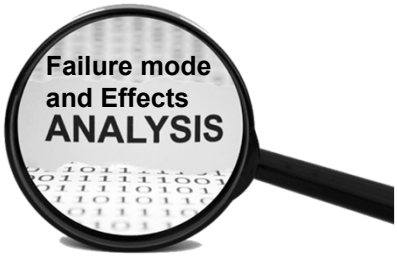
Consequences

Module 2.4en

Why the failure matters

livingReliability
Potenciando el Mantenimiento

1



IS INTERESTING, BUT ..

The reason for our concern with failure

is its

CONSEQUENCES

Stanley Nowlan and Howard Heap
RCM Report 1978

2

The consequences of the failure rather than the failure itself

drive the maintenance plan.

 3

3

Nevertheless, up until the early 90s, massive **yearly** equipment overhauls were carried out religiously in many industries, without a formal analysis the failures' consequences.

Throughout the 70s and 80s most authors and consultants still extolled the benefits of **Age Based Preventive Maintenance**, seemingly, for its own sake.

John Moubray In his book RCM II in 1991 emphasized that shifting the focus of maintenance management onto the **Consequences** of failure was, in his words, "one of the most extraordinary revelations of RCM".

 4

4

How do the analysts decide upon the consequences?

They consider the Effects of Question 4….

EFFECTS

in order to determine

5

5

The effects narrative may direct the analysts towards a policy.

6

6

2.4.1 Quiz 1 Consequences

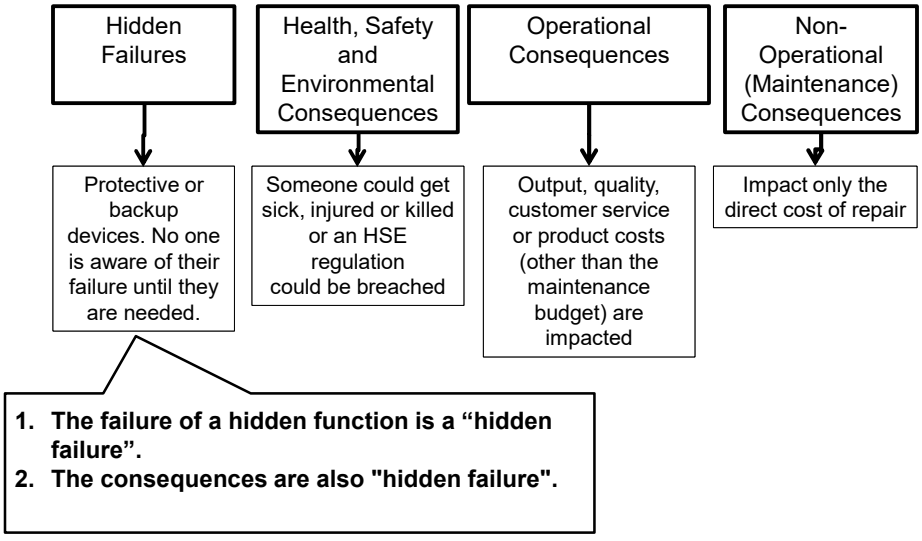
https://forms.gle/epuhqrKEqprDR9Eu5

1. With regard to understanding the difference between "Failure Effects" and "Failure Consequences" which of the following descriptions are most helpful? * 1 point

- ○ A failure mode is the effect by which a failure is observed on the failed item.
- ○ The failure impact on equipment function is the effect on equipment-unit function, for example: critical, degraded, or incipient failure.
- ○ The Effects describe what happens when the failure mode occurs.The Consequences describe why the failure matters.
- ○ The Consequences describe the effect of PM on failure rate.
- ○ All of the above.

7

Four Failure Consequences



8

2.4.1 Quiz 2 Consequences

https://forms.gle/4oqarNFF1XqiiZX48

1. RCM identifies four types of consequences (Hidden, Health-Safety-Environmental, Operational, Non-operational). True or False. * 1 point

- ○ True
- ○ False

9

Question 6 - A proactive task must be:

Applicable:

Technically Feasible

The task is *practical* to do at the *frequency* needed to be effective.

