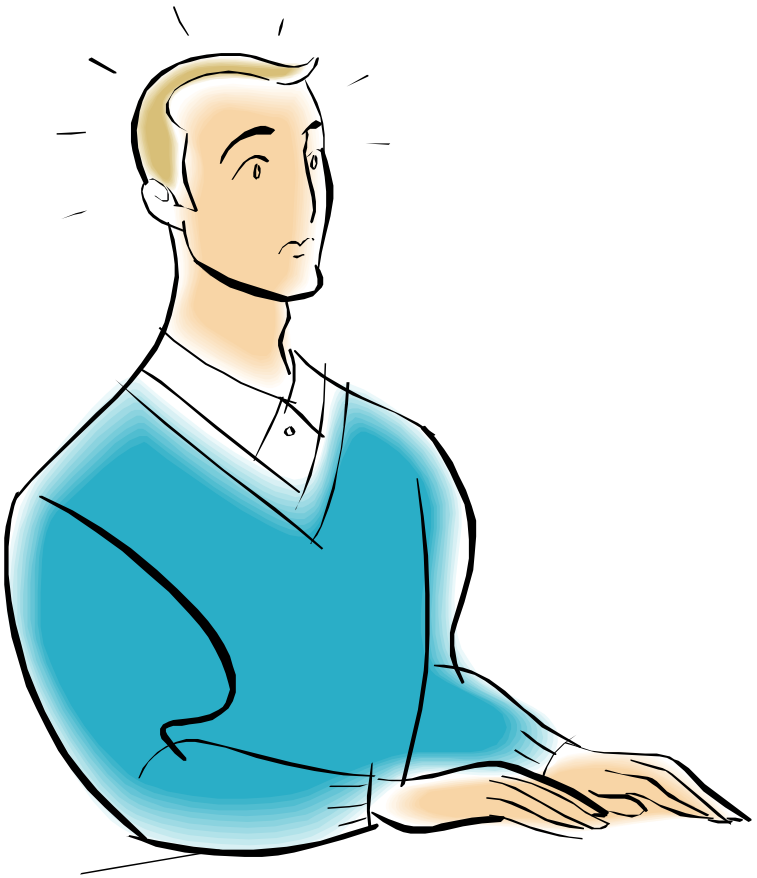
The Fundamentals of Asset Management

Step 6. Determine Business Risk ("Criticality")

A Hands-On Approach

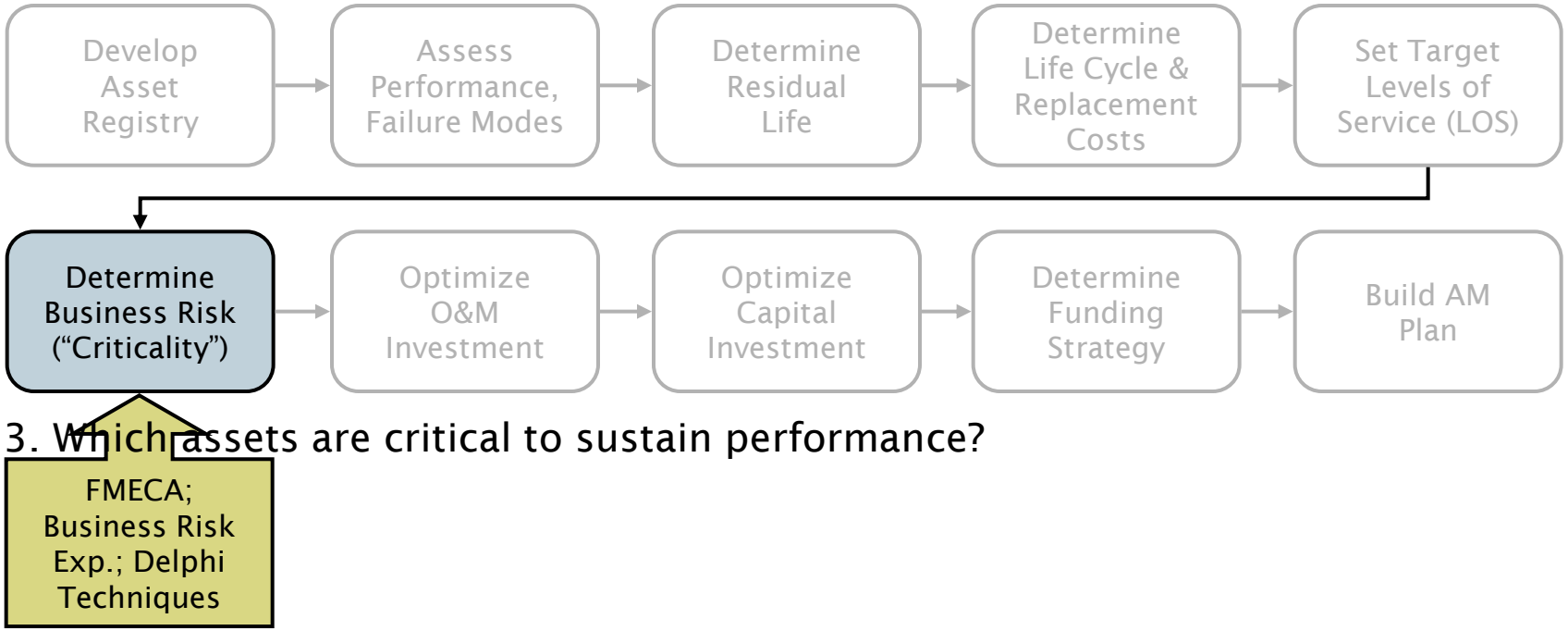
Tom’s bad day…



Third of 5 core questions

3. Which assets are critical to sustained performance?
   - How *does* it fail? How *can* it fail?
   - What is the *likelihood* of failure?
   - What does it *cost* to repair?
   - What are the *consequences* of failure?

AM plan 10-step process



Risk is the heart of AM

Definition of *risk*

- *Risk* in AM-speak is the *consequence of failure multiplied by the probability of failure*
- Often used as a measure of *“criticality”*
- Preferred term is *“business risk exposure (BRE)”*

Variables in *business risk exposure*

- *Probability* or likelihood of failure (PoF)
- *Consequence* or impact of failure (CoF)
- *"Risk mitigation"* or risk reduction and avoidance

Let’s clarify terms

Ambiguous:

- “Risk”
- “Criticality”

Preferred:

