Failures, Failure modes and Effects Analysis

Module 2.3en

FMEA

1

Warning: Terminology clash

Completely different meanings of "Failure Analysis"

In RCFA:
- The discovery of the **latent root cause** of a significant (or catastrophic) failure or near miss that has occurred.

In RCM:
- The analysis of the **manner and extent** to which a performance standard specified within a function statement can be compromised or cease to perform as required by the asset's users.

The term "Failure analysis" in RCM has a completely different meaning from that of Failure analysis in RCFA

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RCM

A process used to
determine what must be done
to ensure that a physical asset continues to do what
its users require it to do in its operating context:

What do its users require it do (Functions)?
Failures **What specific performance losses can occur (Failures)?**
What event causes the failure (Failure mode)?
What happens when it fails (Effects)?
Why does it matter (Consequences)?
Can you predict, prevent or mitigate the failure consequences (Maintenance task)?
What if no mitigating task can be found (Default action)?

3

Q2 identifies the performance losses

The goals of failure analysis in RCM are to:

Determine what performance losses can occur that will cause the asset to fail to meet the requirements of the users (which would include the owner, and even society at large)?

Precisely specify the failed state (i.e. failure, functional loss)?

Note: The term "Failure analysis" in RCM has a completely different meaning from that of Failure analysis in RCFA

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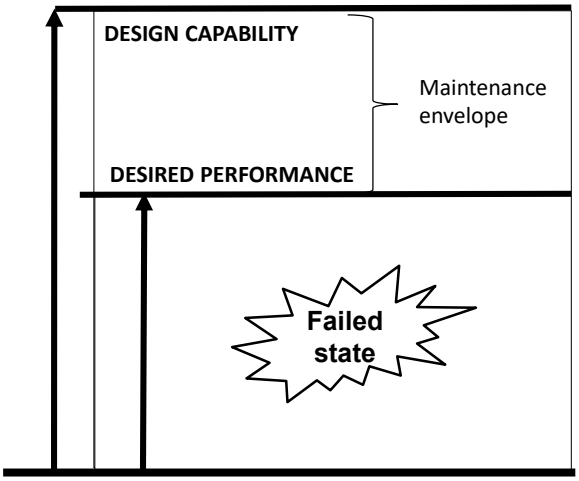
The generalized failed state is:

When the performance we want falls outside the “capability envelope”.



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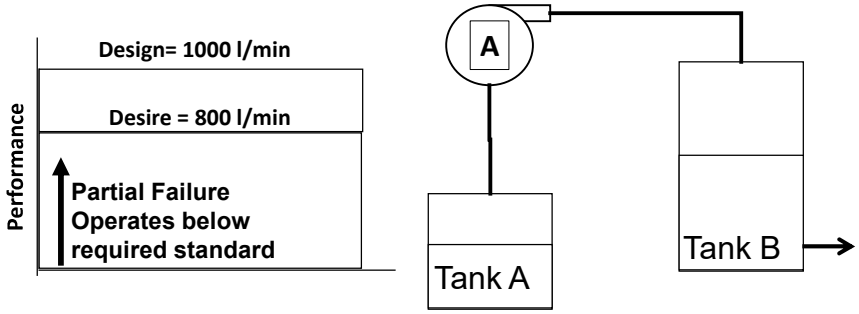
Partial Failure

- Centrifugal pump v4.1
  - 1. To transfer 800 lpm of water from tank A to tank B located 10 ft above tank A
    - 1. Transfers 0 lpm
    - 2. Transfers < 800 lpm



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Partial failure with multiple performance standards

- Hot water and space heating system v4.0
  - 1. To supply hot water with a temperature between 50C and 55C to all taps within 15 seconds of opening the tap in summer and winter in the presence of a full stand-by heating capability.
    - 1. Unable to heat at all
    - 2. Water temperature drops below 50C in winter
    - 3. Water temperature drops below 50C in summer
    - 4. Water temperature drops below 50C in summer or winter
    - 5. Water temperature rises above 55 deg C in summer
    - 6. Hot water arrives more than 15 seconds after opening tap
    - 7. Supplies hot water in winter in the absence of a full stand-by heating capability

Not only are the individual requirements considered, but also the changes in requirements with operational phase.

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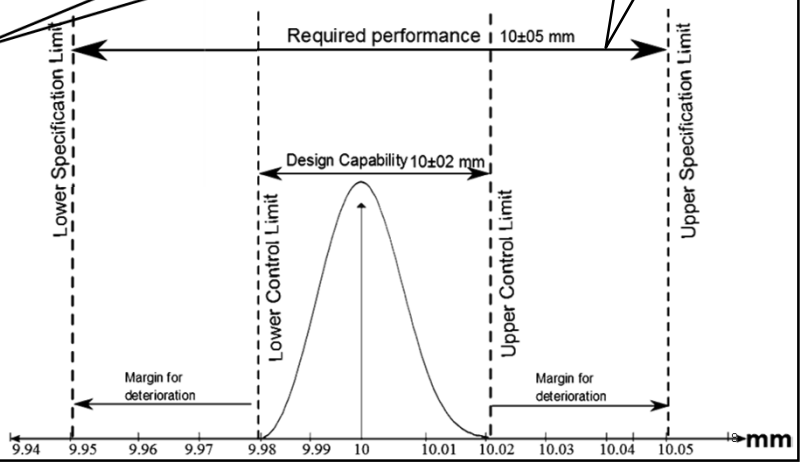
OUTSIDE UPPER AND LOWER LIMITS

Milling Machine v1.2

1. To finish mill a workpiece in a cycle time of 2.25 ±0.03 minutes to a depth of 10.0±0.05mm with a flatness tolerance of 0.1 and a surface finish of Ra5.0v0.8mm
   - 1. Completely unable to mill workpiece
   - 2. Mills workpiece in a cycle time longer than 2.28 minutes
   - 3. Cuts deeper than 10.05mm
   - 4. Cuts shallower than 9.95 mm
   - 5. Mills out of flatness specification
   - 6. Surface finish too rough

The requirements related to time, depth, and finish are dissected into *over* and *under* spec performance. Why?