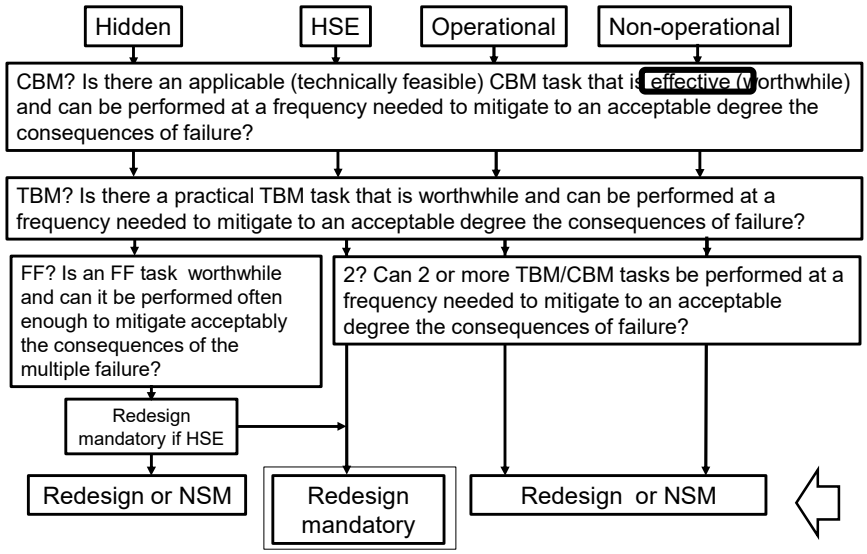
Effective:

Worthwhile

The task reduces the consequences of the failure mode sufficiently to justify the costs (direct and indirect) of doing the task.

10

The RCM Decision Tree



11

2.4.1 Quiz 3 Consequences

https://forms.gle/iTAML9cJGXKp3PB19

1. A PM task that can be done frequently enough to sufficiently reduce risk is (choose one of): * 1 point

- ○ 1. Applicable
- ○ 2. Effective
- ○ 3. Applicable and effective
- ○ 4. Worthwhile
- ○ 5. Technically feasible.

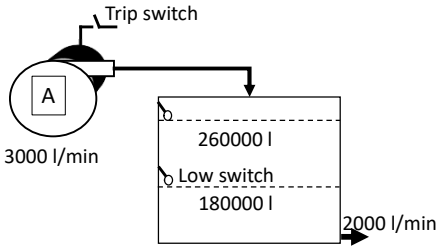
12

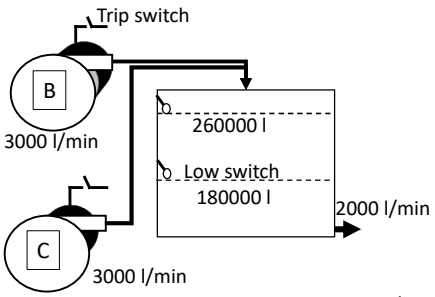
Proposed PdM task: Check for noise weekly
Cost: 20 min/check x 52 checks/y x 1h/60min x $24/h x 3.5 years + 6000 = 8000

Age	1	2	3	4	5	6
Mtbf	3.5 years					

PdM cost / benefit (two idealized contexts)

Bearing seizes
4 hours
$6000





Failure Effects	Quantity	Units	Cost $
Low lvl alarm	180000	l	
Supply	3000	lpm	
Demand	2000	lpm	
Reserve = 180000/2000 x 1/60	1.5	hrs	
Pump downtime	4	hrs	6000
Lost product = 4-1.5 hr @ $5K/h	2.5	hrs	12500
Frequency of failure	3.5	yrs	
Total cost of failure every 3.5 yrs			**18500**

Failure Effects	Quantity	Unit	st $
Low level alarm	180		
Operator switches to C			
Pump downtime			6000
Lost product		0 hrs	0
Total cost			6000

This decision is valid only if C starts on demand.