- Probability of failure
- Consequence of failure
- *“Business risk exposure”*

All assets have a probability of failure

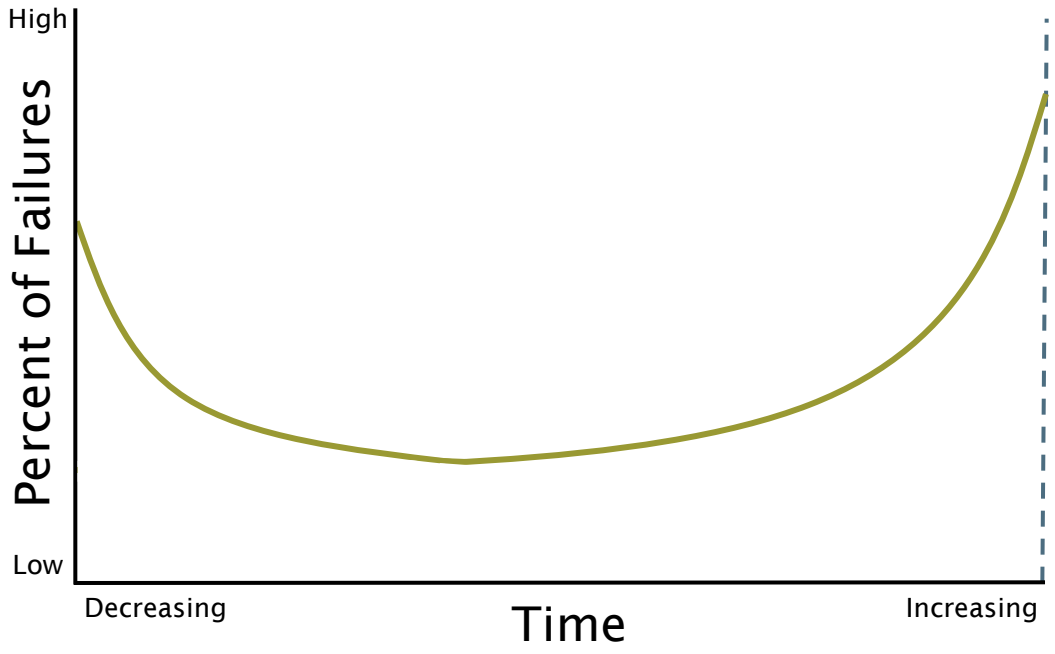
Two key questions…

1. Is the failure reasonably *predictable*?
2. Is it cost-effectively *preventable*?

Most common patterns of failures

Two key failure patterns

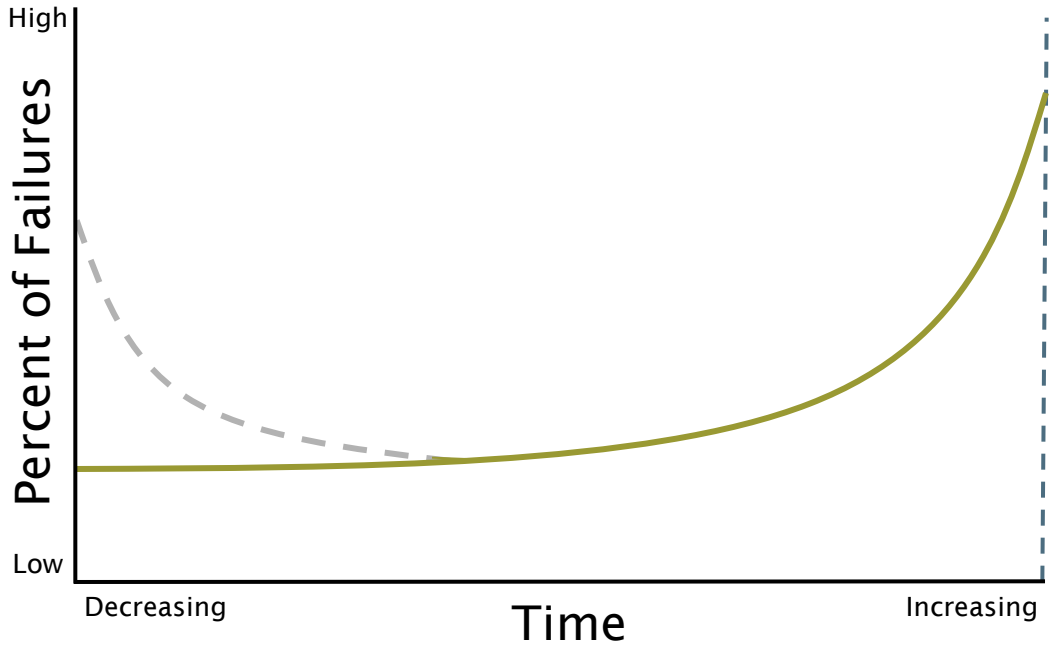
1. *Bathtub curve*—typically applicable for mechanical and electrical assets



Most common patterns of failures

Two key failure patterns

1. *Bathtub curve*—typically applicable for mechanical and electrical assets
2. *Age-based curve*—typically applicable for civil passive assets



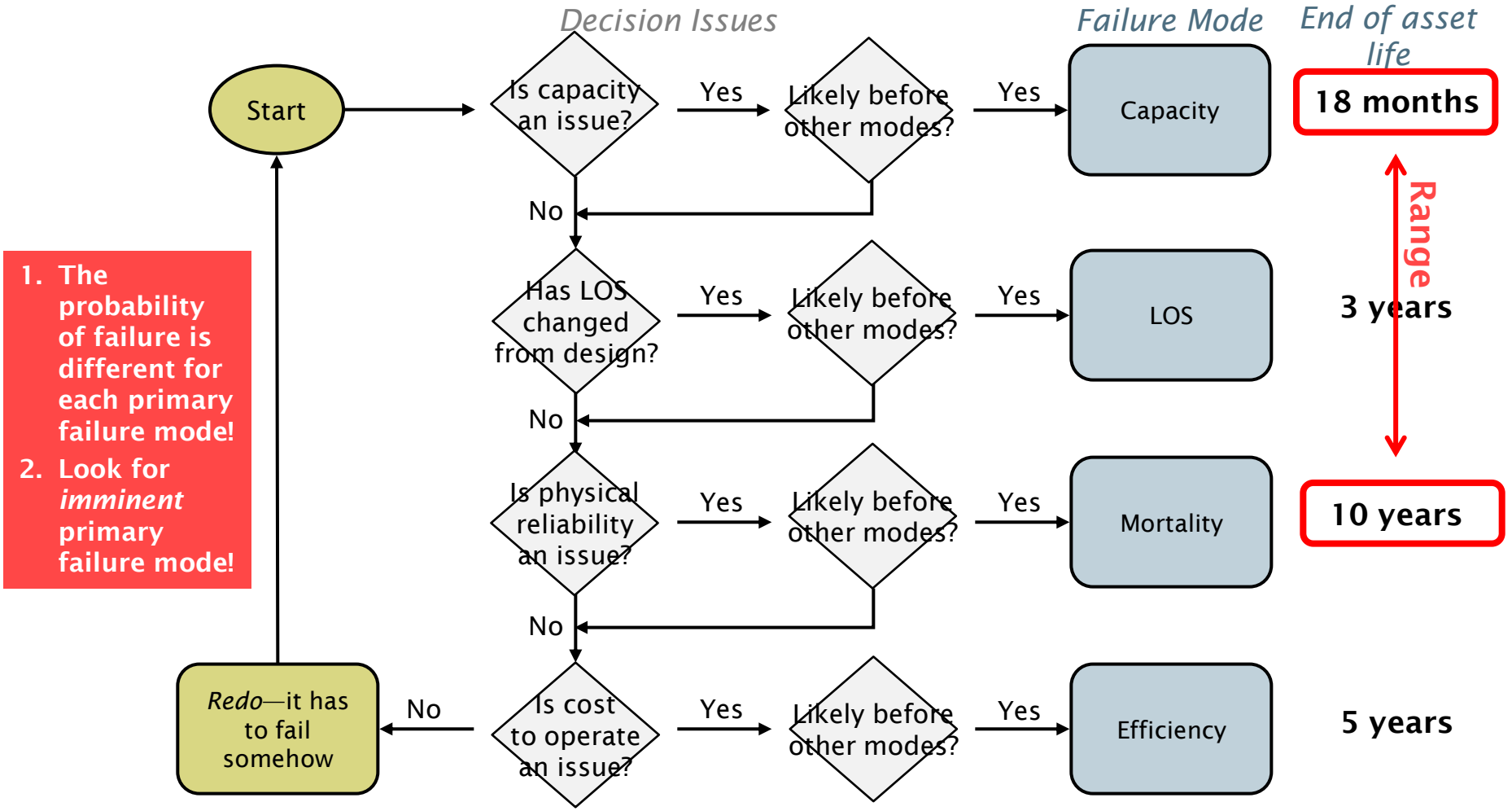
Reliability—the probability that a component or system will perform its specified function for the specified period under specified operation conditions

