CONGRESO DE MANTENIMIENTO & CONFIABILIDAD COLOMBIA 1ª EDICIÓN

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BRÚJULA

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FMEA, FMECA, and RCM – What's the difference?

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James Reyes-Picknell

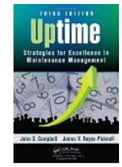
BASc, P.Eng., CMC, CMRP, CAMA, MMP, CSAM, CBPro

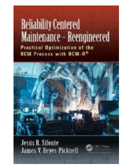
- Mechanical Engineer, University of Toronto, 1977,
- Post grad with RNEC (UK) and TUNS (Dalhousie)

- 45+ year career in Maintenance and Asset Management.
  - Hands on roles in Canadian Navy, Esso Chemcials Canada, Saint John Shipbuilding / Naval Systems, IMP Aerospace.
  - Consulting since 1995: C&L, PwC (1998), IBM (2002), Conscious Asset (2004)

- Thought-leadership (reliability and maintenance management)
  - Magazines and Blog
  - "Uptime - Strategies for Excellence in Maintenance Management", 3rd edition, 2015
  - "Reliability Centered Maintenance – Re-Engineered: Practical Optimization of the RCM Process with RCM-R®" 2017
  - Other books (self-published)
    - "Reliability Centered Maintenance: A Key to Maintenance Excellence" 2000, Hong Kong Polytechnical University
    - "Uptime Made Easy" 2009
    - "No Surprises" 2016
    - "ISO 55000, What's Not to Like" 2016
    - "Paying Your Way" 2020
  - Frequent conference speaker and trainer

- 2016 – awarded PEMAC's prestigious Sergio Guy Award for significant contributions to the profession





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What is FMEA?

- Systematic approach (method) used to identify potential failure modes, and determine their effects in equipment or system design
- This enables risk to be evaluated and determining if any additional controls are needed to address the risk – often by use of design changes
- Starts with component identification using a Bill of Material
- Usually performed by designers (engineers)
  - Often it is a solo-effort

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FMEA Example: ASQC

Function	Potential Failure Mode	Potential Effects(s) of Failure	S	Potential Cause(s) of Failure	O	Current Process Controls	D	R P N	C R I T	Recommended Action(s)	Responsibility and Target Completion Date	Action Results: Action Taken	S	O	D	R P N	C R I T
Dispense amount of cash requested by customer	Does not dispense cash	Customer very dissatisfied	8	Out of cash	5	Internal low-cash alert	5	200	45								
		Incorrect entry to demand deposit system		Machine jams	3	Internal jam alert	10	240	24								
		Discrepancy in cash balancing		Power failure during transaction	2	None	10	160	16								
	Dispenses too much cash	Bank loses money	6	Bills stuck together	2	Loading procedure (riffle ends of stack)	7	84	12								
		Discrepancy in cash balancing		Denominations in wrong trays	3	Two-person visual verification	4	72	18								
	Takes too long to dispense cash	Customer somewhat annoyed	3	Heavy computer network traffic	7	None	10	210	21								
				Power interruption during transaction	2	None	10	60	6								

FMEA often starts with BOM on the left, then describes the function of the item

- Function
- Potential failure mode
- Potential effects of failure
- Severity
- Potential cause (s) of failure
- Occurrence rating (probably of failure: 1 (extremely unlikely – 10 inevitable)
- Current process controls
- D = 1 to 10 (detection rating)
  - 1 is certain to be detected, 10 can't be detected
- RPN = S x O x D
- Crit = S x O
- Recommended actions
- Responsibility and complete target date
- Action results
  - Then new: S, O, D, RPM, Crit

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What is FMECA?

- Similar to FMEA except with the addition of evaluation criticality – consequences to safety, environment, operations and mission
- Criticality assessment
  - Severity of effect + Probability (likelihood) used
  - Also looks at detectability – how easy is it to spot and diagnose the problem
- Enables designers to focus on critical failures and ignore others
- Like FMEA this is usually a solo designer effort

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FMEA from Mil-Std 1629A (1977)