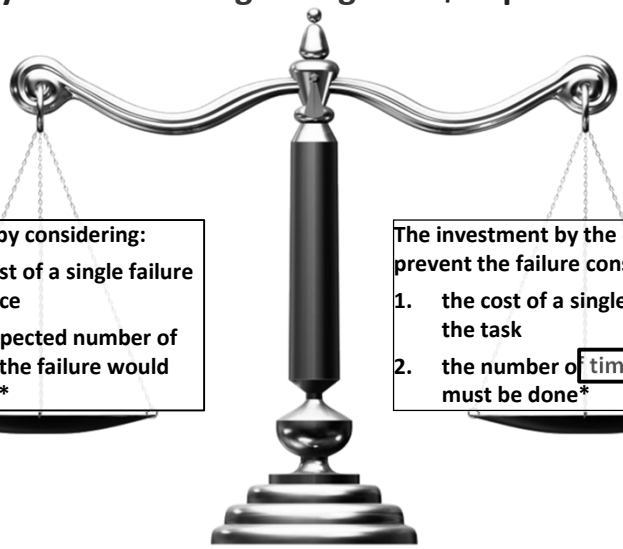
CBM not justified

CBM economically justified

13

13

$ & probability of Failure weighed against $ & prob of Prevention/mitigation



Estimated by considering:
1. **the cost of a single failure instance**
2. **the expected number of times the failure would occur.***

The investment by the enterprise to prevent the failure considers:
1. **the cost of a single instance of the task**
2. **the number of times the task must be done***

*** Assessed over the same reasonably long time period.**

14

14

2.4.1 Quiz 4 Consequences

https://forms.gle/T5CfmDp4biGPzgoYA

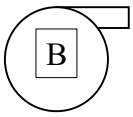
1. If a PM task is considered to be applicable and effective in accomplishing its stated risk objective it should be included in the maintenance plan True or False. * 1 point

- ○ True
- ○ False

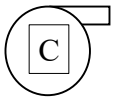
15

15

Hidden Failures (i.e. of a protective function)



If pump B fails, switch to C and repair B



No direct consequences if C fails while B is still working. Failure of C only matters if B also fails

A hidden failure is a functional failure that will not on its own become evident to the operating crew under normal circumstances

Fail-safe device:

- Its failure will be known

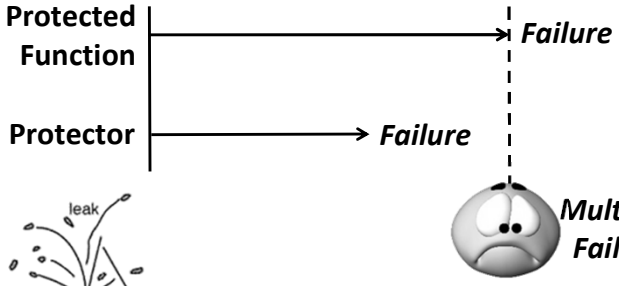
16

16

Hidden Failures

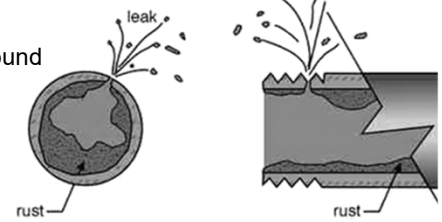
Hidden functions are ~~almost~~ always **protective functions**.

We have the "**protected**" function and the "**protector**" (the protective device or system).



A multiple failure is usually serious or catastrophic

Underground pipe?



17

17

2.4.1 Quiz 5 Consequences

https://forms.gle/crHcnyKH2STAwtCE9

1. A multiple failure can occur without anyone knowing about it. True or false? * 1 point

- ○ True
- ○ False

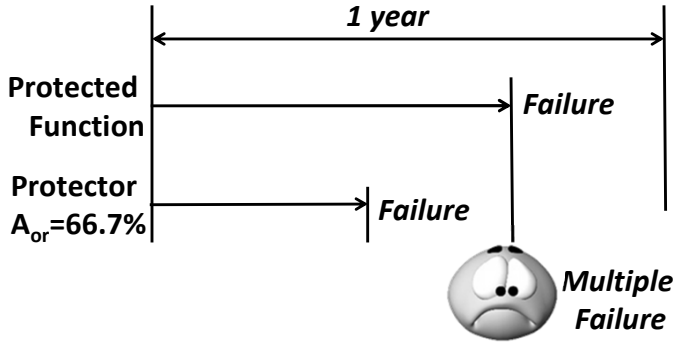
18

18

How is the Protector's performance measured?