Recall the four major *failure modes*

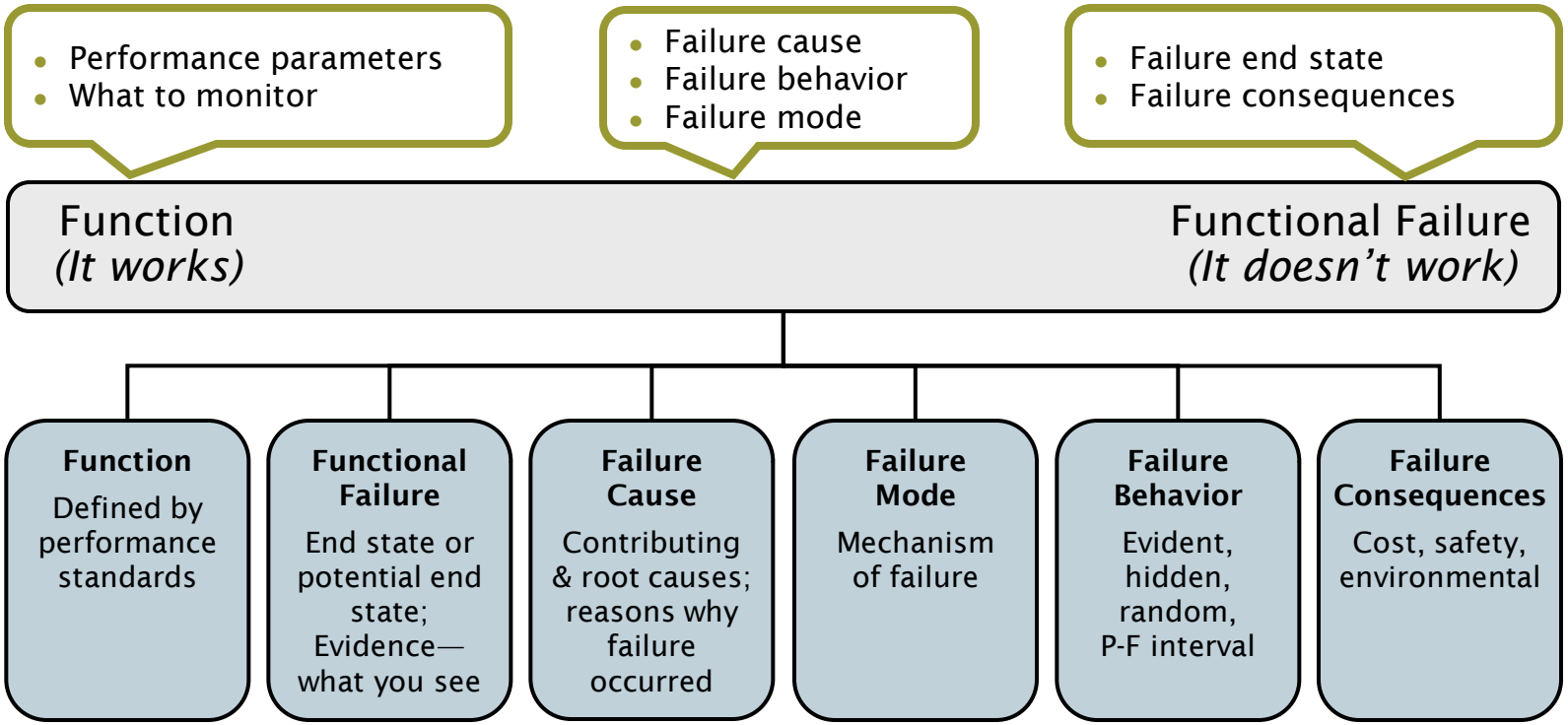
Failure Mode	*Definition*	*Tactical Aspects*	*Management Strategy*
Capacity	Volume of demand exceeds design capacity	Growth, system expansion	Redesign
LOS	Functional requirements exceed design capacity	Codes & permits: NPDES, CSOs, OSHA, noise, odor, life safety; service, etc.	O&M optimization, renewal
Mortality	Consumption of asset reduces performance below acceptable level	Physical deterioration due to age, usage (including operator error), acts of nature	O&M optimization, renewal
Efficiency	Operations costs exceed that of feasible alternatives	Pay-back period	Replace

NPDES is National Pollutant Discharge Elimination System, CSOs are combined sewer overflows, and OSHA is Occupational Safety and Health Administration

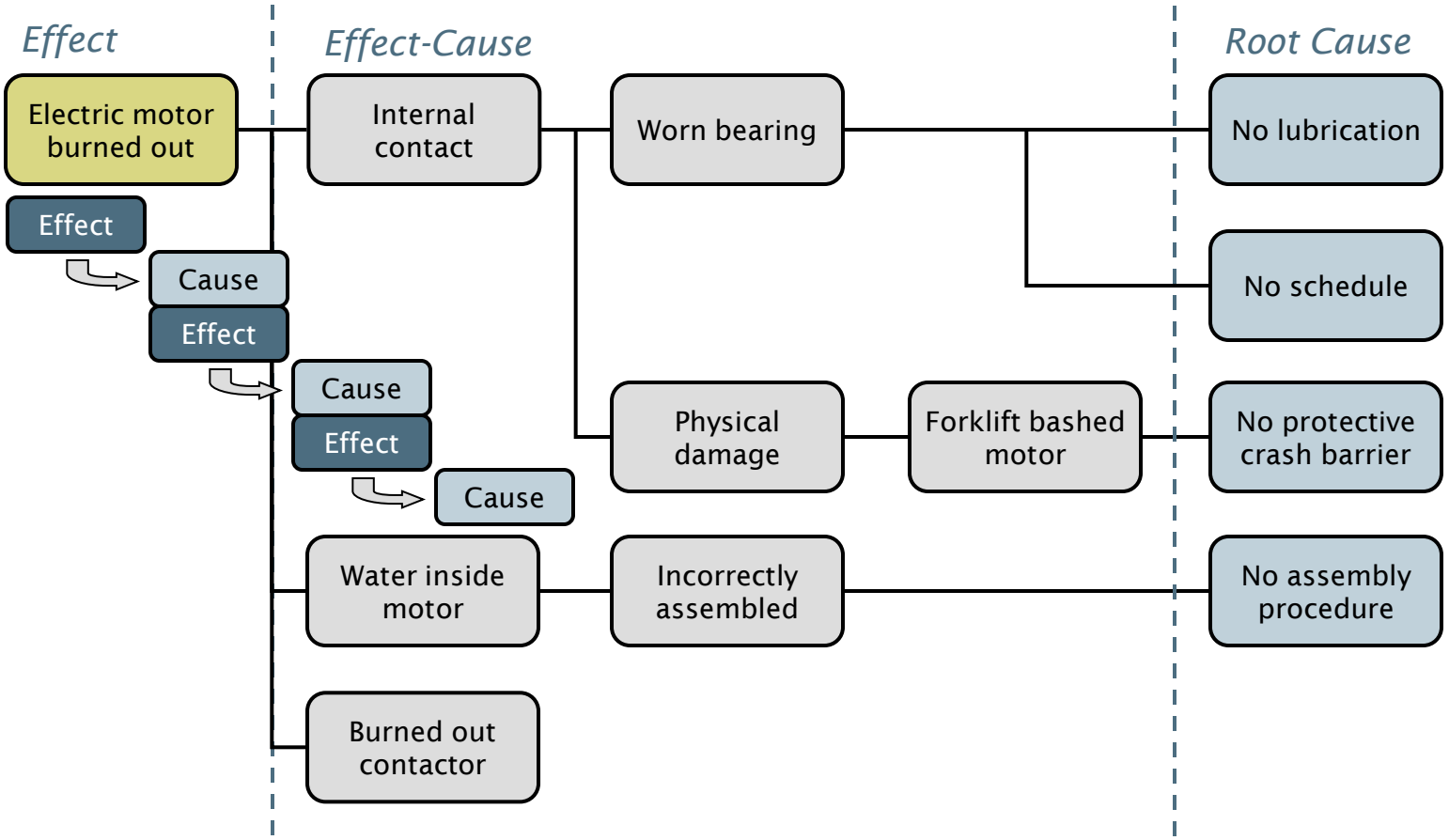
The role of primary failure modes in determining the probability of failure



