

The connection between equipment risk and equipment reliability

SIRFRt WA Maintenance Roundtable Nov 2011

By

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The Common Risk Equation

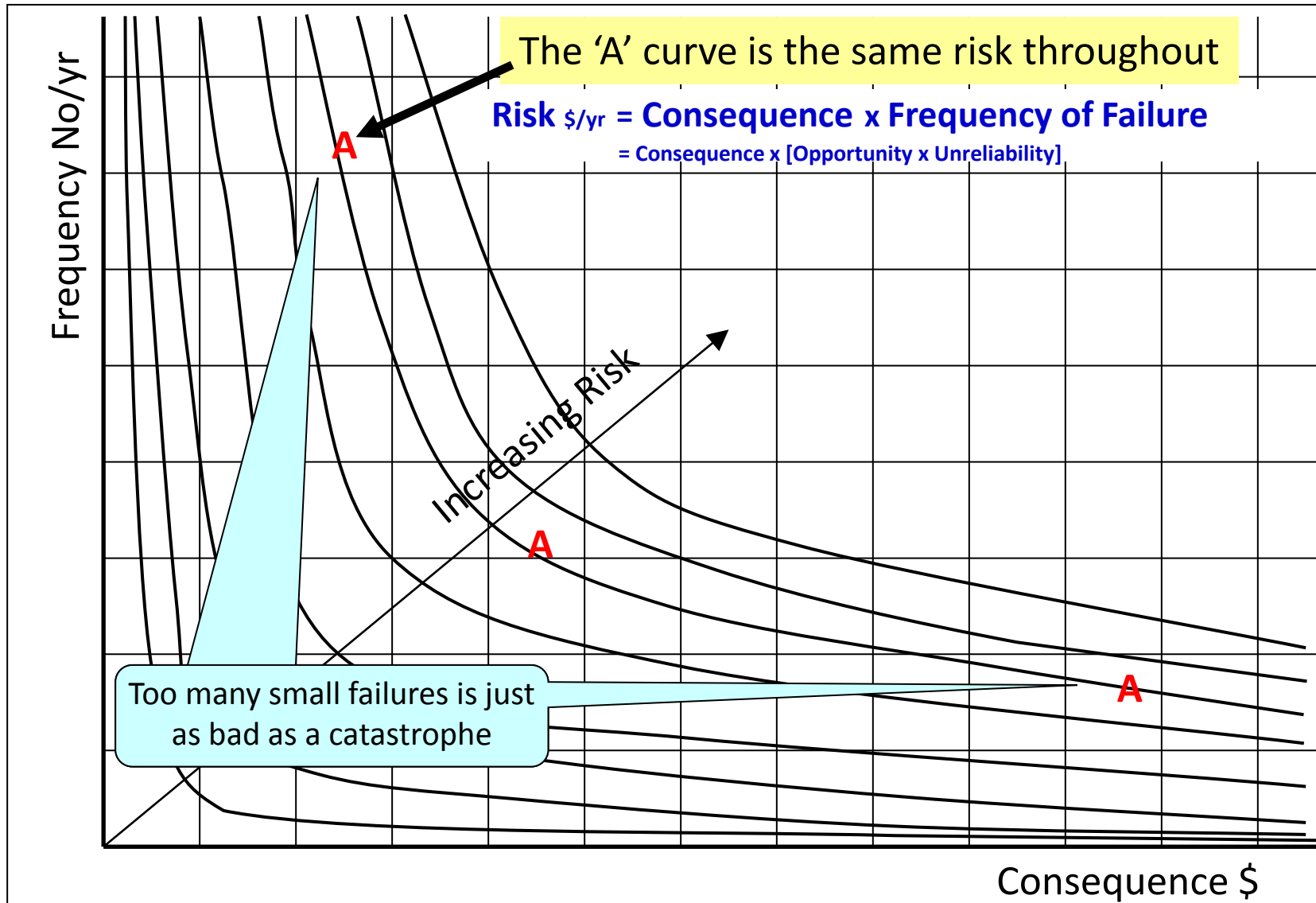
$$risk = (consequence)(frequency)$$

for constant values 'risk' is of the mathematical form

$$C = xy$$

It comprises a family of curves each with a different value of 'risk'. The curves all lie in the first quadrant with the x-y axes as asymptotes.

Risk can be Calculated and Plotted



Letting risk = C, consequence = x and frequency = y and making the transformation from

$$C = xy$$

to

$$\log C = \log x + \log y$$

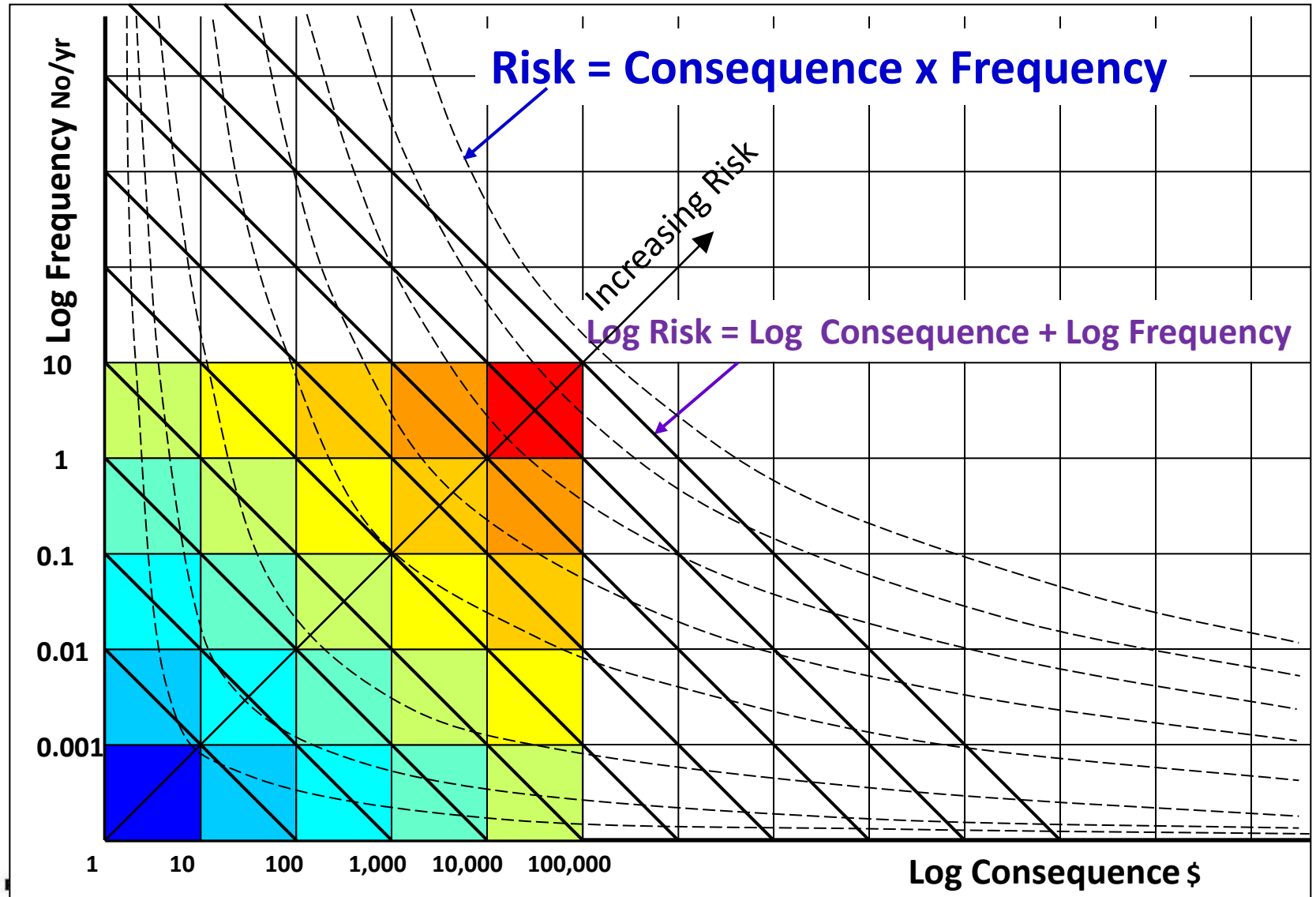
$$\log y = -\log x + \log C$$

shows that logx and logy are linearly related with a slope of -1 and that the y intercept is equal to logC. Therefore, the equation