Availability: The probability that it will be available when called upon. For example, A_{or} = 66.7%. = $\frac{MTBF}{MTBF + MDT}$ = $\frac{4}{4+2}$

Unavailability= $\frac{MDT}{MTBF+MDT} = \frac{2}{4+2} = 33.3\%$

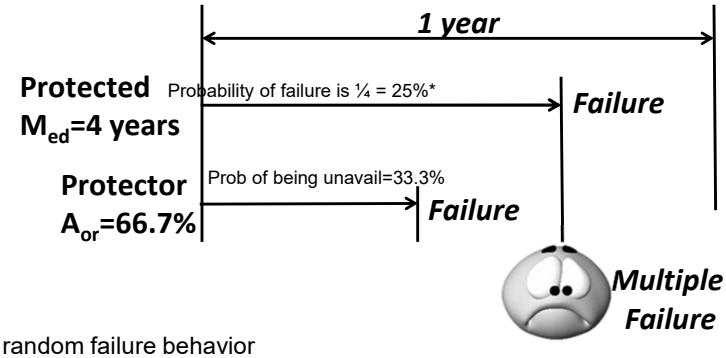


19

19

A protected function's performance is measure by "Reliability"

Reliability: MTBF of the protected function = M_{ed}, say 4 years. So in a given year its



*assuming random failure behavior

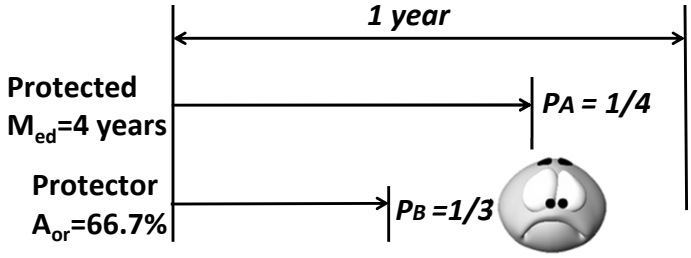
20

20

Probability of a multiple failure

- Event A: The probability that the Protect**ed** Function will fail in the year =1/4
- Event B: The probability that Protect**or** will be down at any given moment = 1/3

The probability of two independent events occurring is determined by multiplying their individual probabilities:



Probability Multiple Failure = P_A * P_B = 1/4*1/3 = 1/12

21

2.4.1 Quiz 6 Consequences

https://forms.gle/KtiQCbhqy5JHkucB6

1. MTBF is a convenient approximation of reliability. A safety system's performance is measured by its availability. Which of the following is most accurate? * 1 point

- ○ 1. A safety function's reliability determines the probability of a multiple failure.
- ○ 2. A protected function's availability determines the probability of a multiple failure.
- ○ 3. The unavailability of the safety device multiplied by the unreliability of the protected function yields the multiple failure probability.

22

Who should decide what the tolerable probability of multiple failure should be?

Those exposed to the risk.
They would be guided by two factors:

1. **Probability** of the MF
2. The degree to which *they believe* they have a **choice** or are in **control** of their exposure

23

23

Tolerable fatality risk examples

Situation	Choice / Control	Probability of death in a year that I am prepared to tolerate
In my car	I think I am in control of my car and have made the choice to operate it on a public road	1/5000
At work	I chose to work there and have some control over the degree of exposure	1/10000 (10^{-4})
In a passenger plane	I chose to fly but have no control	1/1000000 (10^{-6})
A nearby explosives factory that can kill me or a member of my family.	No choice or control	1/10000000 (10^{-7})

24

24

Actual probabilities of being killed in a year

- Probability of being killed on the road in any one year:

GERMANY	1 in 10000
UK	1 in 13500
CHILE	1 in 6250
USA	1 in 6000
FRANCE	1 in 4000
RSA	1 in 3500

- Probability of being killed on the job in any one year :

NORTH SEA FISHING	1 in 1000
FARMING	1 in 10000
MINING	1 in 10000
STEEL	1 in 10000
AUTOMOTIVE	1 in 100000
LIGHT MFG	1 in 100000
OFFICES	1 in 1000000

25

25

Risk of death in a large plant in any one year

Level	No of risk locations	Tolerable probability per instance
Site	1	1/100
Area	10 areas on the site	1/1000
Line	10 production lines in each area	1/10000
Event	100 events in a line that could kill 1 person*	1/1000000

The probability of you or one of your co-workers being killed in your industry a given is 1/10,000.