Failure analysis



Cause and effect diagram



Probability of failure (PoF)

- PoF is directly related to the *failure mode*
- We *cannot* absolutely determine PoF
- Sometimes we have good data, sometimes we do not
- We can estimate a *range of failure*—how early (pessimistic) and how late (optimistic)

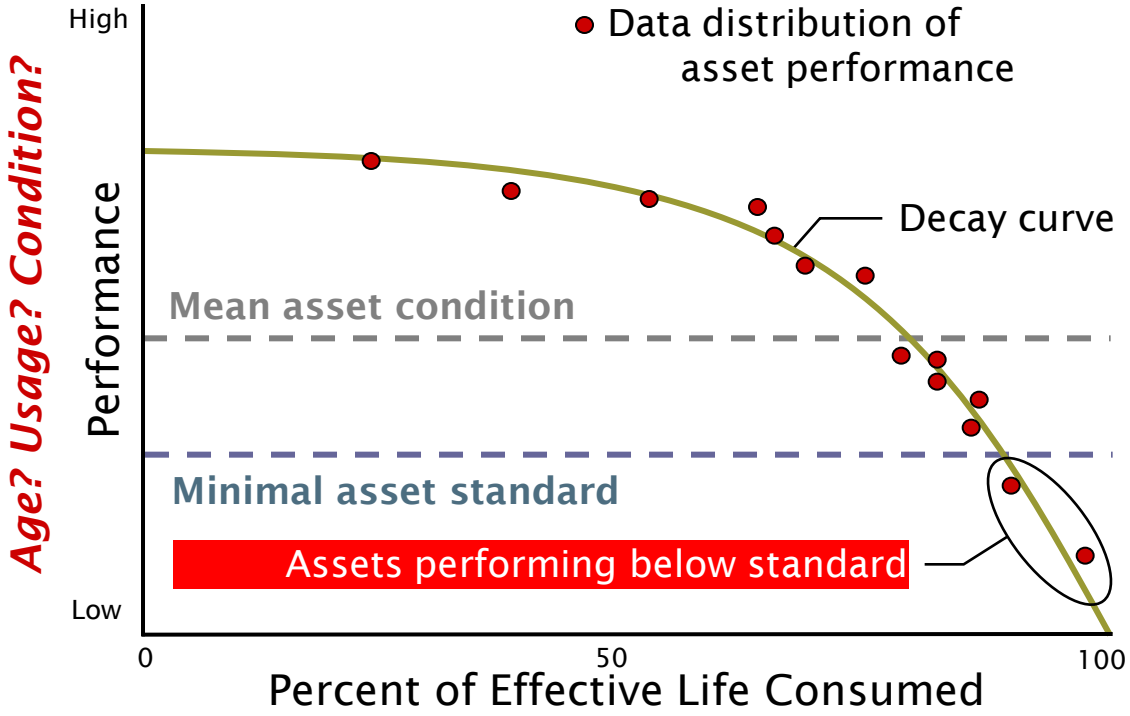
What are sources of Probability of Failure?

- CMMS—*mean time between failures* (MTBF)
- Vendor and industry information
- Other *failure records* (hard copies)
- Our brilliant *memories* (staff)
- Our *SCADA system* (if we have one and if it keeps records on this asset)

PoF is probability of failure, CMMS is computerized maintenance management system, SCADA is supervisory control and data acquisition

Finding a *proxy* for measuring failure

Can *age*, *usage*, or *condition* be substituted?...



Linking probability of failure to age of asset ("% effective life consumed")

% of Effective Life Consumed	*PoF Rating*
<10	1
20	2
30	3
40	4
50	5
60	6
70	7
80	8
90	9
Failed	10

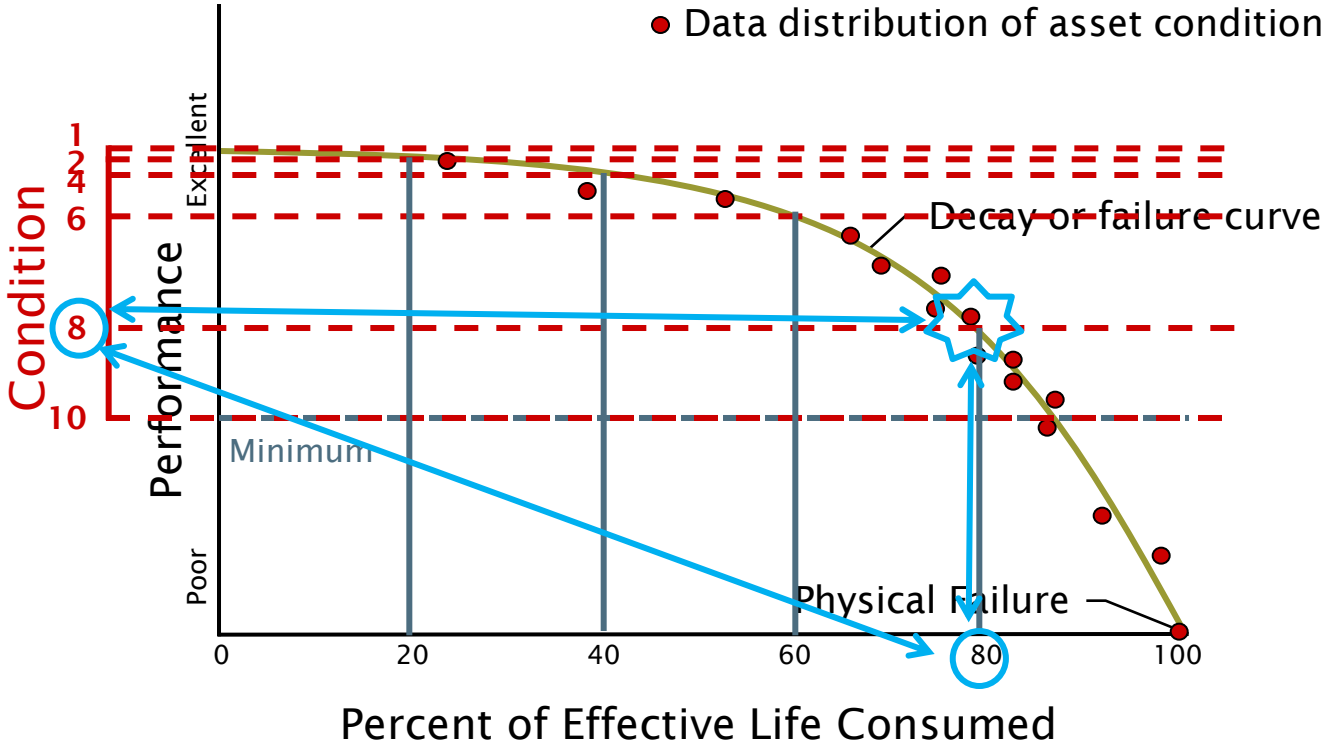
PoF is probability of failure

Linking probability of failure to direct observation tables

*Assessment **	*Probability Weighting*	*Description*
Almost certain	100	Expected to occur within a year
Very high	75	Likely to occur within a year
High	50	Estimated 50% chance of occurring in any year
Quite likely	20	Expected to occur within 5 years Estimated 20% chance of occurring in any year
Moderate	10	Expected to occur within 10 years Estimated 10% chance of occurring in any year
Low	2	Expected to occur within 50 years
Very low	1	Expected to occur within 100 years

***** Likelihood of occurrence within a year

Recall alternative: tying condition score to asset failure – how?