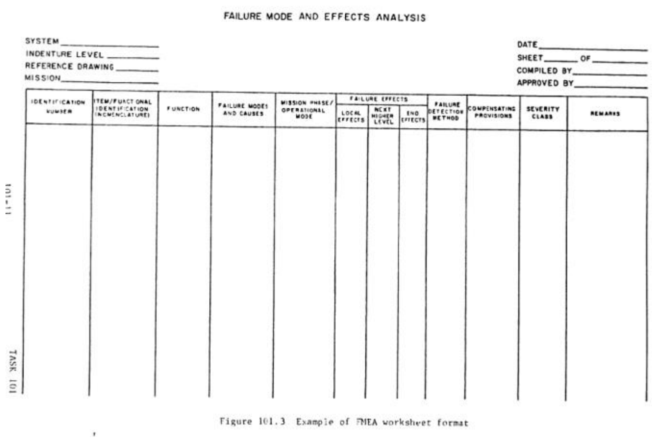

Figure 101.3 Example of FMEA worksheet format

- ID number
- Functional identification number
- Function
- Failure modes and causes
- Mission phase / operational mode
- Failure effects
  - Local, next higher, end effect
- Failure detection method
- Compensating provisions
- Severity class
- Remarks

Criticality Analysis: Mil-Std-1629A (1977)

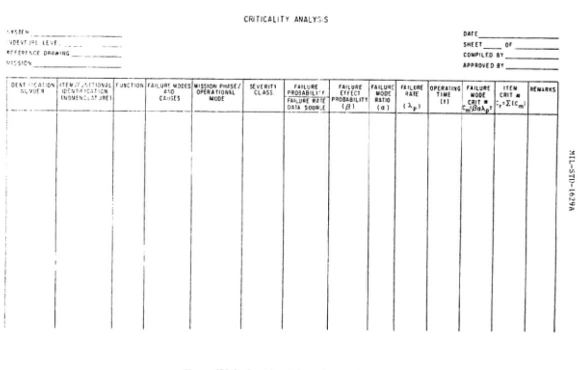

Figure 102.1 Example of CA worksheet format

- First 5 columns same as before
- Severity class (same as before)
- Failure probability / failure rate data source
- Failure effect probability (β)
- Failure mode ratio (α)
- Failure rate (λ_p)
- Failure mode Crit #, $Cm = \beta \alpha \lambda_p t$
- Item Crit #, $Cr = \Sigma (Cm)_I$
  - (for all items in same severity classification C)
- Remarks

Mil Std FMEA can require a lot of effort

- Ship propulsion diesel engine (16 cyl, 20 MW)
  - Approx 6 months to complete analysis
  - > 900 failure modes (began with parts list)

- Similar engine analyzed using RCM-R
  - 9 days (225 failure mode and causes analyzed)

- Functional approach (not Mil Std) dramatically reduces duplications

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Example from DSI International

Item	Failure	Mission Phases	Root Failure Mode Causes	Failure Effects			Compensating Provisions	Severity Class
				Local	Next Higher	End Item		
Fuel Pump	Fuel pump fails to pump fuel.	Landing	Mechanical Failure Electrical Failure	Engine shuts down during landing.	Loss of engine during landing.	Loss of engine during landing.	Compensated for by multiple engines and	MINOR
	Fuel pump fails to pump fuel.	Startup	Mechanical Failure Electrical Failure	Engine fails to start.	Vehicle fails to start.	Vehicle fails to start.		MINOR
	Fuel pump fails to pump fuel.	In Flight	Mechanical Failure Electrical Failure	Engine shuts down during flight.	Loss of engine during flight. Pilot/control adjustment to additional operating engine to keep vehicle running.	Loss of engine during flight. Pilot/control adjustment to additional operating engine to keep vehicle		CATASTROPHIC
Fuel Valve	Pressure restricted in valve	Landing	Valve Obstructed Mechanical Failure due to damaged or worn components	Engine shuts down during landing.	Loss of engine during landing.	Loss of engine during landing.	Compensated for by multiple engines and end-of-flight.	MINOR
	Pressure restricted in valve	In Flight	Mechanical Failure due to damaged or worn components Valve Obstructed	Erratic engine operation in flight.	Engine operates erratically during flight. Pilot compensates with power adjustments between engine.	Engine operates erratically during flight. Pilot compensates with power adjustments between engine.		CRITICAL
	Pressure restricted in valve	Startup	Mechanical Failure due to damaged or worn components Valve Obstructed	Engine fails to start.	Vehicle fails to start.	Vehicle fails to start.		MINOR
	Valve stuck open or closed.	Landing	Mechanical Failure due to damaged or worn components Electrical Failure	Engine shuts down during landing.	Loss of engine during landing.	Loss of engine during landing.	Compensated for by multiple engines and end-of-flight.	MINOR
	Valve stuck open or closed.	In Flight	Mechanical Failure due to damaged or worn components Electrical Failure	Engine shuts down during flight.	Loss of engine during flight. Pilot/control adjustment to additional operating engine to keep vehicle running.	Loss of engine during flight. Pilot/control adjustment to additional operating engine to keep vehicle		CATASTROPHIC
	Valve stuck open or closed.	Startup	Mechanical Failure due to damaged or worn components Electrical Failure	Engine fails to start.	Vehicle fails to start.	Vehicle fails to start.		MINOR
Landing Gear	Landing gear fails on ground.	Startup	Mechanical Failure	Landing gear failure on ground.	Landing gear fails on ground.	Landing gear fails on ground.		MINOR
	Landing gear fails on landing.	Landing	Mechanical Failure	Unable to extend landing gear.	Landing gear fails to extend during landing. Pilot attempts to manually extend gear.	Landing gear fails to extend during landing. Pilot attempts to manually extend gear.		CATASTROPHIC
	Landing gear fails to retract.	In Flight	Mechanical Failure Electrical Failure	Unable to automatically retract landing gear.	Landing gear fails to retract during flight. Drag on vehical performance during operation of vehical in flight.	Landing gear fails to retract during flight. Drag on vehical performance during operation of vehical in flight.		MARGINAL
VCU	Control failure prevents startup of system.	Startup	Power Supply Failure Discrete Output Buffer Failure Discrete Output Failure Controller Failed	Loss of control power during startup. Engine fails to start.	Vehicle fails to start.	Vehicle fails to start.		MINOR