There are 100 workers in your plant, therefore the probability of a fatality in your plant any year would be:

1/10,000 x 100 = 1/100.

*If an event can kill more than one person, say 10 people then the tolerable probability must be reduced to 1/10,000,000

However if an event has a 1 in 10 chance of killing one person than the probability that can be tolerated can be increased to 1 in 100,000

26

26

Tolerable monetary risk example

An event that can cause a loss of:	Probability that the organization is prepared to tolerate
$200	1/1000 (10^{-3})
$2000	1/100000 (10^{-5})
$200,000	1/1000000 (10^{-6})
$2,000,000	1/10000000 (10^{-8})

27

2.4.1 Quiz 7 Consequences

https://forms.gle/THDy2v8Dn2gRmvnY9

1. Risk is often assessed as the multiplication product of failure (or multiple failure) probability and the human value of the losses associated with failure. In the RCM way of thinking whose viewpoint should be key in deciding what level of prevention or mitigation is appropriate? * 1 point

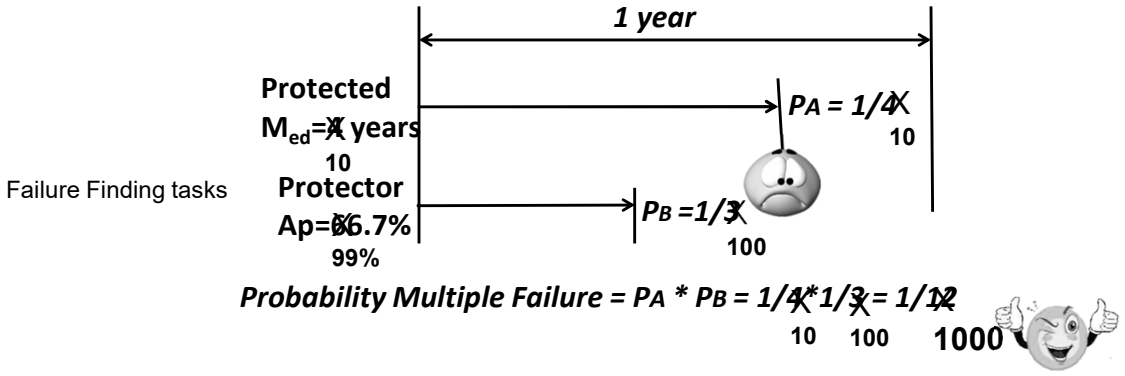
- ○ 1. A government agency should have the final say as to what maintenance or design strategy is required.
- ○ 2. The employee's union should have the final say.
- ○ 3. The likely victims and their survivors, as well as those who will need to deal with the ramifications of the failure should have the decisive voice.

28

How to reduce probability of the multiple failure

- Event A: The probability that Protected will fail in the year =1/10
- Event B: The probability that Protector will be down = 1/100

Dissatisfied with 1/12 we might decide to tolerate 1/1000. We would need to reduce P(A) and / or P(B):



Probability Multiple Failure = P_A * P_B = 1/10*1/100 = 1/1000

29

29

Safety interlocks	Ultimate level, Temperature, pressure switches
Shear pins	Life rafts, parachutes
Backflow valves	Emergency medical equipment
Rupture disks	Over-current circuit breakers
Gas detection	Emergency clothing and breathing apparatus
Emergency stop buttons	Secondary containment
Warning signs and signals	Fire detection, warning and suppression systems
Stand-by equipment	Over-speed switches
Vibration switches	Etc.