Relating condition to Probability of Failure through % Physical Life Consumed

Element	Description					
SCORE	1	3	5	7	9	10
Technical Performance	Substantially exceeds current requirements	Exceeds current requirements	Meets current requirements but with room for improvement	Obvious concerns: cost/benefit questions	Inefficient; becoming ineffective, obsolete	Failing, not capable of sustaining required performance
Operational Performance	Negligible attention required	Exceeds current requirements	Meets current requirements but with room for improvement	Obvious concerns: cost/benefit questions	Difficult to sustain performance	Failing, not capable of sustaining required performance
Reliability	As specified by manufacturer	Infrequent breakdown	Occasional breakdown	Periodic breakdown	Continuous recurrent breakdown	Virtually inoperable
Availability	Virtually always operational	Out of service only for very short periods	Out of service for moderate period; moderately difficult to return to service	Increasingly difficult to return to service; parts becoming a challenge	Extensive downtime duration; difficult to return to service; parts, difficult to acquire, rare skills required	Virtually impossible to return to service; parts no longer available; unavailable trained personnel
Maintainability	Easily maintained; OEM maintenance is straightforward	Largely preventive maintenance with some corrective maintenance beginning to show up; baseline monitoring	Increasing minor maintenance required; periodic corrective maintenance including some repair shortening of monitoring intervals	Scheduled maintenance becoming frequent; more experienced trades people required for maintenance; frequency of work orders increasing substantially with short monitoring intervals	Work orders well above average for type of asset; recurrent minor repair; close monitoring required; most senior people required to sustain performance	Maintenance is frequent with recurrent patterns of failure; asset must be virtually constantly monitored to sustain performance
% Physical life consumed	Almost new; up to 10% physical life consumed	Up to 30% physical life consumed	Up to 50% physical life consumed	Up to 70% physical life consumed	Up to 90% physical life consumed	Virtually consumed, imminent failure
CONDITION SCORE	1	3	5	7	9	10
Prob of Failure	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**	**0.99**

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Scoring the Consequence of Failure

Social/community/ organizational						
Loss of Service	Can be out of service indefinitely	Cannot be down a month	Cannot be down a week	Cannot be down a day	Cannot be down 8 hours	Cannot be down one hour
Safety	No impact	Minor inconvenience	Minor injury	Moderate injury and some sickness	Major injury, sickness, some death	Subsrtantial death, widespread injury and sickness
Agency's Image	No media or no consequence	Neutral coverage	Adverse media	Widely adverse media	Continual; political opposition	Nationally adverse media
	1	3	5	7	9	10

Econcomic/Financial						
Financial impact	Low cost	Moderate cost	High cost	High cost; diverts $	Painful change of priorities	Likely to trigger rate Increase, staff changes
Economic impact	Insignificant	<$100k	<$500k	<$2 million	<$10 million	>$10 million
	1	3	5	7	9	10

Environmental						
Spill, flood	Short duration, small quantity onsite	Some basement backups	Moderate basement backups, some offsite spillage	Many inconvenienced; moderate health and habitat issues	Severe health and habitat issues; some mandatory vacation of premises	Large areas vacated and closed to public access; entensive specialized containement cleanup required
Odor	No complaints	A few compliants adjacent to station	Moderate complaints adjacent to station	Extensive complaints adjacent to station; lingering area odor	Extensive area-wide complaints	Odor at dangerous levels at spill site; evacuation of premises required
Permit compliance	No consequence	Minor violation - reporting only	Regulatory sanction possible	Regulatory sanction likely; Damage reversible less than one year	Extensive regulatory sanction virtually assured; damage reversible in one to five years	Severe sanctions; damage reversible in five years or more
Score	1	3	5	7	9	10

Quantifying *consequence of failure*

Sophisticated

- **Direct Costs to the Local Government**
  - Repair and return to service costs
  - Service outage mitigation costs
  - Utility emergency response costs
  - Public safety costs
  - Admin & legal costs of damage settlements
  - (Lost product costs)
- **Direct Customer Costs**
  - Property damage costs (including restoration of business)
  - Service outage costs
  - Service outage mitigation and substitution costs
  - Access impairment and travel delay costs
  - Health damages
- **Community Costs**
  - Emotional strain/welfare
  - Environmental Pollution, erosion, sedimentation
  - Destruction of/damage to habitat
  - “Attractability” (tourist, economic)

“Full Economic Cost”

Alternative view of *"criticality"*—impact on core processes

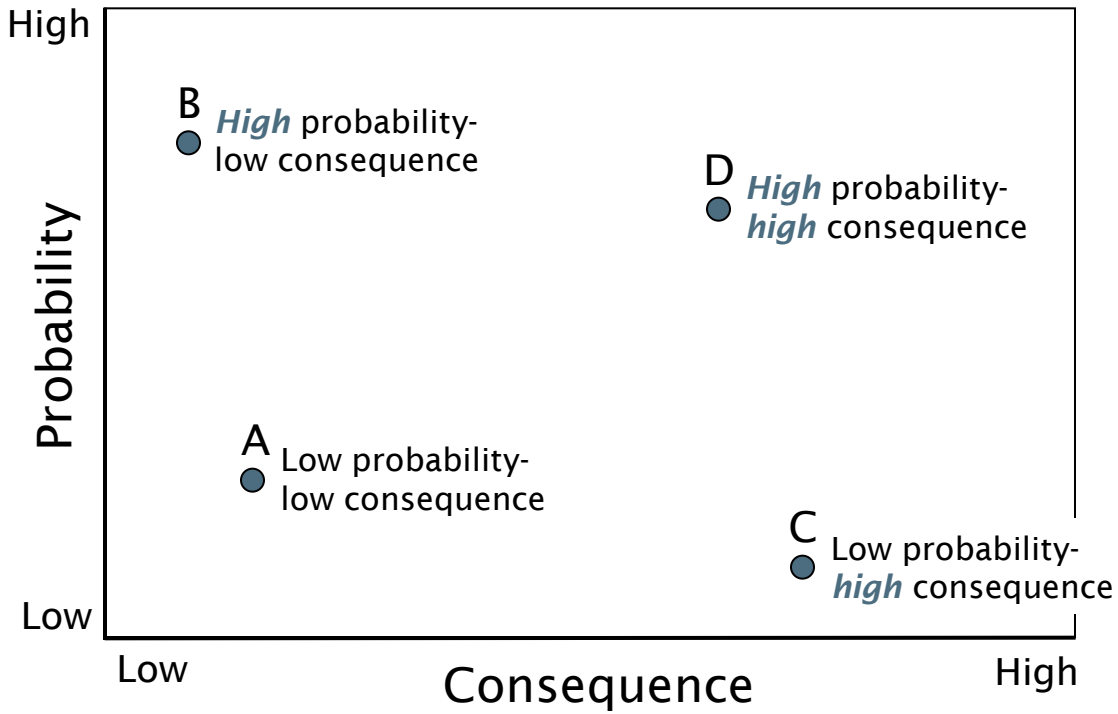
Code	*Description*
1	Mandated by law or corporate policy
2	Impacts multiple processes, runs continuous without an on-line spare
3	Impacts multiple processes, runs intermittently without an on-line spare, and/or causes lost production in fewer than 4 hours
4	Impacts a single process, runs intermittently without an on-line spare, and/or causes lost production between 4-24 hours
5	Impacts a single process, runs intermittently without an on-line spare, and/or causes lost production in fewer than 24 hours
6	Impacts multiple processes, runs continuous with an on-line spare, and causes no lost production
7	Impacts multiple processes, runs intermittently with an on-line spare, and causes no lost production
8	Impacts a single process, runs intermittently or continuous with an on-line spare, and causes no lost production
9	Minor or no impact on safety, product, or cost