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What is RCM?

- A method (approach) for determining failure management strategies
  - Maintenance and operator tasks, changes (various) including design
  - Allows run-to-failure (where consequences are tolerable)
- Emphasis is on dealing with the failure consequences, not necessarily the failures
- Begins with defining system / equipment functions
  - P&IDs and BOMs are useful in this process
  - Often one function involves multiple parts
  - Each part may be involved in more than one function
- RCM is a team effort involving maintainers and operators

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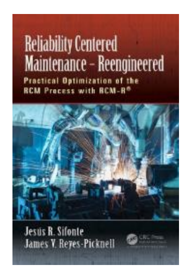
Criticality and RCM

- The RCM standard, SAE JA-1011 does not require criticality to be used
- Criticality is usually assessed across an operational site to determine which equipment / systems warrant RCM's rigor
- Criticality can also be assessed at the level of failure modes and their causes:
  - Enables analysis team to ignore less critical failures,
  - Can also help to focus discussion on the most critical



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RCM-R® FMEA worksheet

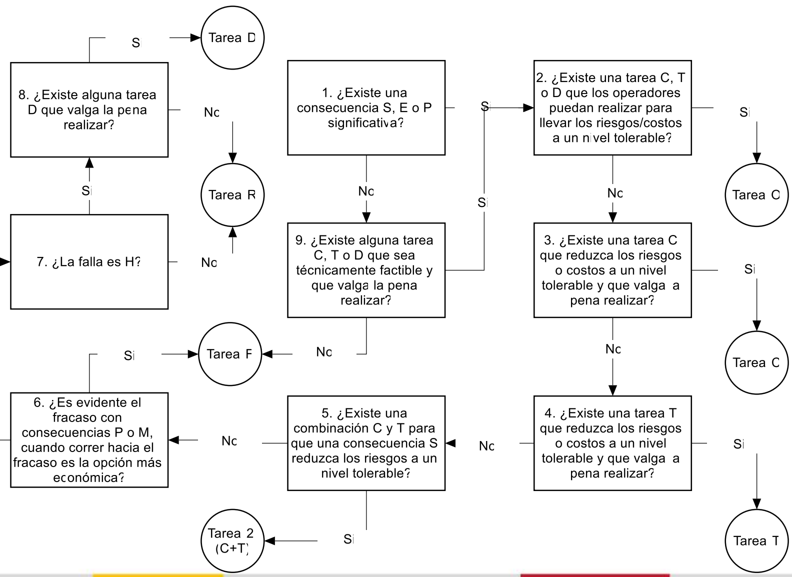
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	R1500 Reactor System and Filter Drier					Critica			ELE			AGE	How detected?	H
2	Piramal					Non-			EXT			DSG	Secondary damage & repair	S/E
3						Hidde			INS			FAB	Safety impacts	O
4									MAT			MGT	Production / operational impacts	M
5									MEC			MIS	Damage & repair	
6									MIS			O&M	Envirionmental impacts	
7														
8	Function		Component	Functional Failure			Failure Modes			FM Causes			Effects	Type
9	#	Description		A#	Description	Type	#	Description	Types	A#	Description	Types	Description	
76	5	To enable charging of solid, liquid and gas ingredients	Inlet ports, nozzles, valves, and manway	A	Fails to enable charging	Critical	1	Valves stuck shut	MEC	A	Cotter pin is broken (glass valves) - vibration induced	AGE	Valve cannot be opened/closed. Maintenance called to correct and "fix" inserted to get operations through the batch. Valve replaced later. Safety impact: nil Environmental impact: nil Quality/production impact: minor delay	O
77	5			A			1			B	Cotter pin is broken (glass valves) - overtightened in order to pass a pressure/vacuum test	O&M	Valve cannot be opened/closed. Maintenance called to correct and "fix" inserted to get operations through the batch. Valve replaced later. Safety impact: nil Environmental impact: nil Quality/production impact: minor delay	O
78	5			A			2	Glass valve broken	MEC	A	Overtightening under vacuum/pressure	O&M	If valve is tightened under vacuum, it will be extra tight when under other pressures and can be broken. Maintenance may not be able to correct if batch is in process, until batch finished. Safety impact: if glass shatters under pressure there is risk to personnel from flying glass Environmental impact: nil Quality/production impact: minor delay, could introduce contamination into batch, deviation likely needed	S/E
	5			A			2			B	Improper securing of charging hoses	O&M	Charging hose vibrates and overstresses the glass leading to breakage. Liquid on floor / loss of containment. Repair time up to 2 hours. Safety impact: product exposure, vapor exposure, shattered	S/E

