RCM ANALYSIS, INFORMATION AND DECISION SHEETS

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Abstract

This paper suggests the inclusion of possible additional questions on the RCM information and decision sheets and presents a decision sheet that incorporates the task type selection diagram. The objectives are to extract more useful information during RCM analyses and greatly reduce the time to analyse an asset class to less than one day on average.

The RCM Information Sheet

Defining the Asset's Function

A function must be specified as complete as possible, because a functional failure is defined in RCM as 'the inability to provide the function at the required performance level'. If we don't pay enough attention to comprehensively describe the function and associated performance levels, we will overlook possible functional failures that we should have considered in the development of the maintenance plan. This implies that we should cover operation policies, such as 'only operate during low electricity tariff periods', control of the asset, either locally or remotely and safety.

Note that the function description must cover the current application of each asset, not what it was originally designed for, as the two could be quite different.

Recording Six Functional Failures for Every Function.

From experience it seems that for every function there are six possible functional failures that should be assessed in each case. These are:

1. not providing the function at all;
2. providing the function at less than the required performance level;
3. providing the function in excess of the required performance level;

4. providing the function intermittently (when continuity is required);
5. providing the function in an unsafe manner; and
6. not being able to control the function, locally or remotely.

From Failure Mode to Failure Cause

There are many web-sites and publications containing a definition of failure mode, such as 'the failure mode represents the ways in which the component is expected to fail' [1,2]. The second reference adds 'in the progression of time a failure mode comes in between a cause and an effect'. Others define failure mode as 'the manner by which a failure is observed. Generally describes the way the failure occurs and its impact on equipment'[3,4]. The latter definition is an excerpt from 'The Reliability Engineering Handbook' by Bryan Dobson and Dennis Nolan.

Failure mode examples in literature include 'exhaust collapses', 'part of component falls off', 'wheel bearings seize' (the cause of the seized bearings was indicated to be lack of oil). There is also an instruction that a failure mode description must contain a noun and a verb, for example 'valve closes shut'.

What these definitions and examples of failure modes have in common is that they definitely don't describe failure causes. Compared to a cause, the failure mode appears to be more the manifestation or symptom of the failure.

The intention of RCM is to minimise unacceptable consequences of failures due to various failure root causes. We can find a statement that we 'must identify the cause so we don't wast effort treating symptoms'. Shouldn't we, then, record root causes in the RCM information sheet instead of failure modes, let alone a mix, such as 'Failure Mode (Cause of Failure)'?

Recording Failure Modes

RCM literature instructs that we should only list failure modes that might reasonably be expected to occur. This means that when we are considering 'failure modes' (read 'root causes'), we have to simultaneously ask the question 'how likely is this'?

> What about the unlikely fault of something as unimportant as a small o-ring in the US Space Shuttle Challenger? What chance would that have to fail? Surely we would not have to consider that?
>
> Some 25 years ago, an independent consultant discovered that there was a clear danger of catastrophic engine fault and fire from an 'explosive' break up of a Concorde wheel, following a blown tyre, with parts of the wheel piercing the aircraft's skin and fuel tank(s). Reports indicate that British Airways at the time acknowledged the report but said that the 'odds of that actually happening were improbable'. An estimate was 'once in twenty-five years! And they were right! Concorde flight 4590 from Air France that crashed with one or two port engines on fire in August 2000 was just about 25 years old. On the fourth day into the investigation of this accident, it was reported that a Concord had previously been found by an inspector in New York to have holes in its fuselage and was dripping fluid, which turned out to be fuel! A tyre had blown on landing, the wheel had broken up, piercing the aircraft skin and punctured a fuel tank, leaking fuel onto the runway. No action was taken to modify the planes after this finding because…its occurrence was very unlikely! (In the mean time all Concords have been retired).