Rule of thumb in SQC: The difference between the specification limits should be 1.5 to 2 times the initial difference between the control limits.



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Total failure vs. partial failure using upper and lower limits performance standards

Milling Machine v1.2

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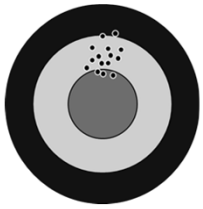

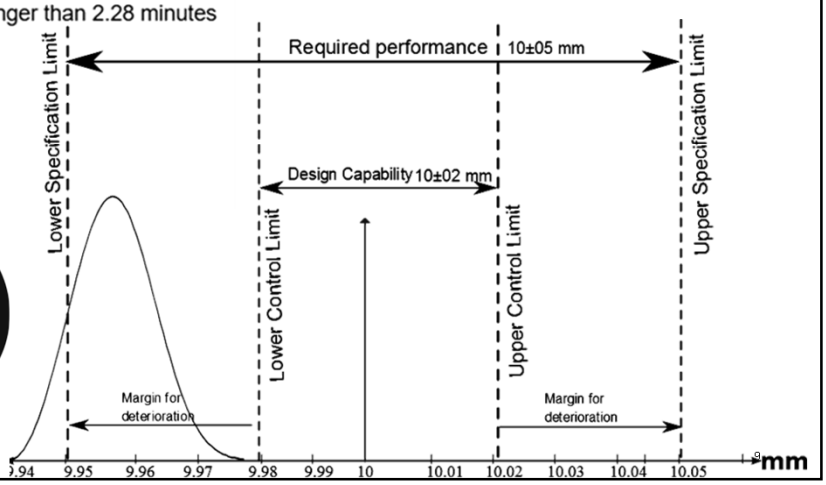

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Total failure vs. partial failure using upper and lower limits performance standards

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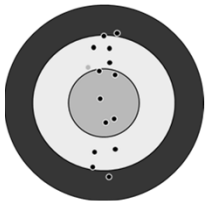
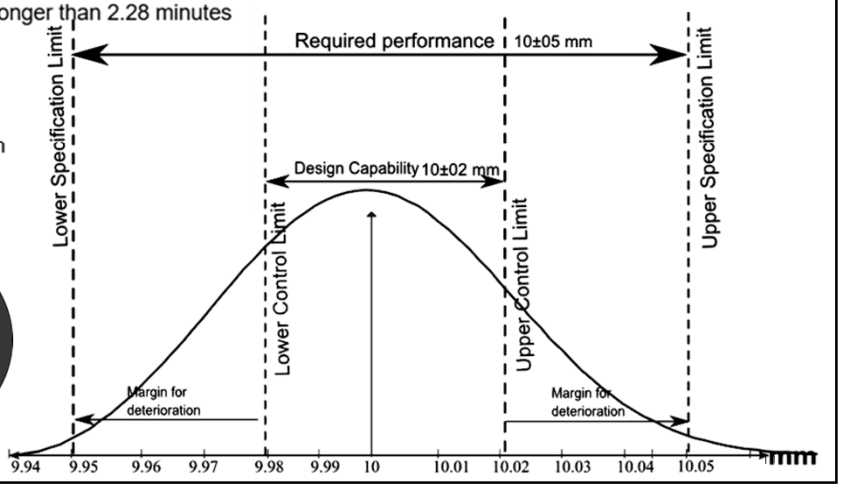
Out of spec both ways





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Specifying Functional Failures

Milling Machine v1.2

1. To finish mill a workpiece in a cycle time of 2.25 ±0.03 minutes to a depth of 10.0±0.05mm with a flatness tolerance of 0.1 and a surface finish of Ra5.0v0.8mm
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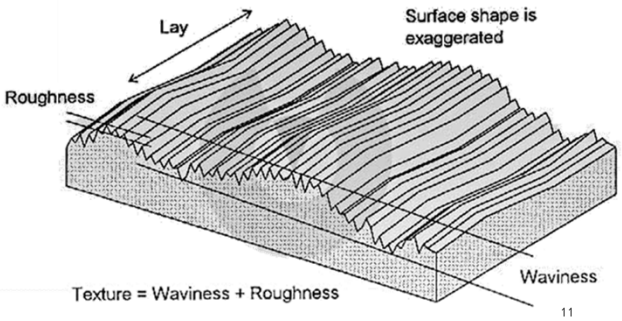
Ra5 √.8mm
R = Roughtness
a = Surface
5 = Assessment length
√.8mm = root mean squared value of all vertical deviations from the mean surface level



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Defining functional failures

The primary function of a milling machine is "To finish mill a work piece in a cycle time of 2.25 ±0.03 minutes to a depth of 10.0±0.05mm with a flatness tolerance of 0.1 and a surface finish of Ra5.0√0.8mm"

Milling Machine v1.2

1. To finish mill a workpiece in a cycle time of 2.25 ±0.03 minutes to a depth of 10.0±0.05mm with a flatness tolerance of 0.1 and a surface finish of Ra5.0v0.8mm
   - 1. Completely unable to mill workpiece
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Not only do “<“ and “>” have different causes but different **consequences**