Alternative view of *"criticality"*—impact on revenue

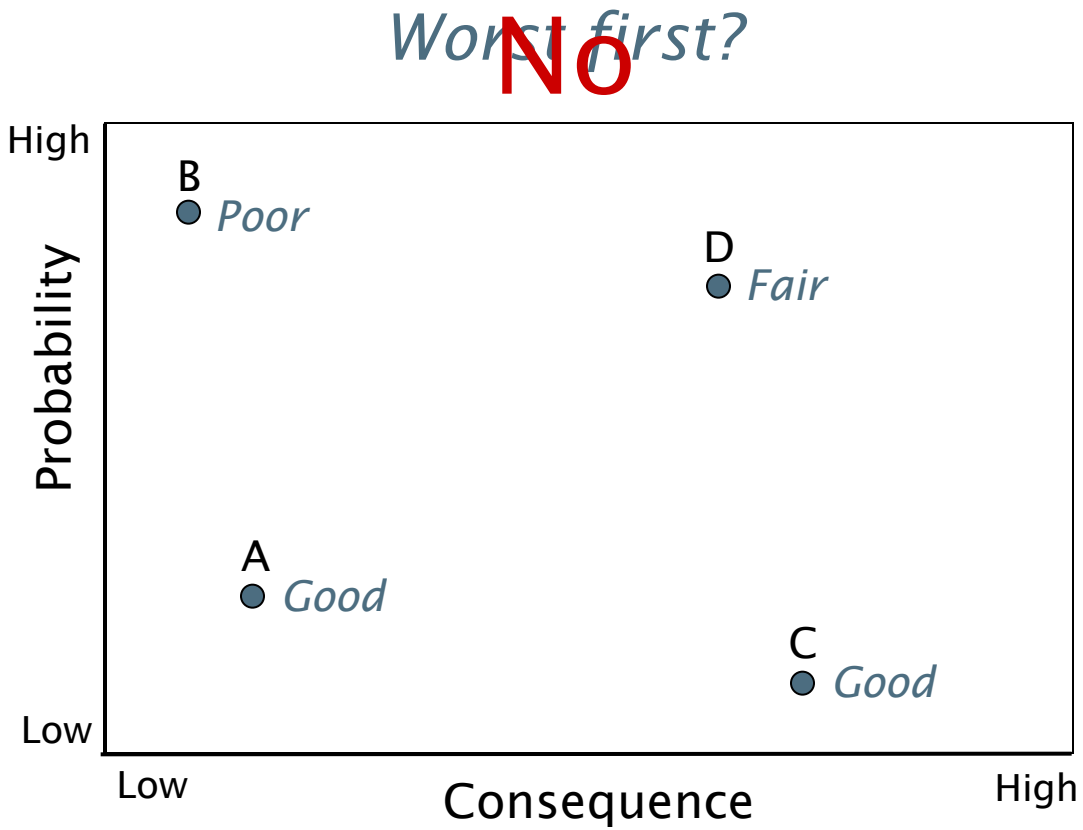
Code	*Description*
1	Assets required for conducting *value stream* functions that produce the core *unit of value*
2	Assets required to ensure that *revenue producing* assets are powered or controlled
3	Assets required for order fulfillment functions such as sales orders, production planning, shipping, and accounting
4	Assets required for other core production or service functions such as material handling or warehousing
5	Non-revenue producing assets required for protecting revenue-producing assets from inoperable conditions
6	Non-revenue producing assets required for conducting supporting business functions
7	Non-revenue producing assets that impact quality of life

Determining significant failures

The business risk exposure trade-off…

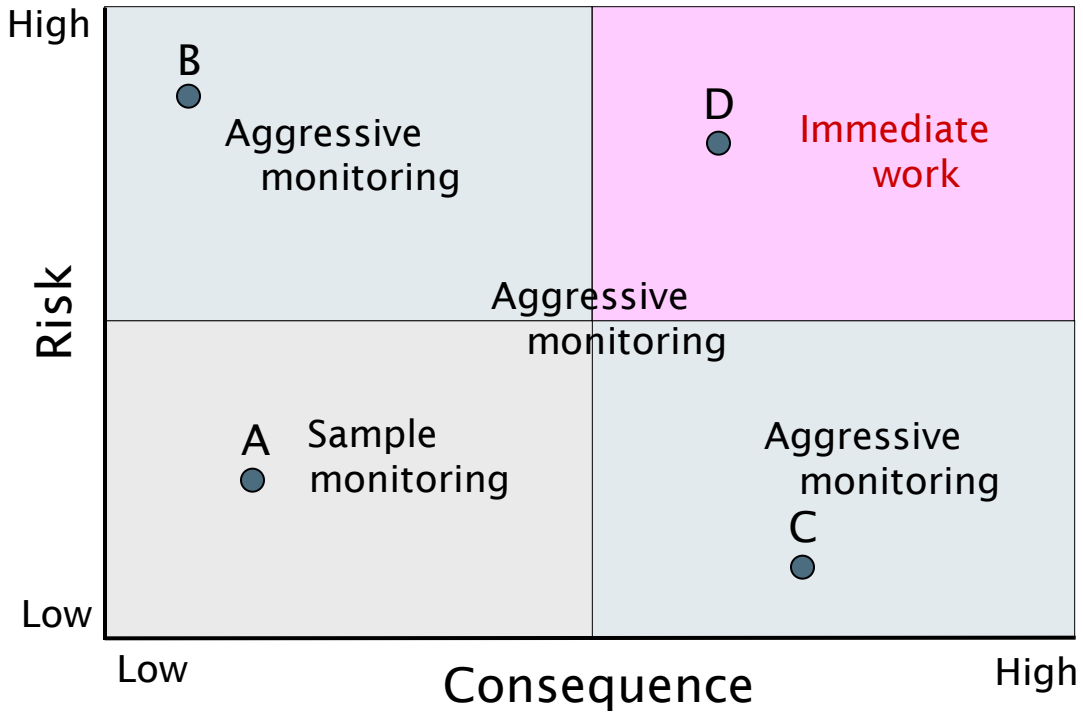


Business risk exposure drives work program



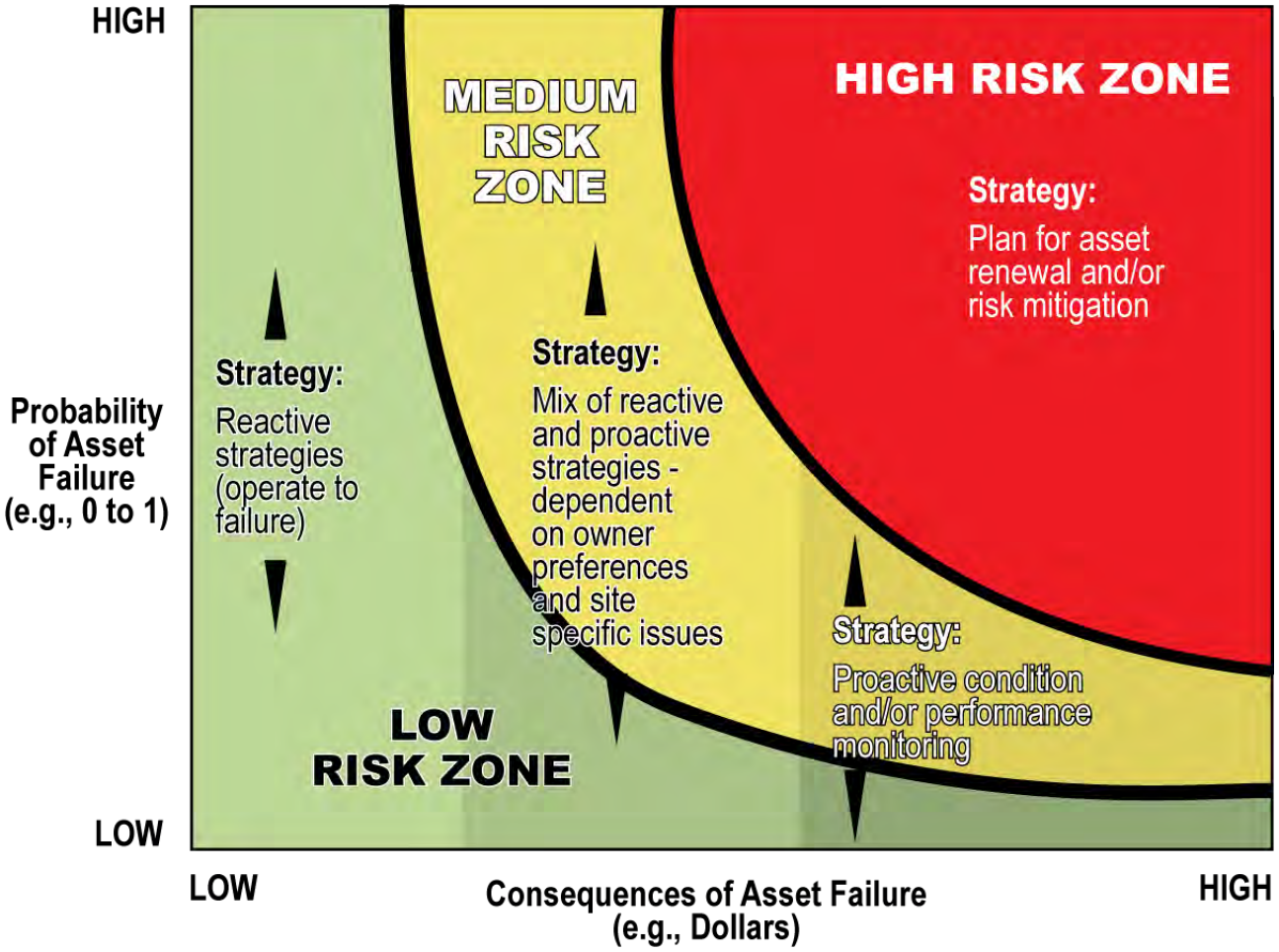
Business risk exposure drives work program