The main danger of this instruction is that an unlikely fault can have disastrous effects. Risk should be assessed as a combination of severity and likelihood, as per various Standards. In our approach we therefore assess severity and likelihood of the consequences for each failure cause, after we have established causes and effects. This in recognition of the fact that we can not afford to simply record 'likely failure modes' but must record all 'modes'. Even if a failure is relatively unlikely, we should assess the need to perform maintenance if the consequence of the failure could be catastrophic. Comprehensive coverage also reduces the chance of overlooking maintenance needs.

Another instruction found in RCM literature is to identify failure modes at a level that results in appropriate failure management policies. At this early point in an RCM analysis, how could we even guess what an 'appropriate' failure management policy could be? After all, the determination of this is a final step in the RCM analysis and, surely, the analysis is not meant to fit a pre-determined outcome, perhaps the one that we already do?

The conclusion is that we should record as many failure causes as possible and, while we do so, disregard any considerations that belong further down in the analysis.

The Importance of Detecting the Onset of a Fault

This question provides a link back to the design of the process or asset. If there is no way of detecting asset or asset output deterioration and we can't accept this deterioration, we might want to modify the design to include some sensors or indicators.

Part of an example of the RCM Information Sheet is shown below.

Reliability Centred Maintenance Information Worksheet

Site		Date	Sheet No 1
Unit	Water Supply System	Recorded by	of
Component	Water Treatment Plant	Audited by	Team 1

	Function		Functional Failure (Loss of Function)		Failure Root Cause	Failure Effect (What Happens When It Fails)	How do we Detect the Failure
1	To supply adequate and uninterrupted drinking water to a defined quality and standard. Adequate defined as the ability to deliver the current capacity required at all times with a maximum 5% loss	A	Water quality outside standards	1	Too little 'chemical' added	Public health consequences (sickness/death)	Monitoring - chemical & physical analysis
				2	Too much 'chemical added	Public health consequences (sickness)	Monitoring - chemical & physical analysis
						Excessive chemical corrodes assets	Monitoring - chemical & physical analysis
				3	Excessive solids in water due to blown filter	Discolouration & minor sickness	Monitoring - physical analysis
				4	Contamination - sabotage	Severe public health issues - multiple fatalities	Monitoring - chemical & physical
				5	Contamination - oil & lubricants	Environmental issues	Monitoring - chemical & physical
				6	Excessive solids due to skimmer failure	Discolouration & minor sickness	Monitoring - physical
		B	No water supply	1	Catastrophic failure of dam wall results in no supply	No supply, potential damage to township down	Monitoring - low level in reservoir & low flow
				2	Blocked filter halts supply	Flow halted	Monitor flowrate
		E	Intermittent supply	1	Short circuits on powerboard	Intermittent operation, asset damage	power surges, monitoring of operations

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The RCM Decision Sheet

Consequences of Evident or Hidden Faults

RCM generally recognises four consequence categories, ranked in order of importance: hidden, safety & environmental, operational and non-operational consequences.

The first question of decision diagrams determines whether the failure is hidden or evident. Failures that give some warning are evident and hidden failures go unnoticed until another failure occurs. Examples of hidden failures are safety devices or a parallel asset where only one of two is required. In practice a failure is deemed evident when 'in the passing of time' it will become evident to the operating crew under normal circumstances. We can find examples, such as 'total loss of vehicle break fluid' and 'an underground tank leak'. Would you bother whether a task is evident or hidden when you find yourself going down a ramp in a dump truck into an underground mine and, when you press the brake pedal, the brakes don't work or that, in the passing of time, your process stops because the highly toxic chemical leaked out of your underground tank? Whether hidden or evident you would want to periodically check your assets.

Apart from this, the definition of evident and hidden failures refers to operators. How does this definition cover remote assets, especially those that are not linked to any remote monitoring system? Remember that we are not yet sending anybody out on a failure finding missing, as the decision diagram wants us to first establish whether the failure is hidden or evident!