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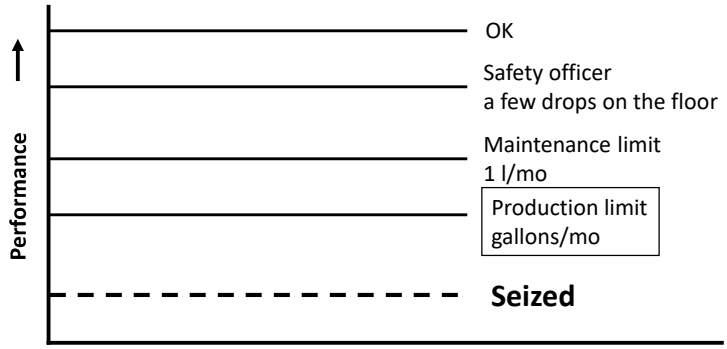
The primary function of a gearbox is *"To transfer power."*
A secondary function is *"to contain the oil"*



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Who should dictate the standard at which the asset is to perform**?**

- All the "users" or their representatives.
- Anyone who could be impacted by diminished performance.
  (That could include the community and society at large.)

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Turbine exhaust system v6.0

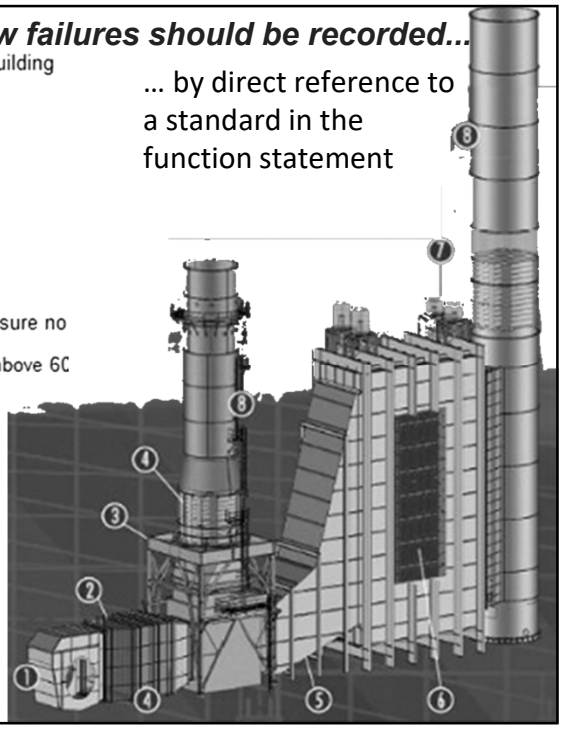
- 1. To deliver all the exhaust gases to an outlet 20 meters above the building
  - 1. Fails to deliver all the gas
  - 2. Delivers no gas
- 2. To contain turbine discharge gases
- 3. Not to introduce flow restrictions
  - 1. Gas flow restricted
- 4. To attenuate sound to ISO 30 at 90 Meters with a reduction of pressure no
- 5. To prevent duct surface temperature in trubine building from rising above 60
  - 1. Allows the surface temperature of the ducting to exceed 60°C
- 6. To warn operators if EGT > 475°C
- 7. To shut down turbine at EGT > 500°C
- 8. Not to distort ducting due to temperature variation

Able

^

How failures should be recorded...

… by direct reference to a standard in the function statement



1 Exhaust Diffuser / Exhaust Plenum
2 Exhaust Duct
3 Exhaust Bypass System
4 Silencer
5 Exhaust / HRSG Inlet Duct
6. HSRG Internal Insulation
7. Vent Silencer
8. Stack
9. EGT warning sensor 475C
10. EGT shutdown sensor 500C

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Passenger Rail Car Bogey v7.1

- 1. To provide smooth rolling support for (up to 26.5 tons) speeds up to 120 kph
  - 1. Unable to support the car on the rails at 120 kph
  - 2. Fails to provide rolling support
  - 3. Fails to provide smooth ride
- 2. To insulate passengers from shocks, Minimize transient oscillations
- 3. To insulate passengers from jerks during acceleration and braking
  - 1. Fails to insulate passengers from jerky stops and starts
- 4. To control the roll angle of the car body relative to the bogie
  - 1. Fails to control the roll angle of the car body at all
- 5. To ensure carriage floor is level with platforms at each station stop
- 6. To assist in stopping the train at up to 0.88 m/s2
- 7. To prevent axle box bogie frame contact under severe bounce conditions
- 8. To permit the bogie to be lifted and/or the car to be towed easily
  - 1. Bogie cannot be lifted or car towed easily
- 9. To ensure wheelsets remain attached to bogie while bogie is being lifted
- 10. To insulate the car from shocks to some extent if the air bag fails
- 11. To limit lateral movement of car relative to bogie
- 12. To prevent traction link retaining nut from coming undone
- 13. To prevent compound spring retaining nut from coming undone

Bogey Failures

https://206.189.168.145:8181/mesh/knowledge/builder/for/6

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RCM: **A process used to**
determine what must be done
to ensure that a physical asset continues to do what
its users require it to do in its operating context:

What do its users require it do (Functions)?
What specific performance losses can occur (Failures)?
Failures Modes → **What event causes the failure (Failure mode)?**
What happens when it fails (Effects)?
Why does it matter (Consequences)?
Can you predict, prevent or mitigate the failure consequences (Maintenance task)?
What if no mitigating task can be found (Default action)?

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2.3.1 Quiz 1 FMEA

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1. Failure analysis is relatively straightforward because the functional analysis will have specified each required performance standard. True or False? * 1 point

- ○ True
- ○ False

2. The definition of failure is universal regardless of which failure management methodology is being used, for example FMEA, RCM, ISO 14224. True or False? * 1 point

- ○ True
- ○ False

3. According to RCM a failure has occurred: * 1 point

- ○ 1. The moment a user's requirement lies beyond the equipment's current capability, for whatever reason
- ○ 2. When a signal indicating abnormal vibration is received.
- ○ 3. When a high level alarm sounds.
- ○ 4. All of the above.
- ○ 5. None of the above.