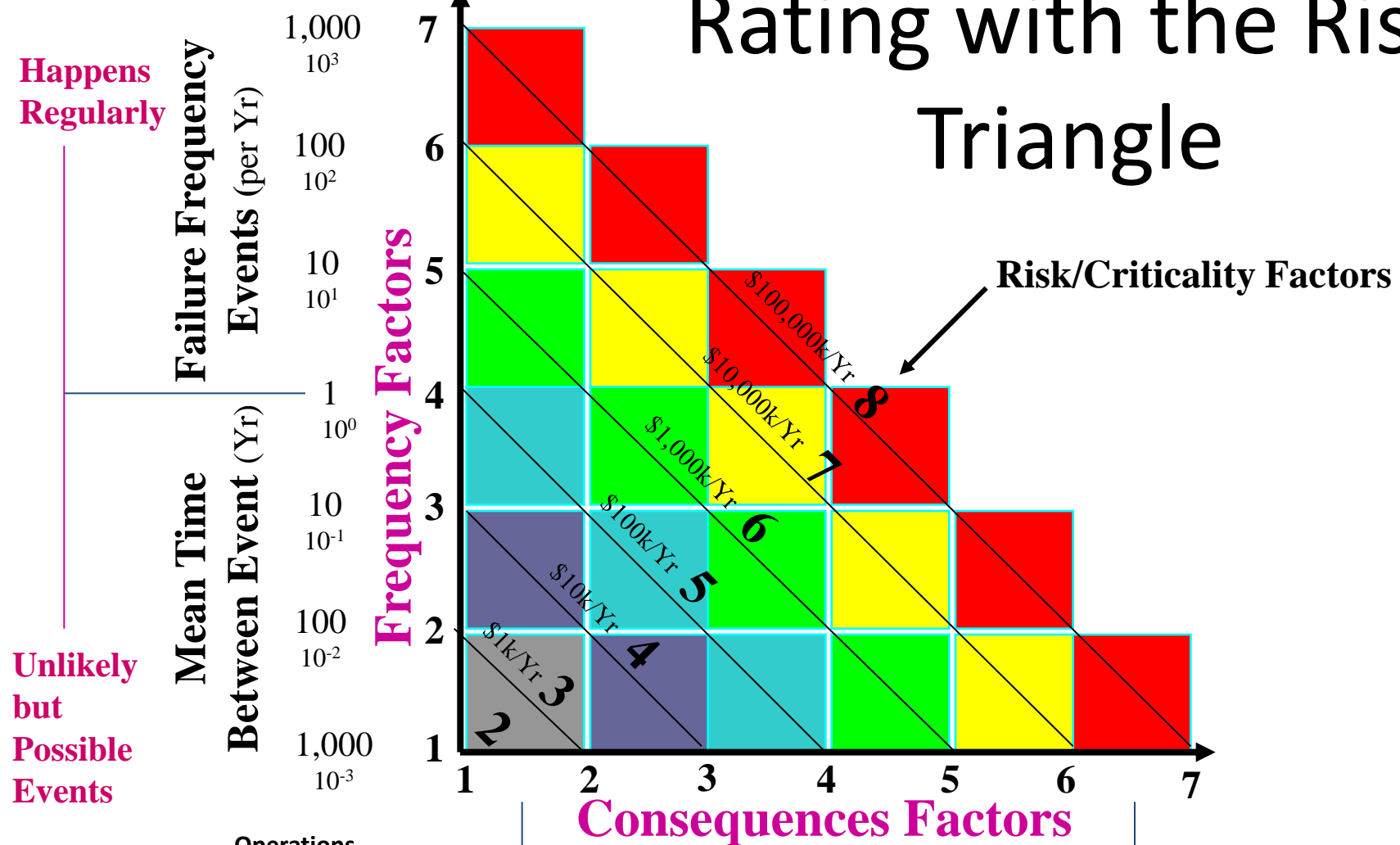
$$\log(\text{frequency}) = -\log(\text{consequence}) + \log(\text{risk})$$

will appear as a straight line on a log-log plot.

Grading Risk on Chance and Consequence



Rating with the Risk Triangle



Consequences Factors							
Operations Maint Cost	\$100	\$1k	\$10k	\$100k	\$1M	\$10M	\$100M
Health & Safety	Trivial injury/ impact	Minor injury/ impact	Moderate injury/ impact	Significant injury/ impact	Serious injury/ impact	Single Fatality	Multiple Fatalities
Environment/ Quality/ Reputation	Negligible effect	Minor effect	Moderate effect	Significant effect	Serious effect	Extreme Event	Major Disaster

Rating with a Risk Matrix

				Consequence					
E – Extreme risk – detailed action plan required H – High risk – needs senior management attention M – Medium risk – specify management responsibility L – Low risk – manage by routine procedures Extreme or High risk must be reported to Senior Management and require detailed treatment plans to reduce the risk to Low or Medium				People	Injuries or ailments not requiring medical treatment.	Minor injury or First Aid Treatment Case.	Serious injury causing hospitalisation or multiple medical treatment cases.	Life threatening injury or multiple serious injuries causing hospitalisation.	Death or multiple life threatening injuries.
				Reputation	Internal Review	Scrutiny required by internal committees or internal audit to prevent escalation.	Scrutiny required by clients or third parties etc.	Intense public, political and media scrutiny. E.g. front page headlines, TV, etc.	Legal action or Commission of inquiry or adverse national media.
				Business Process & Systems	Minor errors in systems or processes requiring corrective action, or minor delay without impact on overall schedule.	Policy/procedural rule occasionally not met or services do not fully meet needs.	One or more key accountability requirements not met. Inconvenient but not client welfare threatening.	Strategies not consistent with business objectives. Trends show service is degraded.	Critical system failure, bad policy advice or ongoing non-compliance. Business severely affected.
				Financial	<\$2K	<\$20K	<\$100K	<\$500K	>\$500K
					Insignificant	Minor	Moderate	Major	Catastrophic
					1	2	3	4	5
Likelihood ↑	Probability:	Historical:							
	>1 in 10	Is expected to occur in most circumstances	5	Almost Certain	M	H	H	E	E
	1 in 10 - 100	Will probably occur	4	Likely	M	M	H	H	E
	1 in 100 - 1,000	Might occur at some time in the future	3	Possible	L	M	M	H	E
	1 in 1,000 - 10,000	Could occur but doubtful	2	Unlikely	L	M	M	H	H
	1 in 10,000 - 100,000	May occur but only in exceptional circumstances	1	Rare	L	L	M	M	H

Adapted from Australian Risk Management AS/NZS 4360 - 2004

This table is the basic approach. There is full mathematical modelling as well, but this basic method is fine to start with. The layout is universal. You change the consequences' description to what you are willing to accept, and the costs to what you are willing to pay.