Thirdly, the use of the term ’in the passing of time’ in determining whether a failure is evident seems at odds with the definition in RCM of a failure as ‘any deterioration from the required functional performance expectation’. Do you really only want to decide on regular fault finding tasks for hidden failures only, and not bother about brake fluid or tank leads because they are defined as ’evident’? In line with the definition of a fault we should act as soon as possible.

So how important is the classification of hidden or evident? Indeed, a well-known decision diagram shows exactly the same questions under hidden failures and evident failures with safety, environmental and operational consequences. The only difference is for non-operational consequences where it is possible not to have any scheduled maintenance. Therefore, we developed a decision diagram where the first question does not consider evident or hidden failure but asks whether there is a significant safety, environment or operational consequence of a failure. This, to quickly identify all failure causes that allow 'repair on failure' or, in other words, 'no planned task'.

Risk Assessment

After describing the effect, which is a qualitative assessment of risk, we can now try and quantify the risk. For this purpose we provide three columns for the assessment of severity, likelihood and detectability of the effects of a fault based on every root cause. We multiply the three values to arrive at a figure of risk.

This part of the analysis has two functions:

- to be able to rank the fault consequences of each fault root cause, if we want to establish the order of implementing maintenance plan updates; and
- as a preparation for the task type selection analysis.

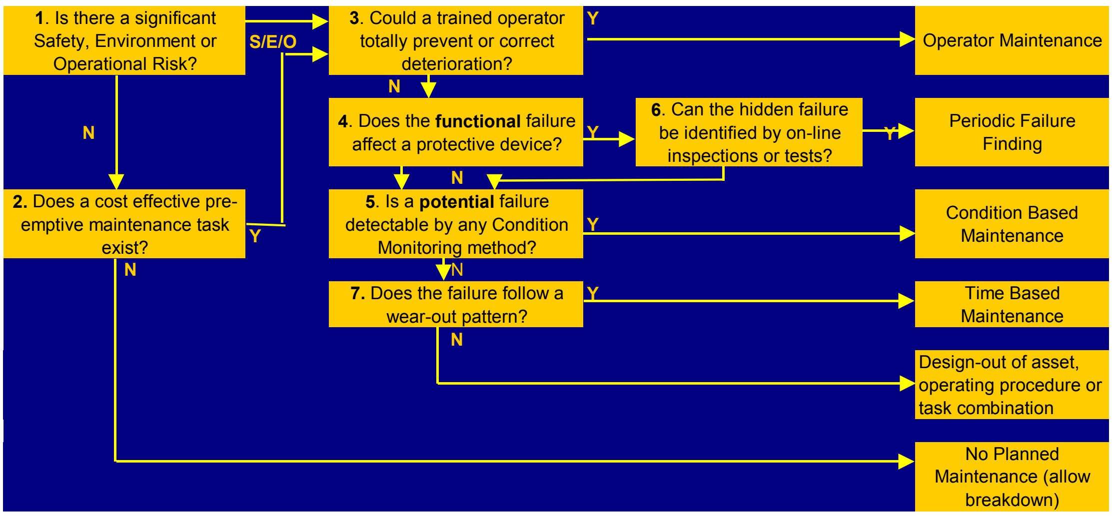
Note that this multiplication of numerical values only indicates a comparative rank. We warn against attaching too much value to the actual rank figure. What this means is that the risk as a result of selecting severity 5 and likelihood 1, or risk = 5 * 1=5, is not necessarily the same as severity 1 and likelihood 5. This would only be the case if each class in severity, likelihood and detectability had exactly the same weighting, which is rarely the case.

Task Type Selection Diagram on RCM Decision Sheet

There are several conventional decision diagrams that do not normally appear on the RCM analysis worksheets and have to be consulted separately. Often, this means that they are not consulted at all. From informal surveys of groups of up to forty-five persons who performed RCM analyses we repeatedly find that only about two claim to have cast an eye on the diagrams and these two may only try and save face. When analysts do not follow any decision flow diagram, how do they know what task to record? In most cases they revert back to 'what we already do'.