4. When performing failure analysis it is essential that the facilitator ask: * 1 point

- ○ 1. Is a total failure reasonably likely regarding this performance standard?
- ○ 2. What partial inabilities to meet the performance standard are reasonably likely to occur?
- ○ 3. Both of the above.
- ○ 4. Neither of the above.

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Failure Modes

(3 important questions to consider)

1. Which failure modes are **significant** enough to be included in the analysis?
2. What is the **grammatical syntax** of the failure mode?
3. **How far down** the causality chain do we go?

Warning: Another terminology clash

Completely different meanings of "Failure Mode" among:

ISO 14224: "**Failure Mode**"
- effect by which a failure is observed on the failed item

FMECA Mil Std 1629A: "**Failure Mode**"
- The analysis of the extent to which a performance standard specified within a function statement can be compromised or cease to perform as required by the asset's users.

RCM: "**Failure Mode**"
- The event that causes the failure.

1. Failure mode – the event causing the failure

Can have 1 to 3 grammatical segments:

1. A noun (e.g. “filter”, "air conditioning unit"), and
2. A verb (action phrase) describing the degradation mechanism (e.g. "blocked, “perforated”, "belts loose"), and
3. A “by …, due to” (“normal use”, “rough handling” clause giving the cause.

You can have a noun there too.

Segment 2 and 3 are optional.

SAP: 1. “Object part”, 2. “Object damage”, and 3. “Failure cause”.

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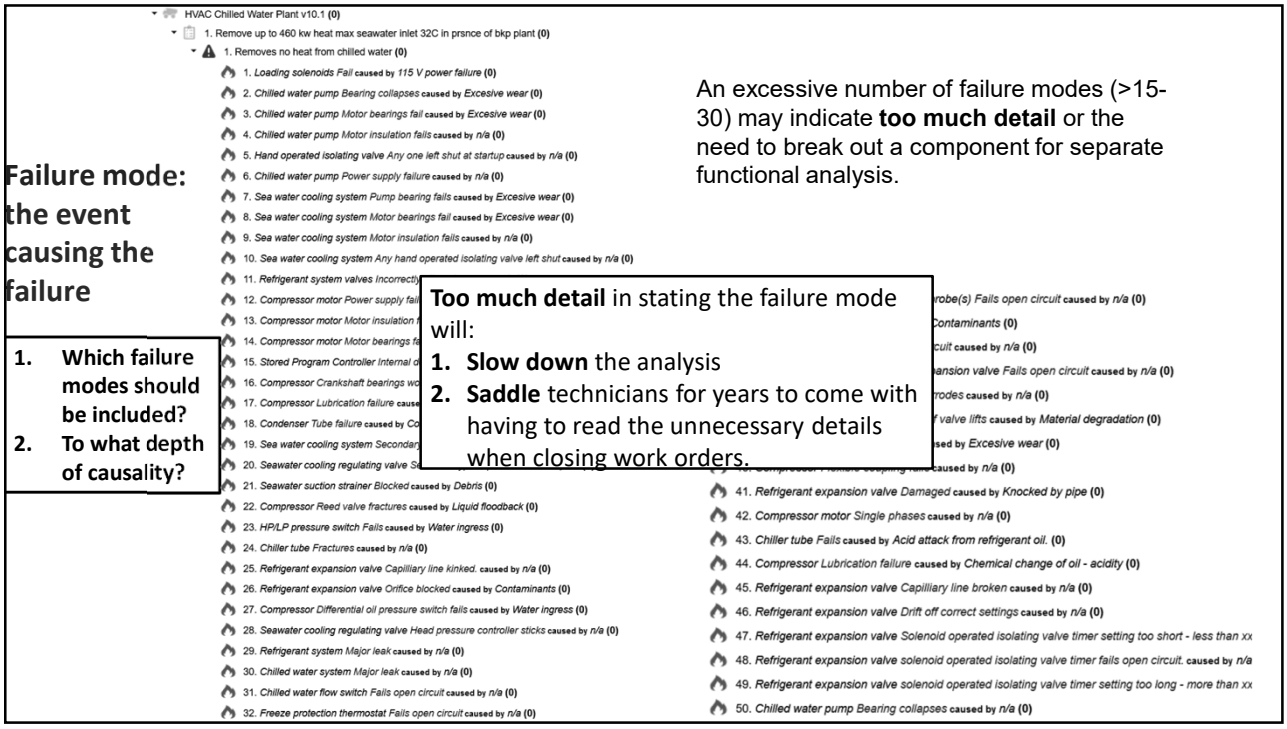

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Failure mode: the event causing the failure

1. Remove up to 460 kw heat max seawater inlet 32C in prsnce of bkp plant **(0)**
   - 1. Removes no heat from chilled water **(0)**
     - 1. *Loading solenoids* *Fail* **caused by** *115 V power failure* **(0)**
     - 2. *Chilled water pump Bearing collapses* **caused by** *Excesive wear* **(0)**
     - 3. *Chilled water pump Motor bearings fail* **caused by** *Excesive wear* **(0)**
     - 4. *Chilled water pump Motor insulation fails* **caused by** *n/a* **(0)**
     - 5. *Hand operated isolating valve Any one left shut at startup* **caused by** *n/a* **(0)**
     - 6. *Chilled water pump Power supply failure* **caused by** *n/a* **(0)**
     - 7. *Sea water cooling system Pump bearing fails* **caused by** *Excesive wear* **(0)**
     - 8. *Sea water cooling system Motor bearings fail* **caused by** *Excesive wear* **(0)**
     - 9. *Sea water cooling system Motor insulation fails* **caused by** *n/a* **(0)**
     - 10. *Sea water cooling system Any hand operated isolating valve left shut* **caused by** *n/a* **(0)**
     - 11. *Refrigerant system valves Incorrectly aligned* **caused by** *n/a* **(0)**
     - 12. *Compressor motor Power supply failure* **caused by** *n/a* **(0)**
     - 13. *Compressor motor Motor insulation fails* **caused by** *n/a* **(0)**
     - 14. *Compressor motor Motor bearings fail* **caused by** *n/a* **(0)**

In all cases a (object) part is identified.