Identify What Risks You WILL NOT Carry

			Consequence					
E – Extreme risk – detailed action plan required H – High risk – needs senior management attention M – Medium risk – specify management responsibility L- Low risk –manage by routine procedures Extreme or High risk must be reported to Senior Management and require detailed treatment plans to reduce the risk to Low or Medium			People	Injuries or ailments not requiring medical treatment.	Minor injury or First Aid Treatment Case.	Serious injury causing hospitalisation or multiple medical treatment cases.	Life threatening injury or multiple serious injuries causing hospitalisation.	Death or multiple life threatening injuries.
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			Business Process & Systems	Minor errors in systems or processes requiring corrective action, or minor delay without impact on	Policy procedural rule occasionally not met or services do not fully	One or more key accountability requirements not met. Inconvenient but not	Strategies not consistent with business objectives. Trends show service is	Critical system failure, bad policy advice or ongoing non-compliance. Business severely affected.
			Financial					>\$500K
				Insignificant	Minor	Moderate	Major	Catastrophic
				1	2	3	4	5
Likelihood ↑	Probability:	Historical:	Almost Certain	M	H	H	E	E
	>1 in 10	Is expected to occur in most circumstances	Likely	M	M	H	H	E
	1 in 10 - 100	Will probably occur	Possible	L	M	M	H	E
	1 in 100 – 1,000	Might occur at some time in the future	Unlikely	L	M	M	H	H
	1 in 1,000 – 10,000	Could occur but doubtful	Rare	L	L	M	M	H
	1 in 10,000 – 100,000	May occur but only in exceptional circumstances						

Adapted from Australian Risk Management AS/NZS 4360 - 2004

This table is the basic approach to identify the extent of risk. There is full mathematical modelling as well, but this basic method is a fine start. The layout is universal. You change 'consequence' descriptions to what you are willing to accept, and the costs to DAFT Costs you are willing to pay.

Identify the New Risk Level

			Consequence					
E – Extreme risk – detailed action plan required H – High risk – needs senior management attention M – Medium risk – specify management responsibility L- Low risk –manage by routine procedures Extreme or High risk must be reported to Senior Management and require detailed treatment plans to reduce the risk to Low or Medium			People	Injuries or ailments not requiring medical treatment.	Minor injury or First Aid Treatment Case.	Serious injury causing hospitalisation or multiple medical treatment cases.	Life threatening injury or multiple serious injuries causing hospitalisation.	Death or multiple life threatening injuries.
			Reputation	Internal Review	Scrutiny required by internal committees or internal audit to prevent escalation.	Scrutiny required by clients or third parties etc.	Intense public, political and media scrutiny. E.g. front page headlines, TV, etc.	Legal action or Commission of inquiry or adverse national media.
			Business Process & Systems	Minor errors in systems or processes requiring corrective action, or minor delay without impact on	Policy procedural rule occasionally not met or services do not fully	One or more key accountability requirements not met. Inconvenient but not	Strategies not consistent with business objectives. Trends show service is	Critical system failure, bad policy advice or ongoing non-compliance. Business severely affected.
			Financial					>\$500K
				Insignificant	Minor	Moderate	Major	Catastrophic
	Probability:	Historical:		1	2	3	4	5
Likelihood	>1 in 10	Is expected to occur in most circumstances	Almost Certain	M	H	H	E	E
	1 in 10 - 100	Will probably occur	Likely	M	M	H	H	E
	1 in 100 – 1,000	Might occur at some time in the future	Possible	L	M	M	H	E
	1 in 1,000 – 10,000	Could occur but doubtful	Unlikely	L	M	M	H	H
	1 in 10,000 – 100,000	May occur but only in exceptional circumstances	Rare	L	L	M	M	H



Adapted from Australian Risk Management AS/NZS 4360 - 2004



Our Maintenance Strategies ought to be Matched to Business Risk Levels

Consequence		Insignificant	Minor	Moderate	Major	Catastrophic
Frequency		1	2	3	4	5
6	Certain	PM / Precision	CM / Precision	Precision / Design-out	Design-out	Design-out
5	Likely	PM / Precision	CM / Precision	Precision / Design-out	Precision / Design-out	Design-out
4	Possible	BD	PM / Precision	CM / Precision	Precision / Design-out	Precision / Design-out
3	Unlikely	BD	PM / Precision	CM / Precision	CM / Precision	Precision / Design-out
2	Rare	BD	PM / Precision	PM / Precision	CM / Precision	CM / Precision
1	Very Rare	BD	PM / Precision	PM / Precision	CM / Precision	CM / Precision

The full Risk Equation is more Meaningful for examining Risk and Equipment Failure

[← *Failure Frequency* →]

Risk=[Consequence] x [Opportunity to Fail x Chance of Failure]

Risk=[Consequence] x [Opportunity to Fail x (1-Reliability)]

Risk=[Consequence] x [Opportunity to Fail x (Unreliability)]

1-reliability = unreliability = $P(T \leq t)$ at every opportunity for failure = failures/opportunity

opportunity = opportunities/time

consequence = cost/failure

- **Risk = cost/time**
- **Reliability = Chance of success**

That means that maximizing reliability is not the best business objective. **From a business standpoint we want to minimize risk.**

We have three ways of minimising Risk

Risk= $\left[\leftarrow \text{Reduce Failure Frequency} \rightarrow \right]$
[Reduce consequence] x [opportunity to fail x (unreliability)]

[CONSEQUENCE REDUCTION] [CHANCE REDUCTION]

1. Increase reliability = Decrease unreliability = Fewer failures/opportunity
2. Reduce opportunity to fail = Fewer opportunities/time
3. Reduce consequence of failure = Less cost/failure

Risk Reduction – Reduce Chance or Reduce Consequence?

$$\text{Risk} = \text{Consequence} \times \text{Chance}$$

Consequence Reduction Strategies

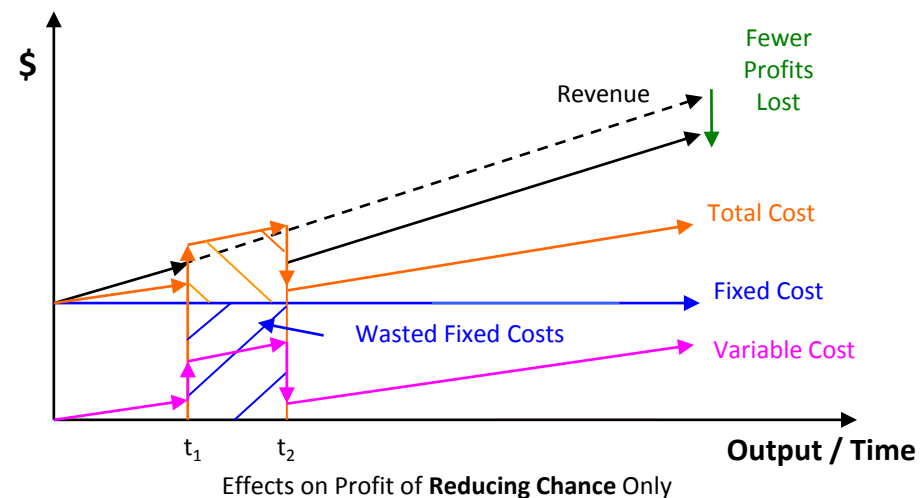
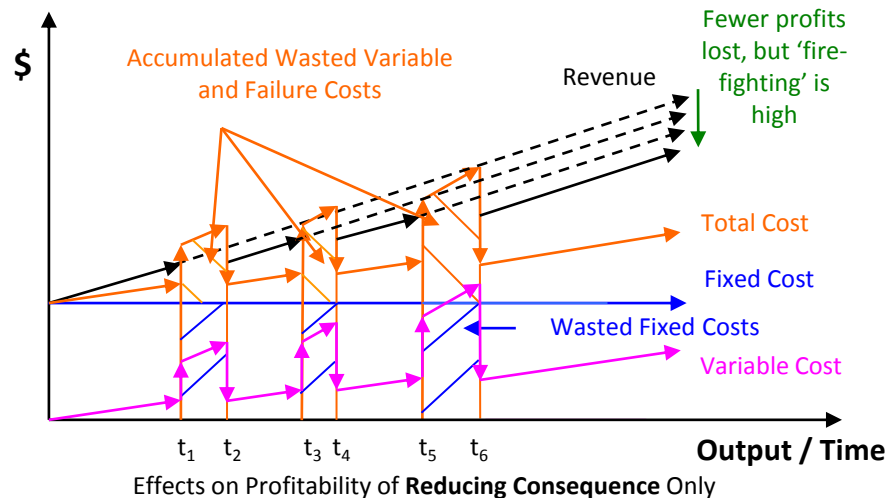
- Preventive Maintenance
- Shutdown Maintenance
- Predictive Maintenance
- Total Productive Maintenance (TPM)
- Non-Destructive Testing
- Vibration Analysis
- Oil Analysis
- Thermography
- Motor Current Analysis
- Prognostic Analysis
- Emergency Management
- Computerised Maintenance Management System (CMMS)

Never ends

Chance Reduction Strategies

- Engineering and Maintenance Standards
- Failure Design-out - Corrective Maintenance
- Failure Mode Effects Criticality Analysis (FMECA)
- Statistical Process Control
- Hazard and Operability Study (HAZOP)
- Root Cause Failure Analysis (RCFA)
- Precision Maintenance
- Hazard Identification (HAZID)
- Training and Up-skilling
- Quality Management Systems
- Planning and Scheduling
- Continuous Improvement

Gain Time



Risk Reduction – Reduce Chance, Opportunity or Consequence?