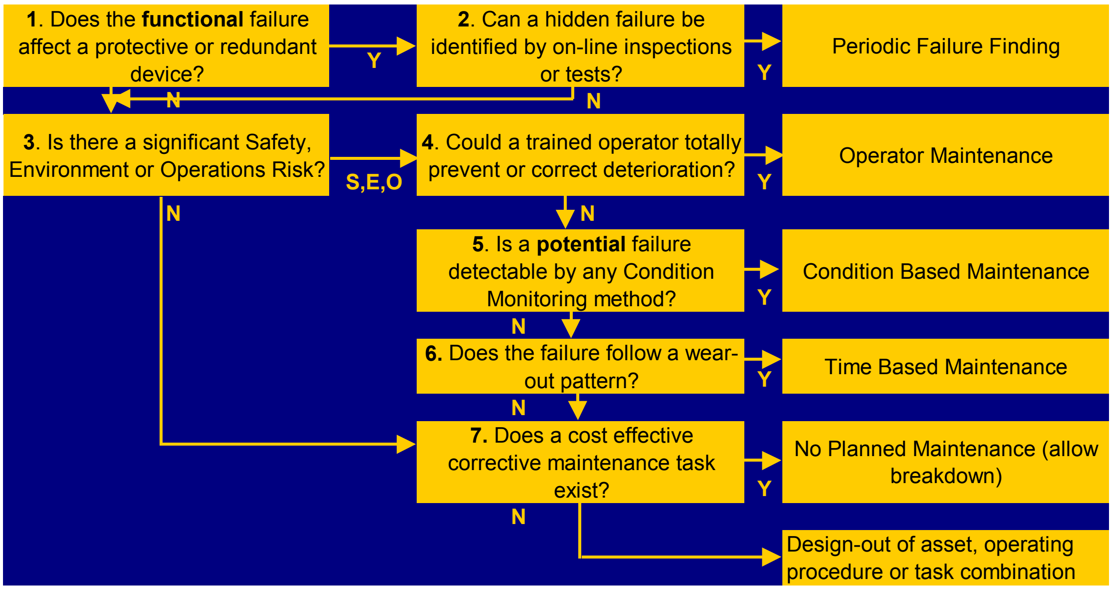
We include seven or eight columns to collect the answers to corresponding questions that appear in the bottom margin of the sheet. Each question offers the possible answers in bold. A small flow chart at the top of the sheet indicates what the next question should be, depending on the answers. The outcome of following questions and flow chart is the suggested maintenance regime, to be entered in abbreviated form in the task column.

We developed and tested three main versions; the first one existed in sub-versions for industries with or without operators (see operator-maintenance section below), the second version incorporated hidden failures and the third version has a totally different approach, going back to the very basics of the RCM philosophy. Below follow the first and second version.



Note that the word pre-emptive in the second question is a combination of preventive, predictive and pro-active.

The answer to one question directs to the next question. For example, 'no' to question 1 leads to question 2, but selecting that there is a significant consequence for safety or environment or operations would lead to question 3.



There are several advantages of including the decision diagram and questions on the worksheet:

- it removes the risk of reverting to only selecting 'what we already do';
- analysing teams are guided to the type of maintenance; and
- this feature results in comprehensive analyses of asset classes within greatly reduced times.

After the selection of the maintenance type with the flowchart, we have to define the actual task. Note that tasks can be of two types:

- diagnostic tasks; and
- maintenance tasks.

Whenever there is a need for a diagnostic task, we need to also record possible secondary (maintenance) tasks that are triggered by the diagnostic tasks.

Operator Maintenance

Total Productive Maintenance includes the principle of operators performing asset cleaning, greasing, adjustments and minor maintenance, to keep the assets from deteriorating and maintaining proper operating conditions.

It seems logical to incorporate operator-maintainer principles into RCM for the selection of the appropriate maintenance task. This has the additional advantage of freeing skilled maintenance personnel for major maintenance and maintainability improvement activities.