1. **Which failure modes should be included?**
2. **To what depth of causality?**

What is the rhyme or reason behind these **seemingly random** variations of depth and specificity?

Use "Fail" or "Fails" when the precise **mechanism of deterioration** is not worth noting.

Sometimes it is worthwhile to state an underlying or root cause of the failures

Or we can include in the second segment the specific part that fails.

Sometimes it is important to describe the mechanism of deterioration.

Often the **cause** of failure adds no **worthwhile** knowledge and we simply say **n/a (not applicable)**

Sometimes we named a part or component as the noun of segment 1

Other times we named a whole sub-system or system as the object part.

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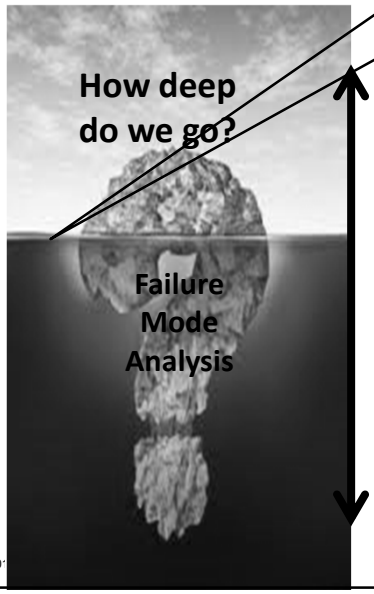
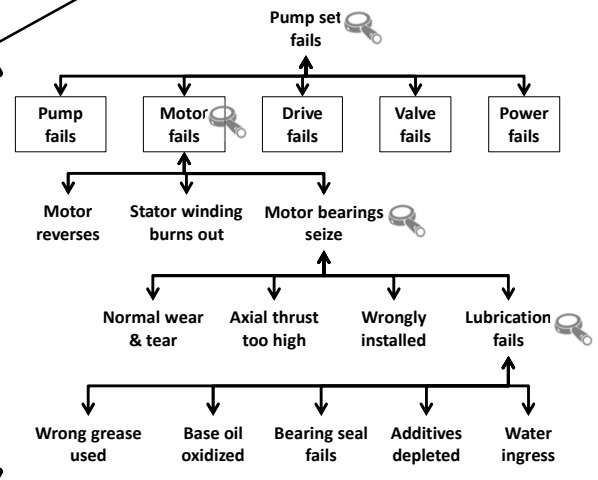
Failure mode – how deep?

At what depth to we identify the object part? Object damage? failure cause?





To the depth where it can be managed

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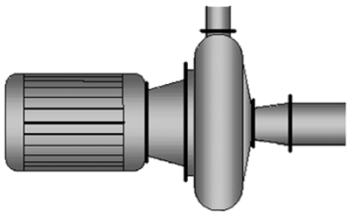
Failure mode – What "event" causes the failure?

For this pump, what failure modes could cause the functional failure:

1. Unable to pump at all
2. Pumps less than 800 lpm?



- Centrifugal pump v4.1
  - 1. To transfer 800 lpm of water from tank A to tank B located 10 ft above tank A
    - 1. Transfers 0 lpm
    - 2. Transfers < 800 lpm

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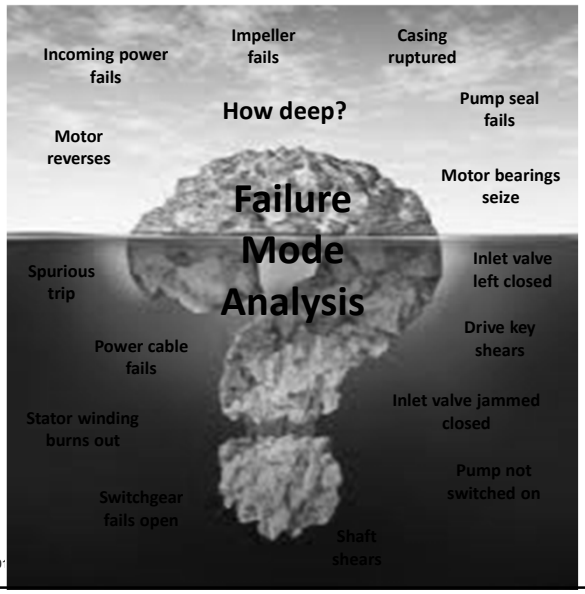
Failure mode – **how many** (*from among infinite possibilities)* must we identify?



Too few or insufficient depth:

Superficial and possibly dangerous maintenance plan.

Too many and/or too much depth

Bogged down analysis

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Failure mode – which ones?

Only failure modes that are reasonably likely:

1. They have occurred in the past
2. They are presently being addressed by existing PM programs
3. They have not occurred yet but are thought to be real possibilities

If the consequences are significant, then less likely failure modes should be analyzed.