Work program response



Relating Business Risk Exposure to management action

1. Set strategic levels of service & tolerable risk limits

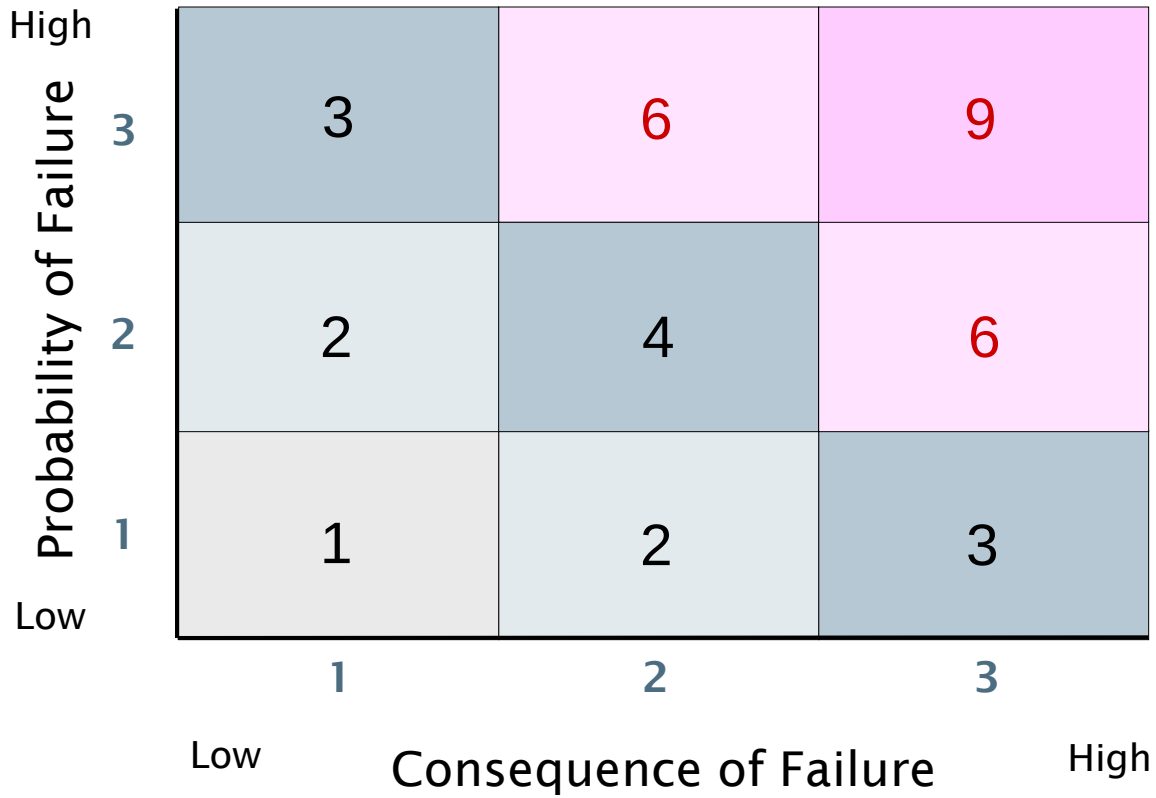


Simple risk (criticality) metric

PoF x CoF = BRE

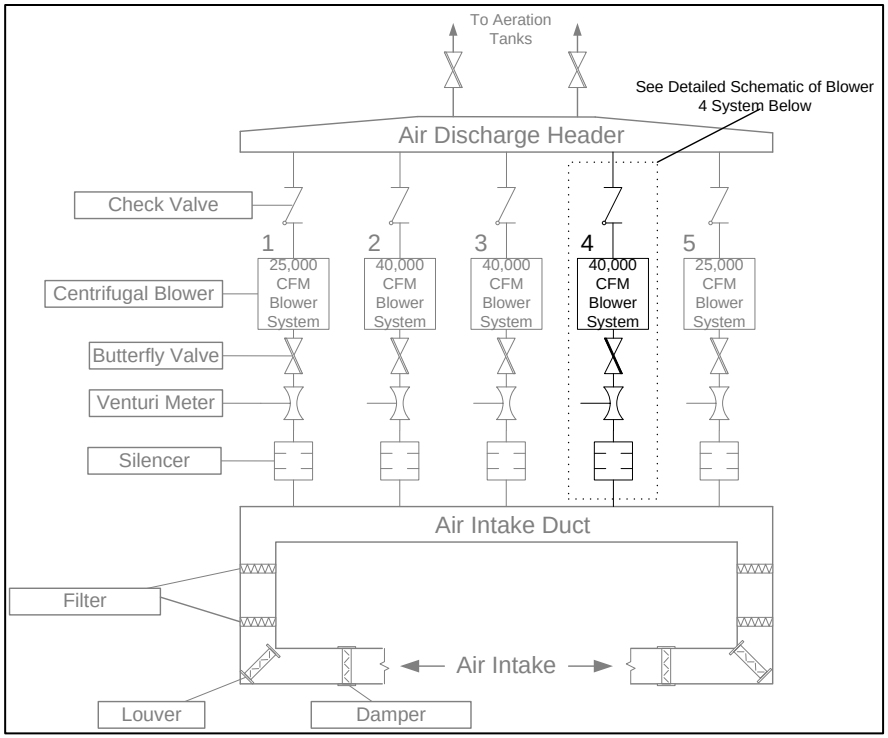
BRE 1—simple approach

Business risk exposure (BRE) increases (higher numbers) as probability of failure (PoF) and consequence of failure (CoF) increase