Risk (\$/yr) = Consequence of Failure x Frequency of Failure

Risk = Consequence of Failure x [Opportunity to Fail x (1 – Chance of Failure)]

Consequence of Failure Reduction Strategies

Strategies presume failure event occurs and act to minimise consequent losses

- Preventive Maintenance
- Shutdown Maintenance
- Predictive Maintenance
- Non-Destructive Testing
 - Vibration Analysis
 - Oil Analysis
 - Thermography
 - Motor Current Analysis
- Total Productive Maintenance (TPM)
- Prognostic Analysis
- Criticality Analysis
- Emergency Management
- Computerised Maint Mgmt Syst(CMMS)
- Key Performance Indicators (KPI)
- Risk Based Inspection (RBI)
- Operator Watch-keeping
- Value Contribution Mapping (Process step activity based costing)
- Logistics, stores and warehouses
- Defect and Failure True Cost (DAFTC)
- Maintenance Engineering

Done to reduce the cost of failure

Opportunity to Fail Reduction Strategies

Strategies prevent opportunities for a failure event arising

- Engineering / Maintenance Standards
- Statistical Process Control
- Degradation Management
- Reliability Growth Cause Analysis (RGCA)
- Lubrication Management
- Hazard and Operability Study (HAZOP)
- Hazard Identification (HAZID)
- Failure Design-out Maintenance
- Failure Mode Effects Analysis (FMEA)
- Hazard and Operability Study (HAZOP)
- Root Cause Failure Analysis (RCFA)
- Precision Maintenance
- Training and Up-skilling
- Quality Management Systems
- Planning and Scheduling
- Continuous Improvement
- Supply Chain Management
- Accuracy Controlled SOPs (ACE 3T)
- Design, Operation, Cost Total Optimisation Review (DOCTOR)
- Reliability Engineering

Done to reduce the frequency of failure

Chance to Fail Reduction Strategies

Strategies reduce probability of failure initiation if failure opportunity present

- Training and Up-skilling
- Oversize / De-rate Equipment
- Hardier Materials of Construction
- Personal Protective Equipment (PPE)
- Segregation / Separation
- Controlled Atmosphere Environment e.g. +ve / -ve pressures, explosion proof atmos

*Interestingly,
Chance Reduction
choices are best
made during
design.*

What is the Reliability of this Drinking Glass?

In other words: 'What's the chance it will hold water next time you use it?'

Stay with me, because understanding how to measure reliability is one of the most important concepts that you need to know of to do maintenance well.

These many ways for the glass to break (the failure mode), are called 'failure mechanisms'.

What can cause this glass to break?

- It can be dropped, for example -
 1. slip from your hand
 2. fall off a tray
 3. slip out of a bag or carry box
- It can be knocked,
 1. hit by another glass
 2. clanked when stacked on each other
 3. hit by an object, like a plate or bottle
- It can be crushed,
 1. jammed hard between two objects
 2. stepped-on
 3. squashed under a too heavy object
- It can be temperature shocked,
 1. in the dish washer
 2. during washing-up
- Mistreated,
 1. It can be thrown in anger
 2. It can be smashed intentionally
- Latent damage
 1. scratched and weakened to later fail more easily
 2. chipped and weakened to later fail more easily