30

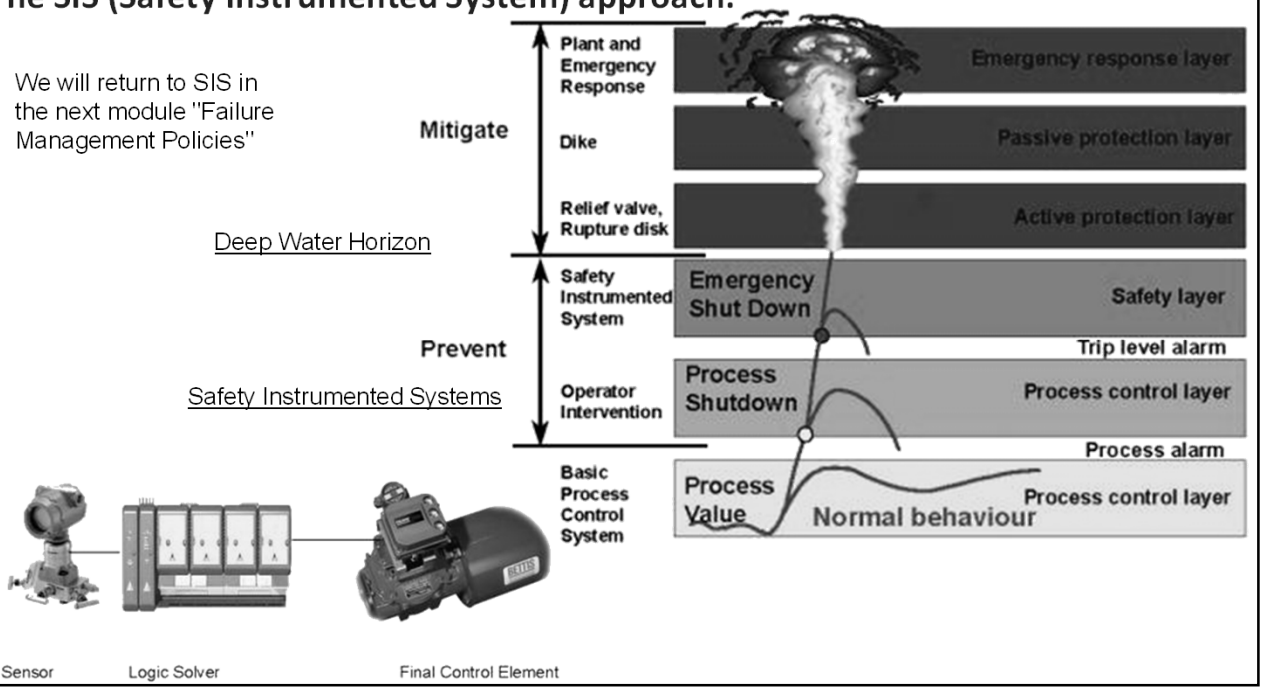
30

The SIS (Safety Instrumented System) approach.

We will return to SIS in the next module "Failure Management Policies"