We, therefore, include a question regarding the possibility of operator-maintenance and the readiness of the operator to perform the task, with or without additional training.

Default Tasks?

For hidden failures, we are initially not supposed to consider failure finding missions, nor a re-design of the system, as these are 'default tasks', only to be considered 'if a preventive task can not be found which is both technically feasible and worth doing, then suitable default action must be taken'.

Preventive maintenance, which is time or count-based, aims at preventing a failure, is only successful if there is a failure characteristic that is time or count-related. If such a task is not available, then the default task of fault finding becomes acceptable. Why can't this task be selected straight away? Furthermore, how is a regular (read time-based) failure finding task different from a preventive task?

Questioning the Task Acceptance Criteria

In a general RCM approach, a task will be included in the maintenance plan if it passes the following two criteria:

- **applicability;** the task must reduce the impact or occurrence of failure due to the identified cause and the task must be technically feasible; and
- **worth doing**; the task must be cost-effective, compared to the avoided consequences and other tasks.

We feel that a task that is applicable and worth doing is not necessarily the best task. The next question should be whether this task is the most cost-effective task available. If it is, then the task 'will' be included, if there is a more cost-effective task, that task should be included instead.

This question must be asked but does not necessarily have to appear on the decision sheet. If the initial answer should be 'no', we then have to select another task that is applicable and more cost-effective. After that the answer in the column would change to 'yes'. Eventually the column should only contain 'yes'. Only if we wanted to record all steps in the analysis, for future audit purposes, would we record both the initial and final tasks and insert the column on the decision sheet.

Obtaining Additional Information

After specifying the task, an RCM analysis determines the frequency for recurring tasks.

However, we feel that we should prompt for more information that we need for the development of the work schedule, such as the average duration of the tasks and the required resources. The resources can cover personnel, tools, equipment, spares and information.

Below follows the corresponding part of the RCM Decision Sheet, containing the second decision diagram, albeit with an earlier version of the first question.

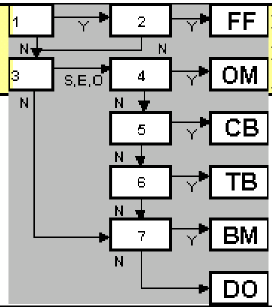
References

1. (http://www.Isis.Vanderbilt-edu/research/fdir/dtoolman/mode7.html).
2. http://www.fmeca.com/ffmethod/definition.htm#Failure%20Mode.
3. http://www.qualityamerica.com/knowledgecentre/articles/cre7.2.html.
4. http://www.wmtrainingsolutions.com/resources/failure-mode.html.

Eerens, Emile W.J. (2003), *Business Driven Asset Management for Industrial and Infrastructure Assets*, Le Clochard, Melbourne.

Reliability Centred Maintenance Decision Worksheet

Site	Installation		Date	
Unit	Unit/Item No		Recorded by	Sheet No
Component	Item/Comp.No		Audited by	of



Information sheet reference			Criticality				RCM Decision Logic									Is this the most cost-effective task possible?	On or Off-line?	Frequency	On or off-line?	Manhours	Resources Needed
			Severity	Likelihood	detectability	criticality															
F	FF	FC					1	2	3	4	5	6	7	Task	Proposed Maintenance Task						

F Function
FF Funct.Failure
FC Failure (root) Cause

7. Does a cost effective corrective maintenance task exist? **(Y, N)**
6. Does the failure follow a wear-out pattern? **(Y, N)**
5. Is a **potential** failure detectable by any Condition Monitoring method? **(Y, N)**
4. Could a trained operator totally prevent or correct deterioration? **(Y, N)**
3. Is there a significant Safety, Environment or Operations Risk? **(S, E, O)**
2. Can a hidden failure be identified by on-line inspections or tests? **(Y, N)**
1. Does the **functional** failure affect a protective or redundant device? **(Y, N)**

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