Chance of Failure for a Drinking Glass



1,000,000 glasses sold in packs of 12

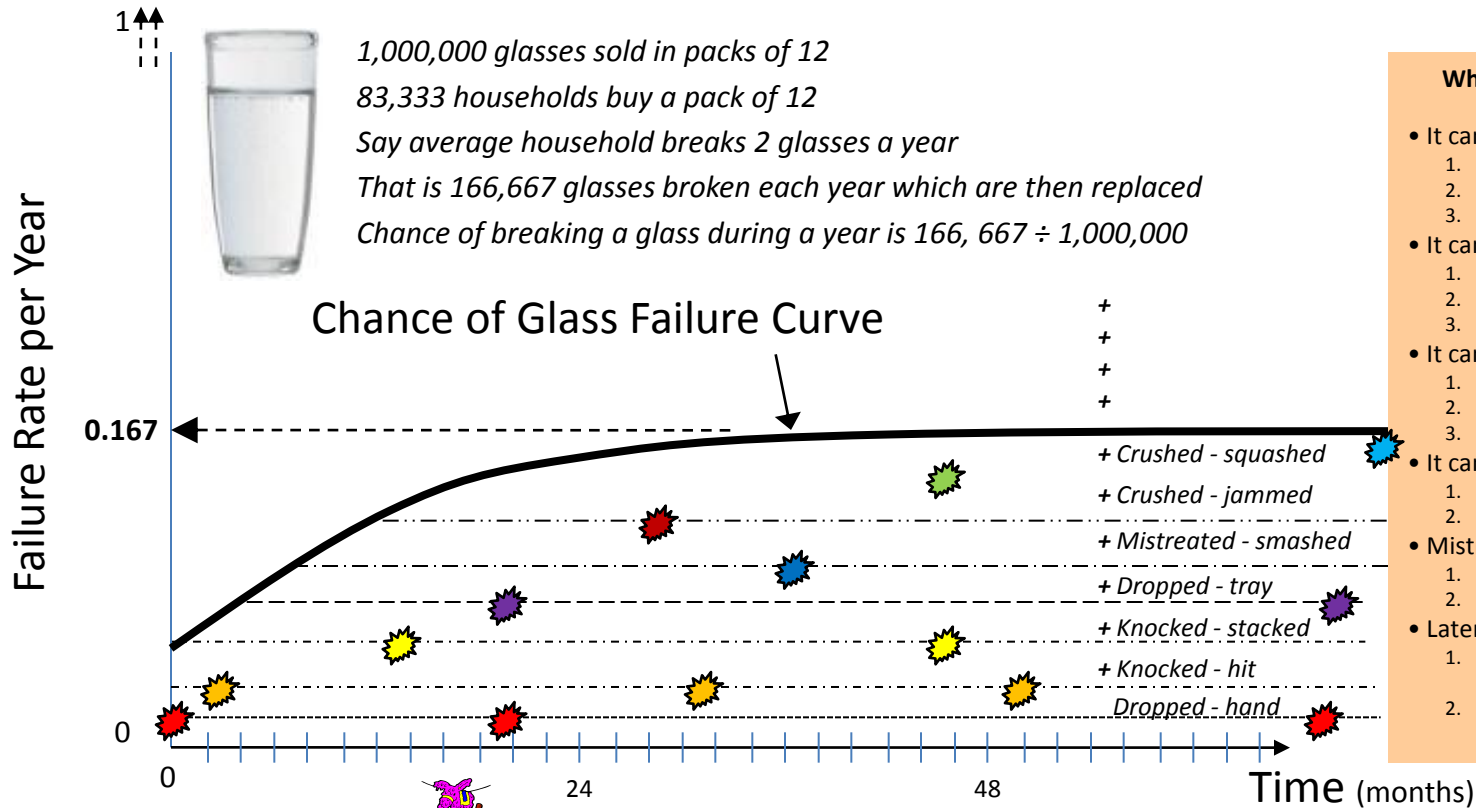
83,333 households buy a pack of 12

Say average household breaks 2 glasses a year

That is 166,667 glasses broken each year which are then replaced

Chance of breaking a glass during a year is $166,667 \div 1,000,000$

Chance of Glass Failure Curve



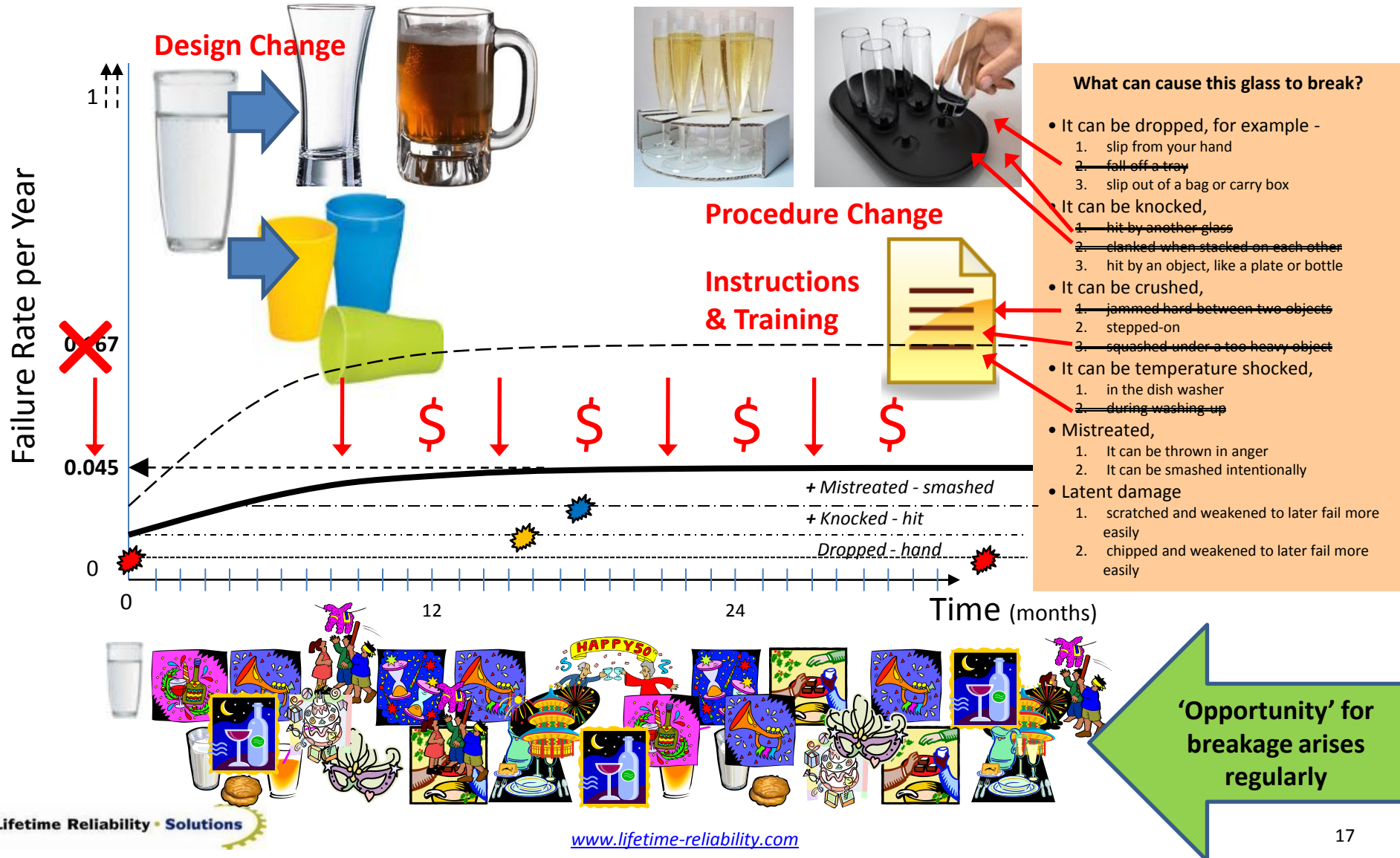
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'Opportunity' for breakage arises regularly



Stop Breakage = Remove Failure Causes = Improved Reliability



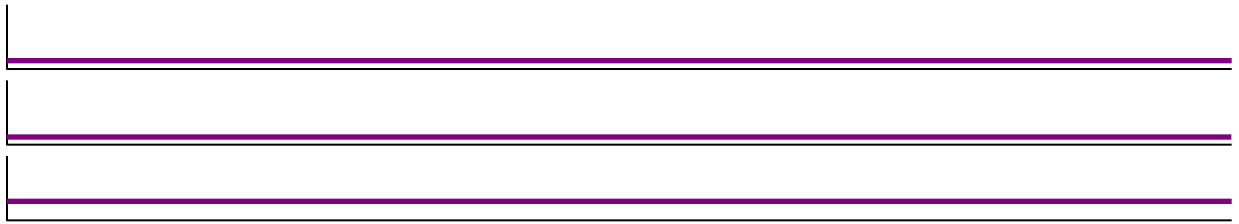
Reliability = Remove Likelihood of Failure