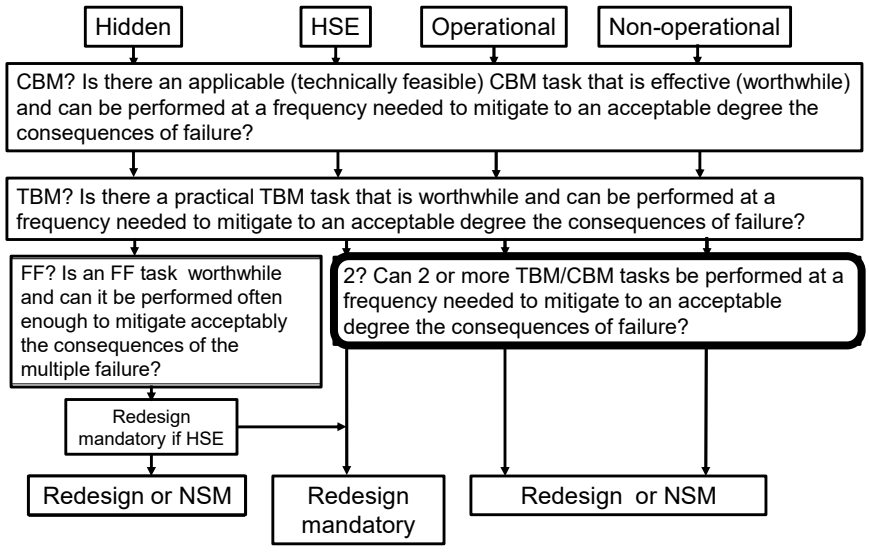
Deep Water Horizon

Safety Instrumented Systems



31

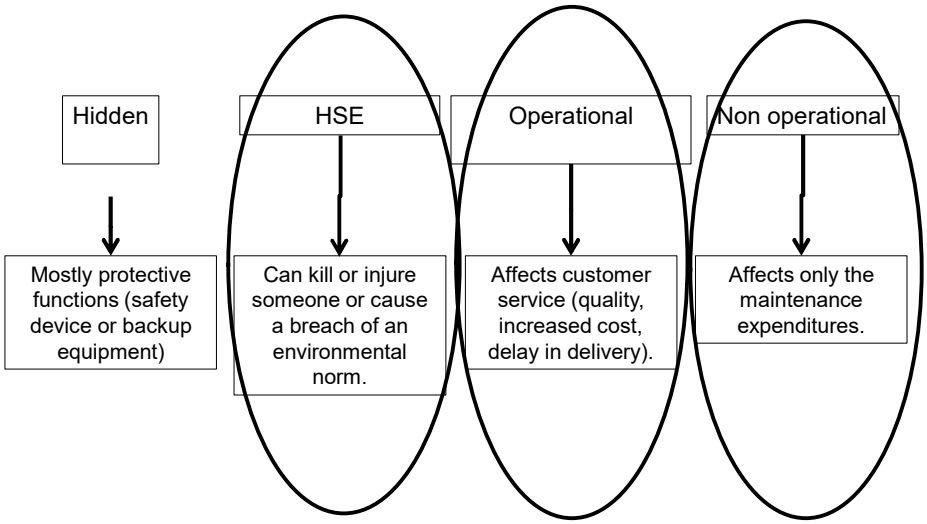
The RCM Decision Tree



32

32

Four failure consequences



33

2.4.1 Quiz 8 Consequences

https://forms.gle/6rnLzuxNDyfYLbDz8

1. When is the decision tree node "Two or more tasks" appropriate for selection by the RCM analysts? * 1 point

- ○ 1. When two applicable and effective tasks are easy and inexpensive to perform.
- ○ 2. When a single PM or CBM task will not sufficiently reduce risk but the combination will.
- ○ 3. When health, safety, or environmental consequences result from the failure.

34

Criticality analysis

Phase I: Prioritizing the systems or equipment for RCM analysis

Phase 2: Risk quantification for each **failure mode**

 35

35

Phase 1
Simple method for system RCM priority

Asset	Issues (cost, throughput, safety, environment, availability, reliability)	Current performance (cost, throughput, safety, environment, availability, reliability)	Target performance	What's it worth to the to attain the target	RCM Priority
C-24	Safety	Lost days 80 /yr	10 days/yr	$50K	High
G-171	Cost				
K-4	Reliability				

 36

36

Phase 2
Step 1: Set up a hazard (severity) classification table

Severity Descriptions

Name	ENVIROMENTAL	SAFETY	OPERATIONAL	COST	
Catastrophic	Major widespread damage or serious breach of legislation. ineffective control measure	Single death or multiple serious injuries or severe occupational illnesses	Loss of the platform or equipment	Greater than €500k	
Critical	Noticeable widespread impact on the environment. Control measures minimally effective	A single severe injury or occupational illness or multiple minor occupational illnesses	Loss of mission capability	Between €200k and €500k	
Marginal	Minor impact on the environment. Control measures substantially effective	At most a single minor injury or a single minor occupational injury	Limite mission capability	Limited mission capability	
Negligible	Little impact. Control measure comprehensive		Minimal disruption to mission capability	Less than €10k	