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The third failure mode segment: the "due to" clause

Should be included if it adds value to the analysis (i.e. will assist in Q4 to Q7)

1. **Deterioration** *(evaporation, erosion, fatigue, abrasion, corrosion, oxidation, wear and tear, calibration drift, etc)*
2. **Lubrication** *(lack of, contamination of, or wrong lubricant)*
3. **Dirt** *(blockage, impedes movement, impedes electrical contact, impedes sight)*
4. **Raw material** *(quality, humidity, spec)*
5. **Dissassembly** *(bolt comes loose)*
6. **Maintenance error**
7. **Operation error**

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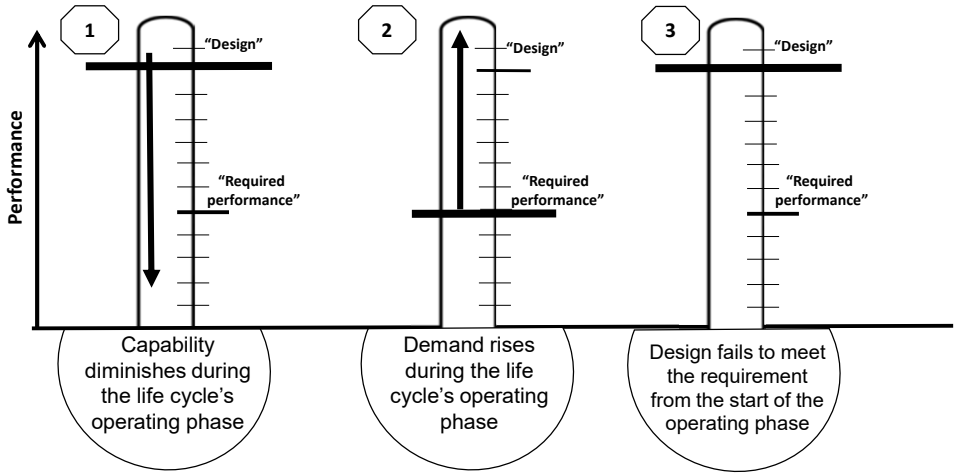
3-way collaboration



Reliability is a collaboration among

Maintainers and **Operators** and **Designers/builders**

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2.3.1 Quiz 2 FMEA

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1. In the language of RCM a failure mode is: * 1 point

- 1. an effect of failure
- 2. a loss of function
- 3. an event that causes the failure
- 4. all of the above.
- 5. none of the above.

2. By "reasonably likely", referring to a failure mode, it is meant that: * 1 point

- 1. The failure mode can occur often enough or has consequences severe enough to be of concern.
- 2. A failure mode with more severe consequences may be "reasonably likely" even if it occurs less often.
- 3. A failure mode that can occur more often may be "reasonably likely" even if the consequences are less severe.
- 4. A consensus of analysts having judged the frequency and severity conclude it is "reasonably likely".
- 5. All of the above.
- 6. None of the above.

3. A failure mode is said to be the "lowest common denominator" or "currency of maintenance". Which of the following statements are true? *

- 1. The failure mode encompasses its own complete set of Effects, Consequences, and Mitigation tasks.
- 2. The failure mode is the level in the asset hierarchy at which we will manage the consequences of failure.
- 3. If we address the consequences of all reasonably likely failure modes our maintenance plan will be complete.
- 4. All of the above.
- 5. None of the above.

4. At what depth in the hierarchical structure of a physical asset should we identify a failure mode? *

- 1. As deeply as we can.
- 2. To the depth where the organization can mitigate, in a practical way, the consequences of failure.
- 3. We should ask "why" five times.
- 4. All of the above.
- 5. None of the above.

5. In RCM analysis, when the failure mode is determined to be human error, which category requires particular objectivity and sensitivity as recommended by James Reason? *

- 1. anthropometric factors
- 2. sensory factors
- 3. physiological factors
- 4. psychological factors
- 5. none of the above.

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Human error four categories (Ben Blanchard)

- **Anthropometrical factors**: A person (or part of a person, such as a hand or arm):
  - *cannot fit into the space available to do something*
  - *cannot reach something*
  - *is not strong or dexterous enough to lift or move something*
- **Human sensory factors**: A person cannot see (field of view, color schemes), or cannot hear (background noise levels)
- **Physiological factors**: Environmental stresses reduce human performance (temperature, vibration, humidity, duration)
- **Psychological factors**: Can be a sensitive issue but RCM handles it carefully and objectively. – see next slide

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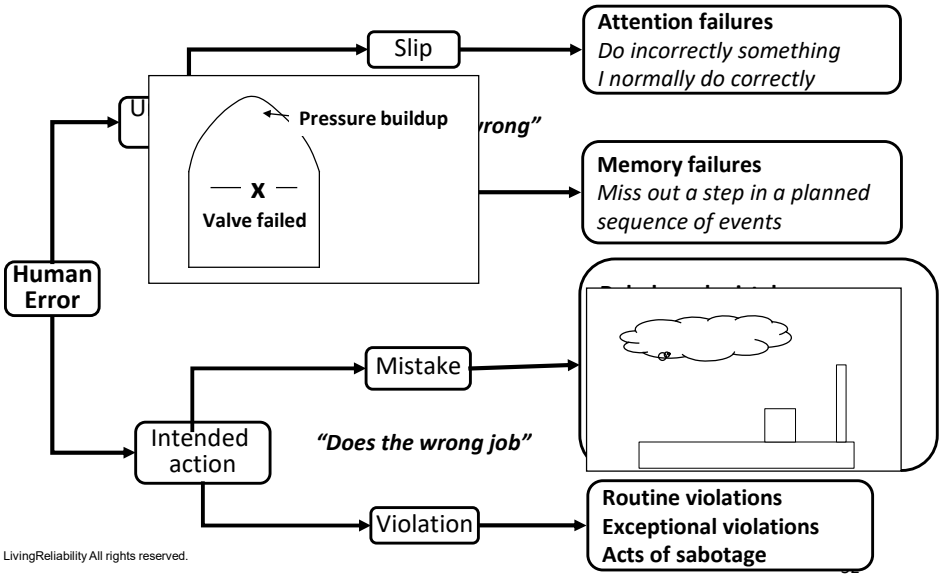
Psychological errors: Slip, Lapse, Mistake, Violation