Dropped

Hit/Impact

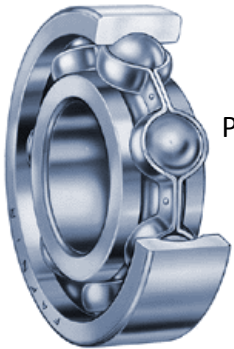
Total Group



Wear

Puncture

Total Group



Misaligned

Insufficient Lube

Wrong Lube

Particulate/Dirt

Moisture

Poor Fit

Overload

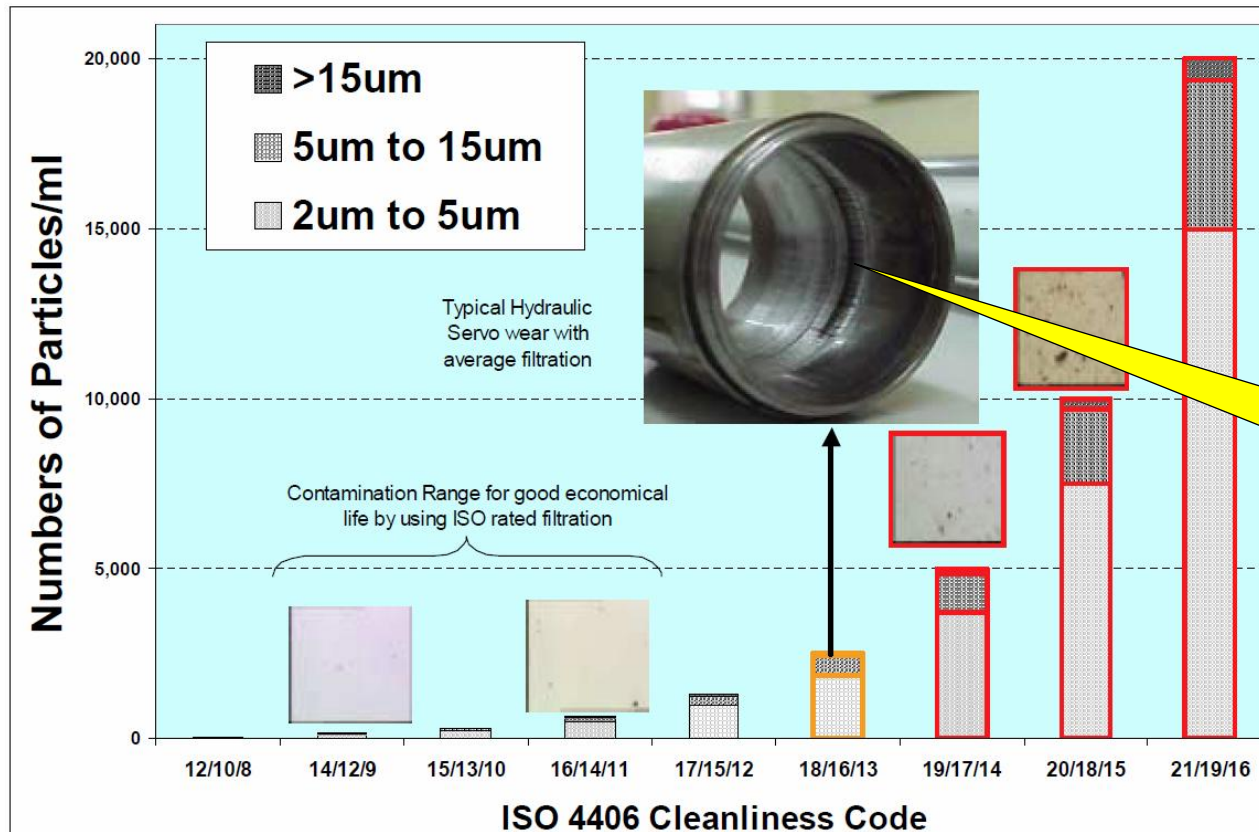
Total Group



Where Equipment Risks Come From

Lubricating Oil and Hydraulic Oil Cleanliness

Relativity of ISO 4406 Codes



New System
with Built-in Contaminants
23/22/20
40,000 to 80,000 particles/ml

Opportunity!!

System With
Typical Hydraulic Filtration
22/20/18
20,000 to 40,000 particles/ml

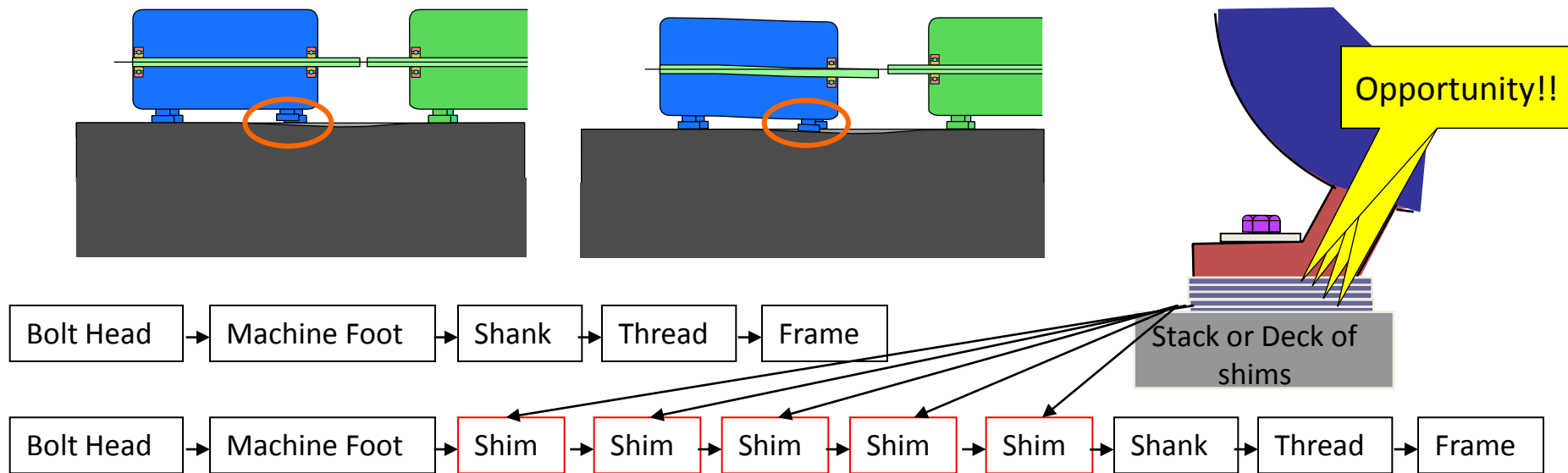
Became a
\$25,000,000
Risk

System with $\beta_3 > 1000$
Clearance Protection Filtration
14/13/11
80 to 160 particles/ml

Source: Wayne Bissett, 'Management of Particulate Contamination in Lubrication Systems' Presentation, CM and Lubrication Forum 2008, Australia

The trouble with accepting Softfoot is You provide ever present opportunity for failure

Soft-foot is an example of a defect regularly brought into companies, that then causes on-going problems.

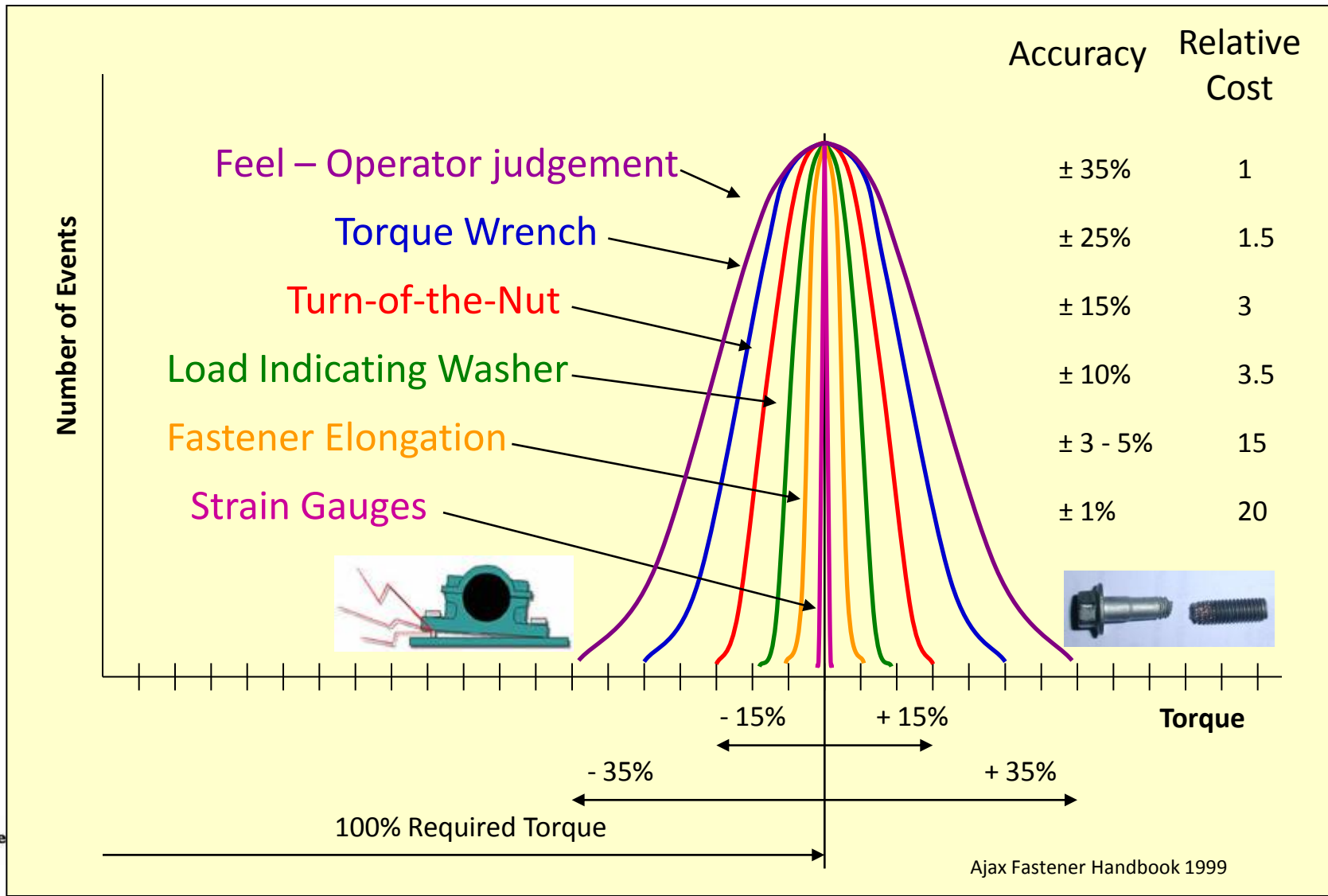


The shims have made the connection more unreliable. There are now more things to go wrong. They have added cost, additional maintenance and certainty of human error at some point in time.