37

37

Step 2 Set probabilities of occurrence (POC) and weights

Probability Levels

Name	Description	Weight	
Frequent	1 per 500 measures of operation	1	
Probable	< 1 per 500 operating units, but > 1 per 5000 measures of operation	2	
Occasional	< 1 per 5,000 operating units, but > 1 per 50000 measures of operation	3	
Remote	< 1 per 50,000 operating units, but > 1 per 1,000,000 measures of operation	4	
Extremely Unlikely	< 1 per 1,000,000 measures of operation	5	

POC weights

38

38

Step 3 Set the hazard severity (HS) classifications and weights

Severity Levels

Name	Weight	
Catastrophic	1	
Critical	2	
Marginal	3	
Negligible	4	

HS weights

39

39

Step 4 Set the criticality ranges and color codes

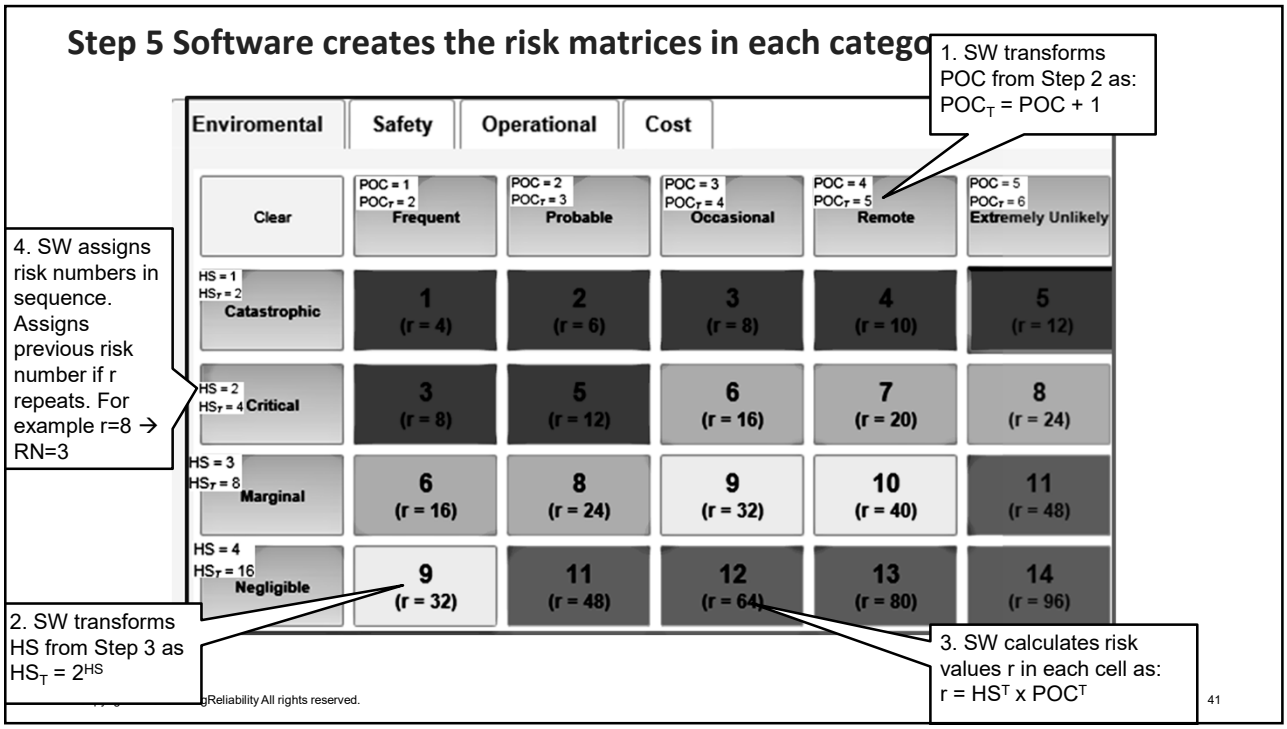
Interpretation of the indices of criticality risks

Color	Criticality	Interpretation	
	5	Unacceptable	
	8	Undesirable	
	10	Tolerable	
	14	Acceptable	

40

40

Step 5 Software creates the risk matrices in each catego



41

41

Step 6 Set failure mode criticality based on RCM Effects and Consequences analysis.

42