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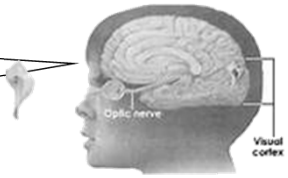
Human error

Regardless of which of the four categories of human error are being analyzed

1. Anthropometrical
2. Human sensory
3. Physiological, or
4. Psychological factors

there are two cardinal rules when analyzing hurman error in RCM:

1. **Do not say "who", and**
2. **No comeback.**



Who?

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Flight AA965 Miami to Cali

1. Takes off from Miami 21:34 Dec 20, 1995 on direct flight to Cali
2. Flight navigation totally automatic guided by radio beacons at Tulua, Rozo, Cali
3. Control tower at Cali suggests direct approach to Rozo runway
4. Pilot programs “R”, engages air brakes to allow time for change

Investigation

1. *Failure to plan, Automation.*
2. *Numerous cues*
3. *Situational awareness*
4. *Radio navigation*
5. *Time*
6. *Speed brakes*
7. *FMS logic*
8. *Naming convention*

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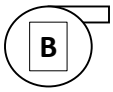
Identical items can have different failure modes if the operating context is different...

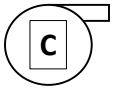
Protected Pump (functions in the presence of a Stand-by)



- Bearings seized
- Impeller cracked by collision with object
- Suction line blocked by dirt
- Coupling bolts shear due to fatigue
- Power drops/fails
- *etc*

Same pump different failure mode due to operational context

Backup Pump



- Brinelling of bearings
- Suction line blocked by dirt
- Key component "borrowed" in emergency
- Lack of Grease in bearings
- Power drops/fails
- *etc.*

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Failure mode – the event causing the failure

- Passenger Rail Car Bogey v6.1
  - 1. Smooth rolling support for (up to 26.5 tons) speeds up to 120 kph
    - 1. Fails to provide support
      - 1. *Frame Weld fails* **caused by** *Fatigue*
      - 2. *Wheel Collapses* **caused by** *Fatigue*
      - 3. *Axle Fails* **caused by** *Fatigue*
      - 4. *Frame Component fails* **caused by** *Fatigue*
    - 2. Unable to support the car on the rails at 120 kph
    - 3. Fails to provide rolling support
    - 4. Fails to provide smooth ride
  - 2. Insulate passengers from shocks, Minimize transient oscillations

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RCM:

A process used to
determine what must be done
to ensure that a physical asset continues to do what
its users require it to do in its operating context:

What do its users require it do (Functions)?
What specific performance losses can occur (Failures)?
What event causes the failure (Failure mode)?
Failure Effects **What happens when it fails (Effects)?**
Why does it matter (Consequences)?
Can you predict, prevent or mitigate the failure consequences (Maintenance task)?
What if no mitigating task can be found (Default action)?

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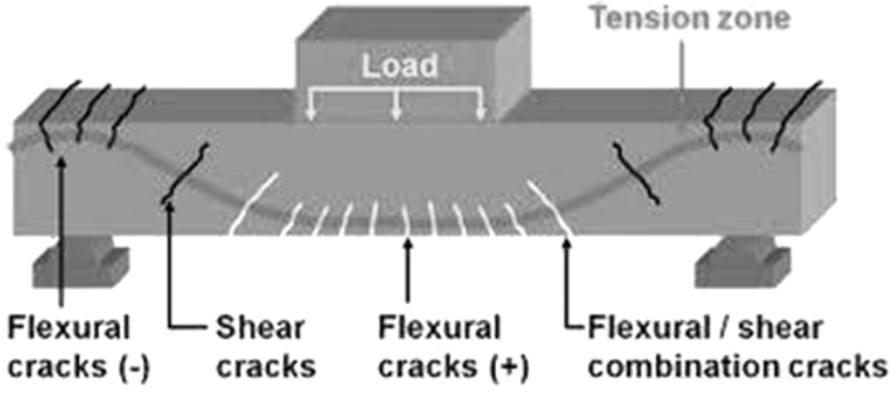
Caution: Confusing Failure *mode* with Failure *effects*



Wrong! Why?

Failure mode: Cracks form in rail car suspension frame

Failure effects: Cracks form. Inspectors discover cracks > 20 mm. Unit removed from service and repaired. Downtime 4 hours.

Failure consequences: Operational

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Effects: Should be a "Zero based analysis"

What if there is already a PM or other consequence mitigating action in place?

The effects describe what *would* happen if nothing were done to prevent it.

(But should mention what activities or circumstances currently mitigate the consequences.)

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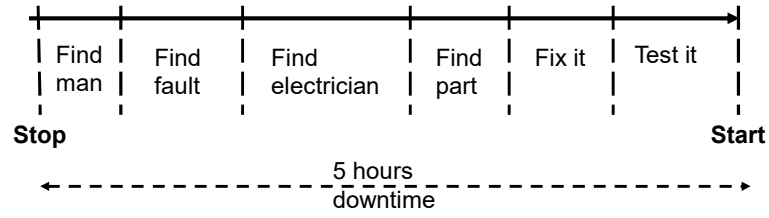
Repair time or downtime? Which to use (in describing the "Effects"?