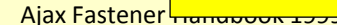
IT DID NOT HAVE TO BE SO!

Where does Failure Start in a Process?

Problems start with 'chance' variation in our decisions... for example



Lifetime



Risk from Fastening Process Choice Variation

$$\text{Risk} = [\text{Consequence}^3] \times [\text{Frequency}]$$

$$\text{Risk} = [\text{Consequence}] \times [\text{Opportunity to Fail} \times \text{Chance of Failure at Opportunity}]$$

$$\text{Risk} = [\text{Consequence}] \times [\text{Opportunity to Fail} \times (1 - \text{Reliability})]$$

Risk from Fastener Tensioning Method Process Variation

No	Tensioning Method	Distribution	Reliability	Unreliability (Area outside ± 10% of 'Feel')	At Risk Fasteners per 100 Bolt/Nut Sets ² R = C x [O x (1-R)]	Opportunity of Error
1	Operator Feel	± 35%	0.65	0.35	35	1) From outer distribution of tensioning method choice 2) Other events not related to tensioning method choice
2	Torque Wrench	± 25%	0.8	0.2	20	1) From outer distribution of tensioning method choice 2) Other events not related to tensioning method choice
3	Turn of Nut	± 15%	0.95	0.05	5	1) From outliers of tensioning method choice 2) Other events not related to tensioning method choice
4	Loading Indicating Washer	± 10%	1 ¹	0	0	1) From extreme outliers of tensioning method choice 2) Other events not related to tensioning method choice
5	Fastener Elongation	± 5%	1 ¹	0	0	Other events not related to tensioning method choice
6	Strain Gauges	± 1%	1 ¹	0	0	Other events not related to tensioning method choice

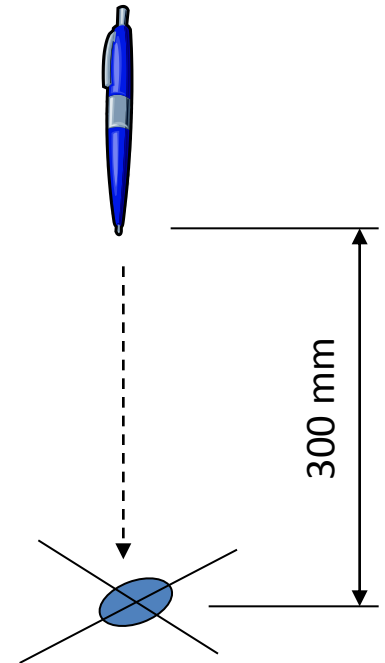
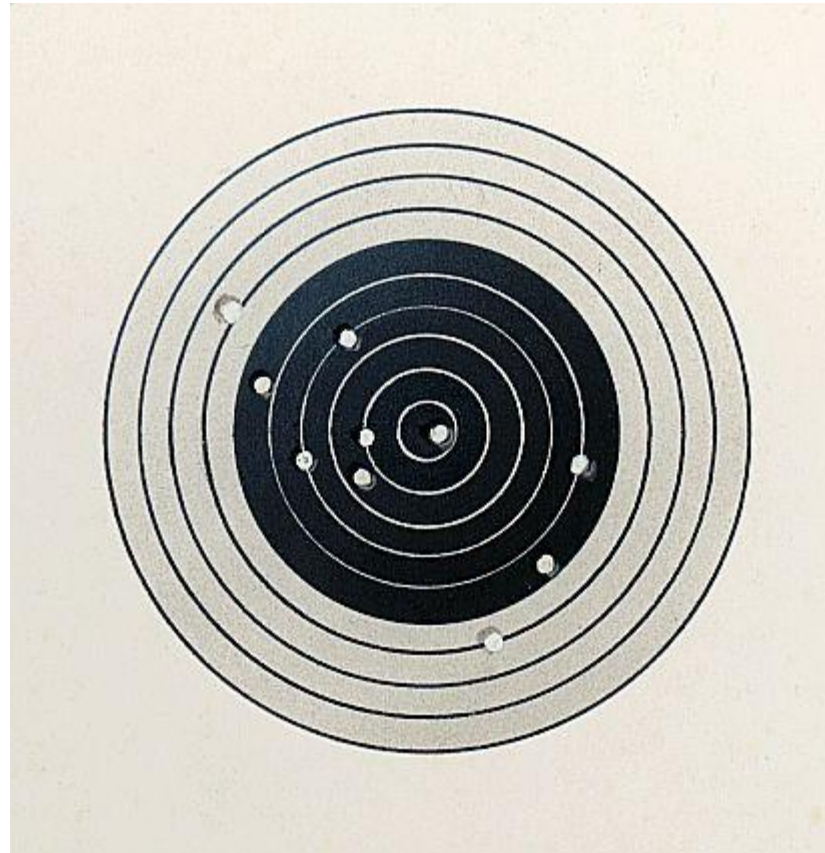
Note 1: Based on research of tension method performance, at around ± 10% of required fastener tension there is substantial reduction in connection failures.

Note 2: Each bolted fastener is an opportunity to be incorrectly tensioned

Note 3: Consequence is presumed to remain the same for each event (mostly not true, which is why determining Criticality first is vital for good maintenance decisions).

The Cross-Hair Game:

