major impact or protect our assets from major damage. This means we pretty much always conduct failure finding tasks on equipment with protective functions.

To be clear, a failure finding task does not prevent a failure. Instead a failure finding task does exactly what its name implies. It seeks to find a failure. A failure that has already happened, but has not been revealed to us. It has remained hidden.

We must find hidden failures and fix them before the equipment is required to operate.

PRINCIPLE #6: IDENTICAL EQUIPMENT DOES NOT MEAN IDENTICAL MAINTENANCE

Just because two pieces of equipment are the same doesn't mean they need the same maintenance. In fact, they may need completely different maintenance tasks.

The classic example is two exactly the same pumps in a duty – standby setup. Same manufacturer, same model. Both pumps process the exact same fluid under the same operating conditions. But Pump A is the duty pump, and Pump B is the standby. Pump A normally runs and Pump B is only used when Pump A fails.

When it comes to failure modes Pump B has an important hidden failure mode: it might not start on demand. In other words, when Pump A fails or under maintenance you suddenly find that Pump B won't start. Oops.

Pump B doesn't normally run so you wouldn't know it couldn't start until you came to start it. That's the classic definition of a hidden failure mode. And hidden failure modes like this require a failure finding task i.e. you go and test to see if Pump B will start. But you don't need to do this for Pump A because it's always running (unless when it's off or failed).

So when building a maintenance program you must consider the operating context.

A difference in criticality can also lead to different maintenance needs. Safety or production critical equipment will need more monitoring and testing than the same equipment in low criticality service.

It's important to reinforce that identical equipment may need different maintenance requirements. This is far too often forgotten or simply ignored for convenience. But you could find yourself facing critical failures by ignoring this basic concept. Especially if you use a library of preventive maintenance tasks.

PRINCIPLE #7: "YOU CAN'T MAINTAIN YOUR WAY TO RELIABILITY"

I love this quote from **Terrence O'Hanlon** and it's so very true. Maintenance can only preserve your equipment's inherent design reliability and performance.

If the equipment's inherent reliability or performance is poor, doing more maintenance will not help.

No amount of maintenance can raise the inherent reliability of a design.

To improve poor reliability or performance that's due to a poor design, you need to change the design. Simple.

When you encounter failures – defects – that relate to design issues you need to eliminate them.

Sure, the more proactive and more efficient approach is to ensure that the design is right to begin with. But all plants startup with design defects. Even proactive plants. And that's why the most reliable plants in the world have an effective defect elimination program in place.

PRINCIPLE #8: GOOD MAINTENANCE PROGRAMS DON'T WASTE YOUR RESOURCES

This seems obvious, right? But when we review PM programs we often find tasks that add no value. Tasks that waste resources and actually reduce reliability and availability.

It's so common for people to say "whilst we do this, let's also check this. It only takes 5 minutes."

But 5 minutes here and there, every week or every month and we've suddenly wasted a lot of time. And potentially introduced a lot of defects that can impact equipment reliability down the line.

Another source of waste in our PM programs is trying to maintain a level of performance and functionality that we don't actually need.

Equipment is often designed to do more that what it is required to do in its actual operating conditions. As maintainers we should be very careful about maintaining to design capabilities. Instead, in most cases we should maintain our equipment to deliver to operating requirements. Maintenance done to ensure equipment capacity greater than actually needed is a waste of resources.

Similarly, avoid assigning multiple tasks to a single failure mode. It's wasteful and it makes it hard to determine which task is actually effective. Stick to the rule of a single, effective task per failure mode.

Most organisations have more maintenance to do than resources to do it with. Use resources on unnecessary maintenance, and you risk not completing necessary maintenance. And not completing necessary maintenance, or completing it late, increases the risk of failures.

And when that unnecessary maintenance is intrusive it gets worse. Experience shows that intrusive maintenance leads to increased failures because of human error. This could be simple mistakes. Or because of defective materials or parts, or errors in technical documentation.

A lot of maintenance is done with the equipment off-line. So doing unnecessary maintenance can also increase production losses.

So make sure you remove unnecessary maintenance from your system. Make sure you have a clear and legitimate reason for every task in your maintenance program. Make sure you link all tasks to a dominant failure mode.

And have clear priorities for all maintenance tasks. That allows you to prioritise tasks. In the real world we are all resource constrained.

PRINCIPLE #9: GOOD MAINTENANCE PROGRAMS BECOME BETTER MAINTENANCE PROGRAMS

The most effective maintenance programs are dynamic. They are changing and improving continuously. Always making better use of our scarce resources. Always becoming more effective at preventing those failures that matter to our business.

When improving your maintenance program you need to understand that not all improvements have the same leverage:

First, focus on eliminating unnecessary maintenance tasks. This eliminates the direct maintenance labour and materials. But it also removes the effort required to plan, schedule, manage, and report on this work.

Second, change time based overhaul or replacement tasks into condition based tasks. Instead of replacing a component every so many hours, use a condition monitoring technique to assess how much life the component has left. And only replace the component when actually required.

And third, extend task intervals. Do this based on data analysis, operator and maintainer experience. Or simply on good engineering judgment. Remember to observe the results.

The shorter the current interval, the greater the impact when extending that interval. For example adjusting a daily task to weekly reduces the required PM workload for that task by more than 80%.

This is often the simplest and one of the most effective improvements you can make.

ABOUT THE AUTHOR

Erik Hupjé is the founder of the **Road to Reliability™** and has over 20 years' experience in asset management, and specifically managing maintenance & reliability. He has worked in the Netherlands, the United Kingdom, the Philippines, the Sultanate of Oman, and Australia. Erik has a passion for continuous improvement and keeping things simple. Through the Road to Reliability™, he helps Maintenance & Reliability professionals around the globe improve their plant's reliability and their organisation's bottom line.

REFERENCES

I wrote this article based on a number of key sources listed below (and throughout the article). I strongly recommend getting yourself a copy of Moubray's book if don't already own a copy. And I'd definitely get the NAVSEA RCM manual as its well written and easy to understand:

- Moubray, J. (1997) Reliability Centered Maintenance Second Edition. Industrial Press. Available at: https://www.amazon.com/Reliability-Centered-Maintenance-Second-John-Moubray/dp/0831131462.

- NAVSEA (2007) Reliability Centered Maintenance (RCM) Handbook [S9081-AB-GIB-010]. Available at: https://www.amazon.com/NAVSEA-Reliability-Centered-Maintenance-RCM-Handbook-ebook/dp/B00U1UJPKK.

- Allen, T. M. (2001) 'U.S. Navy Analysis of Submarine Maintenance Data and the Development of Age and Reliability Profiles'. Available at: http://www.plant-maintenance.com/articles/SubmarineMaintenanceDataRCM.pdf.

- White Paper (no date) 'What is Reliability Centered Maintenance?' Available at: http://www.mainsaver.com/pdf/Reliability_Centered_Maintenance_White_Paper.pdf.

- Wikipedia (2017) Reliability-centered maintenance. Available at: https://en.wikipedia.org/wiki/Reliability-centered_maintenance