FMEA

RCM-R® Criticality

	A	B	C	D	EFGHI	J	K	L	M	N	O	P	Q
1						0	No effect	No effect	< $5k	No impact	> Annual	Audible alarm	
2						1	First aid/minor ill	Minor Internal (conti	$5k to $20K	1 h to 1 shift	Semi-annual to annu	Visual alarm	
3						2	Lost time/reversible	Minor External (offsi	$20k to $50k	1 shift to 1 day	Quarterly to semi-an	Operator spots	
4						3	Perm disability	Reportable	$50k to $100K	1 d to 2 d	Monthly to quarterly	Mtc/Eng'r	
5						4	Death	Bus Stop/ Fine	> $100k	> 2 d	Daily to monthly	SME/Contractor	
8							Safety & Health	Environ	Mtc Cost	Operations	Like-h.	Detectability	
9	F	FF	FM	C		Type	4	3	1	3	x^2	1	Crit Score
13	1	A	1	D		M	0	0	0	0	3	3	

RCM-R® Decision Logic



Consecuencias

H	Oculto
S	Seguridad
E	Ambiental
P	Producción
M	Mantenimiento

Tareas

O	Operador (C o T)
C	Condición
T	Tiempo (uso)
“2”	C+T
R	Rediseño
D	Detectiva
F	Correr hacia el fracaso