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Failure Effects and **Failure Consequences** are commonly confused:

What is the difference between them?

Effects: "What happens"

Consequences: "Why it matters"

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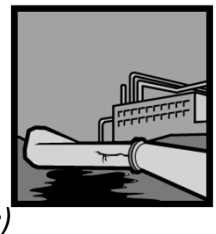
Failure effect description should enable RCM review group to assess **failure consequences:**

1. **What sequence of events** *(internally and organization wide) could be touched off by or precede (influence or render more likely) the failure mode event?)*
2. **How does the failure make itself known** (on its own)*?
3. **Can someone be harmed?** *How is safety or the environment impacted? (without mentioning the words "safety" or "environment")*
4. **How is production impacted?** *(quality, cost, customer service)*
5. **Is there any additional damage** *caused by the failure?*
6. **How does** *the likelihood of this failure depend on* **deeper causes?** *Has it happened before? Under what circumstances?*
7. **How long** *will it take (to get asset back up) and what (general) actions must be accomplished to correct the failure?*



***Under normal circumstances.**

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Effects examples

What can happen when the Failure Mode occurs. A hypothetical narrative of the likely plausible events and resulting actions by operators and maintainers.

1A1 Spring charge chain has insufficient lubrication.	Over a period of time the chain will corrode,stiffen,seize,then break. The closing spring will not be charged. Breaker will trip but will not re-close. Therefore the breaker is unable to switch closed. This will increase the risk of customer outage/system stability. The spring charging motor will continue to run.Troubleshoot up to 2 hours, repair up to 2 days, 2people, $2000. This has occurred in the past elsewhere but the actual frequency has not been documented.
1A2 Endless chain has insufficient lubrication.	Over a period of time the chain will corrode,stiffen,seize,then break.The closing spring will not be charged. Breaker will trip but will not re-close.Therefore the breaker is unable to switch closed. This will increase the risk of customer outage/system stability. Troubleshoot up to 2 hours, repair up to 4 days, 2 people, $4000. This has occurred in the past elsewhere but the actual frequency has not been documented.This could result in secondary damage to the operating mechanism components.
1A3 Closing springs has insufficient lube.	Over a period of time the springs will corrode,weaken, break this could jam the operating mechanism. Breaker will trip but will not re-close.Therefore the breaker is unable to switch closed.This will increase the risk of customer outage/system stability.Troubleshoot up to 2 hours, repair up to 4 days, 2 people, $4000. The actual frequency has not been documented.This could result in secondary damage to the operating mechanism components.
	The clutch will slip excessively, not turning the gear, does not drive the chain, closing springs are not

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Effects examples

What can
plausible

1A1 Spring charge chain has insufficient
lubrication.

1A2 Endless chain has insufficient
lubrication.

1A3 Closing springs has insufficient lub

Failure Mode

Feedscrew V-belt pulley key fails caused by n/a

(From RCMCost):

Effects

Summary:	Motor turns but material flow stops, eventually sounding bin level alarm. It takes two hours to replace the key. (The only times this has occurred on the old conveyors has been shortly after the feed screw has been reassembled, which suggests that keys only tend to fail if they are incorrectly fitted.
Corrective Task:	Replace key
Skills:	Mechanic

Est. Downtime(h): 2

Consequence

Operational

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Effects : the story

RCM REF	Function Statements (Quantitative Performance Requirements)	Failed States (Ways Performance is Lost)	Failure Causes	Effects
1	To provide smooth rolling support for half the weight of a passenger car (up to 26.5 tons) on the rails at speeds up to 120 kph	Fails to provide support	Weld in frame fails due to fatigue	The bogie as a whole collapses. This is most likely to occur when the car is most heavily loaded - in other words when it is full of passengers, and probably while the train is going round a corner. As a result, it would almost certainly be derailed. At present, the bogie is replaced when a crack longer than 100 mm is found. (Such a crack would be found during course of other inspections that occur often enough to detect it). Downtime to replace bogie on its own 16 hours.
2	To provide smooth rolling support for half the weight of a passenger car (up to 26.5 tons) on the rails at speeds up to 120 kph	Fails to provide support	Wheel collapses due to fatigue	The bogie as a whole collapses. This is most likely to occur when the car is most heavily loaded - in other words when it is full of passengers, and probably while the train is going round a corner. As a result, it would almost certainly be derailed. Only one cracked wheel has been found to date. It takes 8 hours to replace a wheel
3	To provide smooth rolling support for half the weight of a passenger car (up to 26.5 tons) on the rails at speeds up to 120 kph	Fails to provide support	Axel fails due to fatigue	The bogie as a whole collapses. This is most likely to occur when the car is most heavily loaded - in other words when it is full of passengers, and probably while the train is going round a corner. As a result, it would almost certainly be derailed. No axles have failed so far.
4	To provide smooth rolling support for half the weight of a	Fails to provide support	Bogie frame component	Initial cracking is likely to lead to frame distortion, which could make the bogie unstable enough to derail the train. As before, this is most likely to happen when heavily loaded - in other words, when it is full of

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2.3.1 Quiz 3 FMEA

https://forms.gle/UhnJ59WxqygbXv346

1. Which of the following should not be included in the Effects narrative: * 1 point

- ○ 1. The sequence of relevant hypothetical events surrounding a failure mode.
- ○ 2. Sufficient detail to allow the selection, in the subsequent question, of the consequences of the failure.
- ○ 3. The words "Health", "Safety", or "Environment"
- ○ 4. An estimate of the downtime and skills required for corrective action.
- ○ 5. Any dissenting opinions.
- ○ 6. Judgments of probability and whether the failure mode has happened before.

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