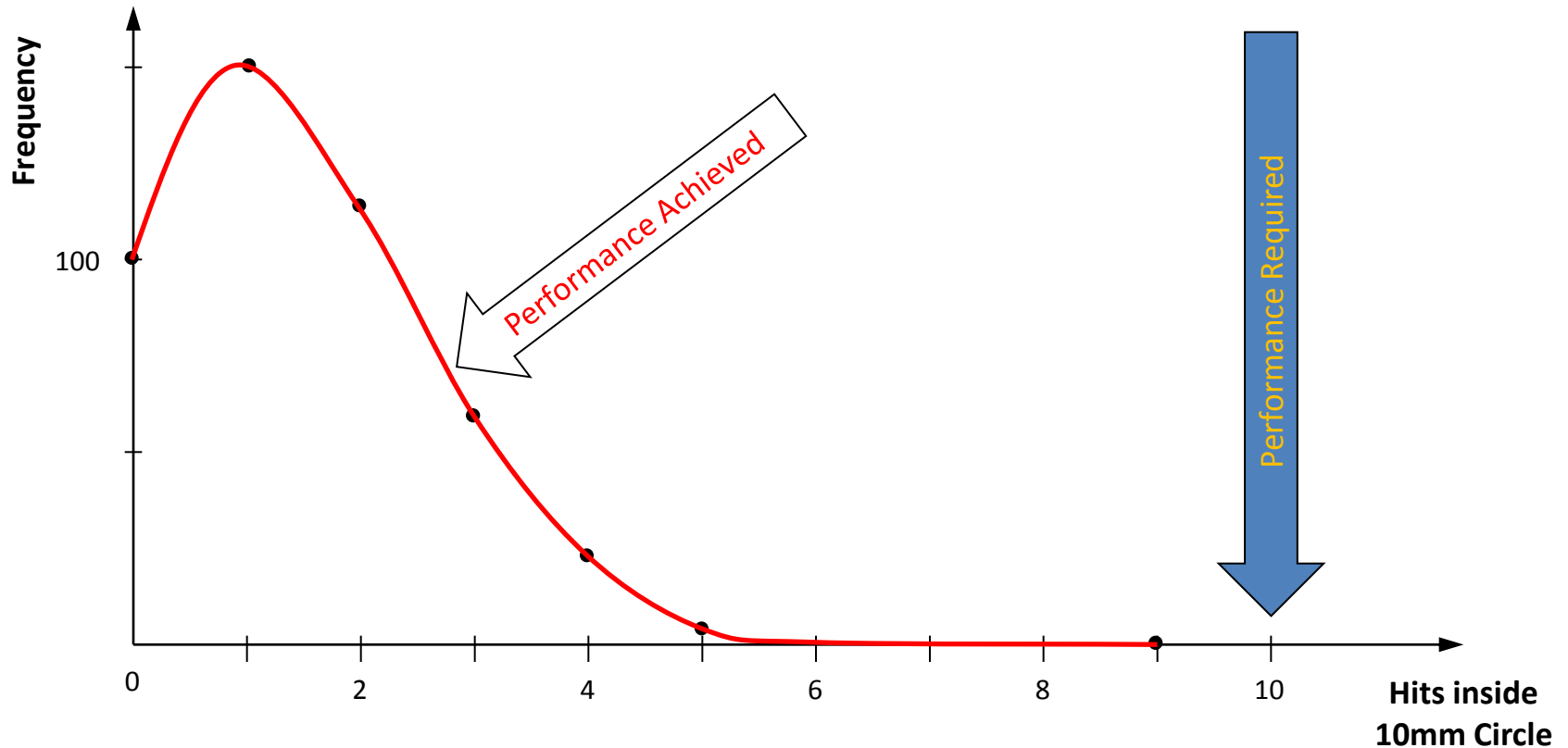
Observing Business Process Outcomes



Cross-hairs and
10 mm diameter
circle

How do you hit the bulls-eye every time?

'Cross Hair' Production Process Results



Identify Business Risk of Asset Failure on a Refined and Calibrated Risk Matrix

Likelihood/Frequency of Equipment Failure Event per Year			DAFT Cost per Event																		Comments
Count per Year	Time Scale	Descriptor Scale		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16		
100	Twice per week		L13	H	H	H	E	E	E	E	E	E	E	E	E	E	E	E	E		
30	Once per fortnight		L12	M	M	E	E	E	E	E	E	E	E	E	E	E	E	E	E		
10	Once per month	Certain	L11	L	L	L	L	M	H	E	E	E	E	E	E	E	E	E	E		
0.3	Once per quarter		L10																		
1	Once per year	Almost Certain	L9																	Event will occur on an annual basis	
0.3	Once every 3 years	Likely	L8																	Even has occurred several times or more in a lifetime career	
0.1	Once per 10 years	Possible	L7																	Event might occur once in a lifetime career	
0.03	Once per 30 years	Unlikely	L6																	Event does occur somewhere from time to time	
0.01	Once per 100 years	Rare	L5																	Heard of something like it occurring elsewhere	
0.003	Once every 300 years		L4																		
0.001	Once every 1,000 years	Very Rare	L3																	Never heard of this happening	
0.0003	Once every 3,000 years		L2																		
0.0001	Once every 10,000 years	Almost Incredible	L1																	Theoretically possible but not expected to occur	

Reduce Chance

Reliability Improving

Reduce Consequence

Failure Cost Decreasing

\$\$\$

\$\$\$

Note:

Risk Level

Red = Extreme

Amber = High

Yellow = Medium

Green = Low

Blue = Accepted

1) Risk Boundary is adjustable and selected to be at 'LOW' Level. Recalibrate the risk matrix to a company's risk boundaries by re-colouring the cells to suit.

2) Based on HB436:2004-Risk Management

3) Identify 'Black Swan' events as B-S (A 'Black Swan' event is one that people say 'will not happen' because it has not yet happened)

How to Reduce the Chance of Failure

Chance of Failure = 1 – Chance of Success

Chance of Failure = 1 – Reliability

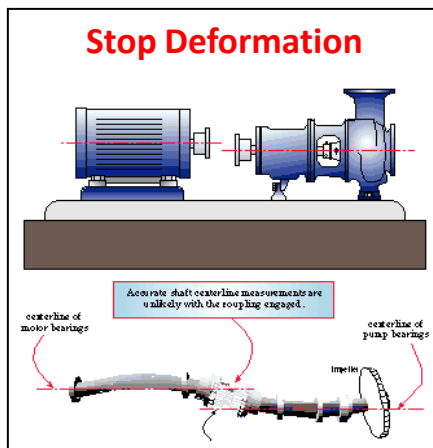
Risk = *Consequence \$ x Chance /yr*

Risk = *Consequence \$ x [Freq of Opportunity /yr x Chance of Failure at Each Opportunity]*

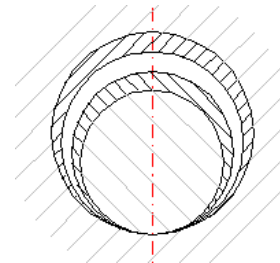
Risk = *Consequence \$ x [Freq of Opportunity /yr x {1 – Reliability}]*



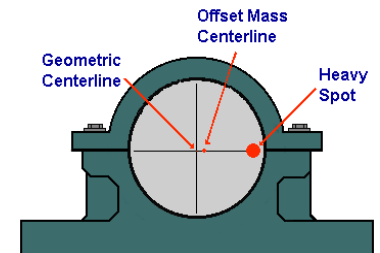
**Excellent
Lubricant
Cleanliness**



**Correct Fastener
Torque**



**Proper Fits and
Tolerance**



**No
Unbalance**

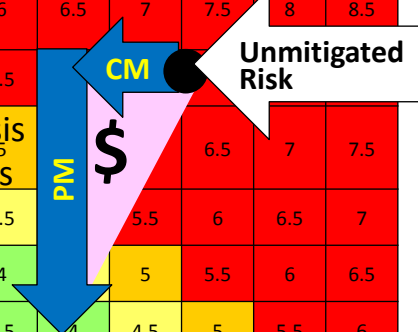
Here are some opportunities...

Tracking Risk Matrix Used to Prove Asset Operating Risk Reduction

Likelihood of Equipment Failure Event per Year				DAFT Cost per Event	\$30	\$100	\$300	\$1,000	\$3,000	\$10,000	\$30,000	\$100,000	\$300,000	\$1,000,000	\$3,000,000	\$10,000,000	\$30,000,000	\$100,000,000	\$300,000,000	\$1,000,000,000
Event Count / Year	Time Scale	Descriptor Scale	Historic Description		1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9
100	Twice per week			2	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11
30	Once per fortnight			1.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5
10	Once per month	Certain		1	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
3	Once per quarter			0.5				3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5
1	Once per year	Almost Certain	Event will occur on an annual basis	0						4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9
0.3	Once every 3 years	Likely	Event has occurred several times or more in a lifetime career	-0.5						3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5
0.1	Once per 10 years	Possible	Event might occur once in a lifetime career	-1							3.5	4	4.5	5	5.5					
0.03	Once per 30 years	Unlikely	Event does occur somewhere from time to time	-1.5								3.5	4	4.5	5					
0.01	Once per 100 years	Rare	Heard of something like it occurring elsewhere	-2									3.5	4	4.5					
0.003	Once every 300 years			-2.5										3.5	4					
0.001	Once every 1,000 years	Very Rare	Never heard of this happening	-3											3.5	4				
0.0003	Once every 3,000 years			-3.5												3.5	4			
0.0001	Once every 10,000 years	Almost Incredible	Theoretically possible but not expected to occur	-4													3.5	4		



CM oil condition analysis
 CM cable thermographs
 PM oil filtration
 PM oil change
 PM oil leaks from TX
 PM water ingress paths
 PM oil breather contamination
 PM cable connections



Note: **Risk Level** 1) Risk Boundary 'LOW' Level is set at total of \$10,000/year
 Red = Extreme 2) Based on HB436:2004-Risk Management
 Amber = High 3) Identify 'Black Swan' events as B-S (A 'Black Swan' event is one that people say 'will not happen' because it has not yet happened)
 Yellow = Medium 4) DAFT Cost (Defect and Failure True Cost) is the total business-wide cost from the event
 Green = Low
 Blue = Accepted