RCM-R® Decisions

	F	FF	FM	C		Function	Functional Failure	Failure Mode	Cause	Crit	Type	Evident (Y is default)	Sig S,E,S	Proactive	Op'r?	C task?	T task?	2 for SE?	O or M?	H?	Test?	Decision	Logic Check	Task (describe task in detail)	Freq	Units	Who	RCM Analysis F
7																									n/a	59	207	
8						27	38	92	155				1	9	2	3	4	5	6	7	8							
76	5	A	1	A	5A1A	To enable charging of solid, liquid and gas ingredients	Fails to enable charging	Valves stuck shut	Cotter pin is broken (glass valves) - vibration induced	5	O	Y	Y		N	N	N		Y	N		R	OK	This is already part of start up checks				
77	5	A	1	B	5A1B				Cotter pin is broken (glass valves) - overtightened in order to pass a pressure/vacuum test	5	O	Y	Y		N	N	N		Y	N		R	OK	Modify pressure/vacuum test procedure to use soap test on cam locks before any glass valve is re-tightened.				
78	5	A	2	A	5A2A			Glass valve broken	Overtightening under vacuum/pressure	14	S/E	Y	Y		N	N	N		N	N		R	OK	Reinforce the rules that prohibit tightening of glass valves under pressure or vacuum.				
79	5	A	2	B	5A2B				Improper securing of charging hoses	21	S/E	Y	Y		N	N	N		N	N		R	OK	Reinforce the need to secure charging hoses and how to secure them properly. May require operator training in how to secure properly.				
80	5	A	2	C	5A2C				Glass valve clamps loose	21	S/E	Y	Y		N	Y			N	N		C	OK	Check glass valve clamps that are used to secure charging valve for tightness. Tighten if found loose.	1	Batch	Mech	
81	5	A	3	A	5A3A			Manway can't be opened	Spring assist damaged	6	O	Y	Y		N	Y			Y	N		C	OK	Check manway operation (spring assist and j-clamps) during the reactor cleaning (change to procedure)	1	Batch	Operator	
82	5	A	3	B	5A3B				J-clamps seized	5	O	Y	Y		N	Y			Y	N		C	OK	Check manway operation (spring assist and j-clamps) during the reactor cleaning (change to procedure)	1	Batch	Operator	
83	5	B	1	A	5B1A		Charges at too slow a rate	Valve partially open	Operator error	3	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
84	6	A	1	A	6A1A	To provide for batch sampling	Can't sample	Plugged	Operator fails to flush tube with Nitrogen	3	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
85	6	A	1	B	6A1B				Slurry is too thick for the tube diameter	5	O	Y	Y		N	N	N		Y	N		R	OK	Greater care needed to forecast slurry problems when scaling up from R&D to production				
86	6	A	2	A	6A2A			Slurry level is below bottom of dip tube	Small batch in large reactor	5	O	Y	Y		N	N	N		Y	N		R	OK	TT to be cautious about what size reactor is being used for each batch				
87	6	A	3	A	6A3A			Dip tube valve stuck shut	Mechanical wear inside valve	5	O	Y	Y		N	N	N		Y	N		R	OK	Modify pre-start procedure to include check of dip tube valve operation.				
88	7	A	1	A	7A1A	To inert the reactor envornment	Fails to inert	PCV 1520 Valve fails to position	Control signal loss (box)	5	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
89	7	A	1	B	7A1B				Air leak	5	O	Y	Y		N	Y			Y	N		C	OK	Survey for air leaks (listen and feel)	1	Day	Mech	Is there an intr monitoring too
90	7	A	1	C	7A1C				Valve actuator failed (diaphragm / spring)	6	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
91	7	A	2	A	7A2A			Pressure transmitter (PT 1520) failed	Random electronic	3	n/a	Y	N						n/a	N		n/a	OK					
92	7	A	3	A	7A3A			Loose joints	Vibration induced	6	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
93	7	A	3	B	7A3B				Incorrectly tightened	3	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
94	7	A	3	C	7A3C				Thermal cycling	6	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
95	7	A	4	A	7A4A			Open valves	Operator mistake	3	O	Y	Y		N	N	N		Y	N		F	OK	No scheduled maintenance				
	7	A	5	A	7A5A			Failure to follow	Mind not on task	16														Add step for manual inertion in pre-startup checklist and				Explore if DCS c

Comparison

- Similarities
  - All 3 methods focus on failure modes and their effects
  - When presented in tabular formats, they all look similar
  - All analyze equipment and / or systems

Comparison - differences

- FMEA and FMECA used at design stage – RCM at any stage of life cycle
- FMEA and FMECA usually performed by engineers – RCM performed by teams of operators and maintainers
- FMEA ignores criticality
- FMECA uses criticality
- RCM uses criticality in two way
- FMEA and FMECA have no decision logic – engineer has full discretion
- RCM includes a decision logic
- FMEA and FMECA usually begin with BOM may start with functions
- RCM begins with Functions (BOM may be used to help)
  - FMEA and FMECA – functionality is often duplicated
  - RCM functionality is not duplicated – analyses are shorter (by half or less)

Should you use a BoM or Functional approach?

- Consider your objective
  - If you want to beef-up design – use FMEA or FMECA and start with parts
  - If you want a failure management program – use RCM and a functional approach
- If you have an FMEA or FMECA created using BOM, using it as a start point for RCM is possible, but not recommended – start over for RCM
  - Component / part based approaches do not follow a logical functional sequence and can be confusing
  - Volume of work can be multiple times the effort when compared with functional approach

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Summary

- FMEA – design tool, usually based on parts (BoM) and very detailed.
  - Engineering tool for design
- FMECA – similar to FMEA, includes criticality.
  - Engineering tool for design in complex systems
- RCM – a method to determine failure management policies.
  - RCM includes FMEA or FMECA.
  - Can be based on BoM, but most efficient if based on functions.
  - Operational focus is on failure consequence management.
  - Design changes are a “last resort”.
  - Team based

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Questions and Discussion

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Thank you!

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