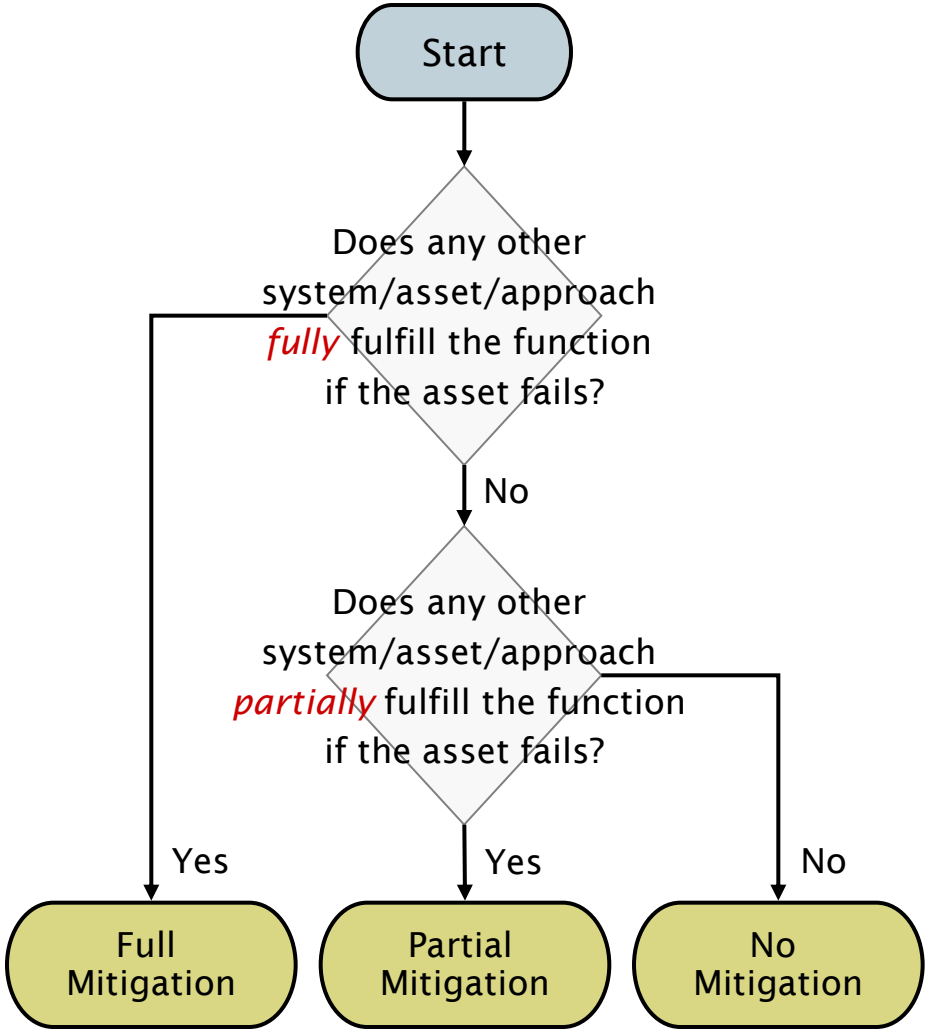


Introducing “risk mitigation” into the risk metric

- *Risk mitigation”* significantly reduces the risk metric
- BRE = PoF x CoF *x R*
- Where
  - PoF is probability of failure
  - CoF is consequence of failure
  - R is a *risk mitigation factor (≤1.0)*



Determining risk mitigation factor



Example of assigning weight to risk mitigation – in this case, redundancy

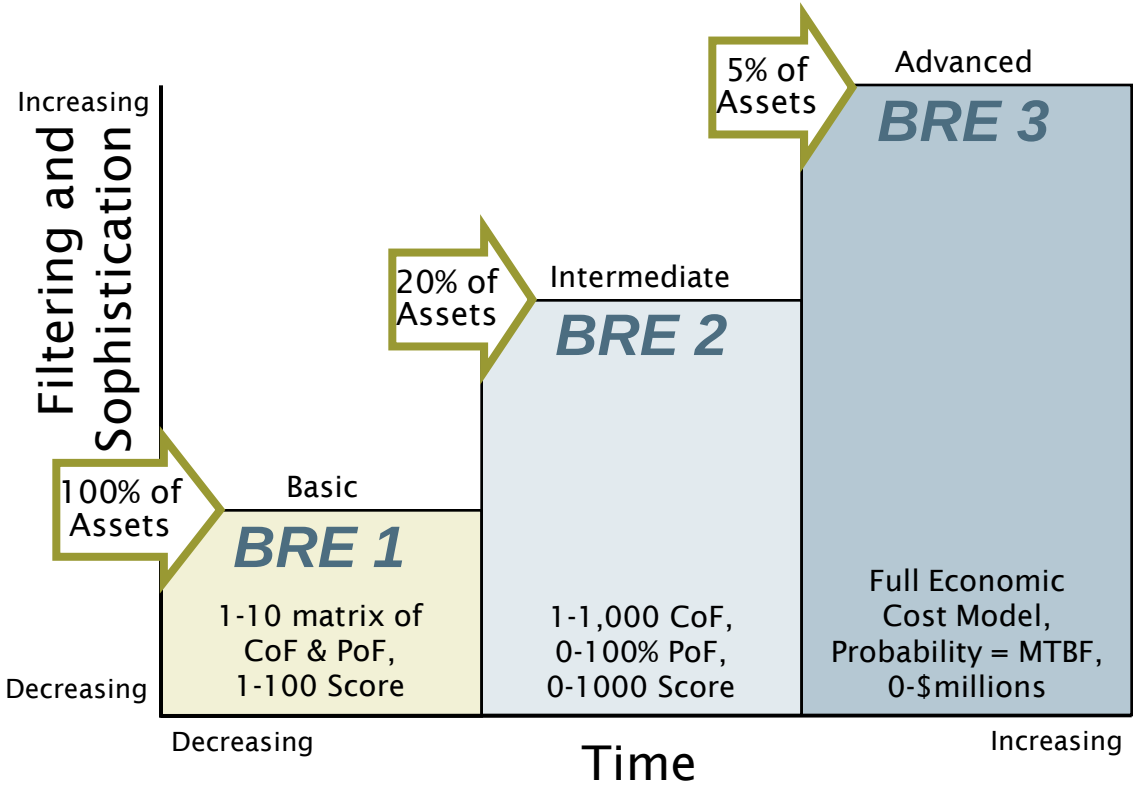
Type Redundancy	*Percent Redundancy*	*Percent PoF Reduction*
Partial	50	50
Full	100	90
Double	200	98

Set weights considering operating circumstances, where possible

- *True redundancy* (peak vs. average)
- Age and condition of equipment
- Nature of operating environment
- Nature of failure modes (evident, hidden, random)

Step-by-step BRE methodology

Levels of filtering and sophistication



BRE is business risk exposure, CoF is consequence of failure, PoF is probability of failure, MTBF is mean time between failures

Level 1—simple

BRE rating = probability x consequence

Asset No.	*% Probability*	*Consequence*	*Risk Mitigation Factor*	*Risk Rating*
1	.60	4	0.50	1.2
2	.70	2	1.00	1.4
3	.40	5	1.00	2.0
4	.66	10	1.00	6.6*
5	.95	7	1.00	6.7*
6	.10	10	0.90	0.9

* Requires further investigation

Level 2—intermediate

Multiple elements, enhanced FMECA analysis techniques

Element	*Rating*	*Weighting*	*Max. Score*
Safety	1-5	10	50
Environment	1-5	6	30
Functionality	1-5	5	25
Cost	1-5	8	40
			145

FMECA is failure mode effect critical analysis

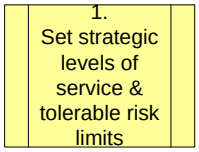
Example of risk table

Matrix of probability and consequence of failure

Probability of Failure	*Consequence of Failure*					
	1	*2*	*3*	*4*	*5*	*6*
Very low	L	L	L	L	M	M
Low	L	L	L	M	M	S
Moderate	L	L	M	M	S	S
Quite likely	L	M	M	S	S	H
High	M	M	S	S	H	H
Very high	M	S	S	H	H	H
Almost certain	S	S	H	H	H	H

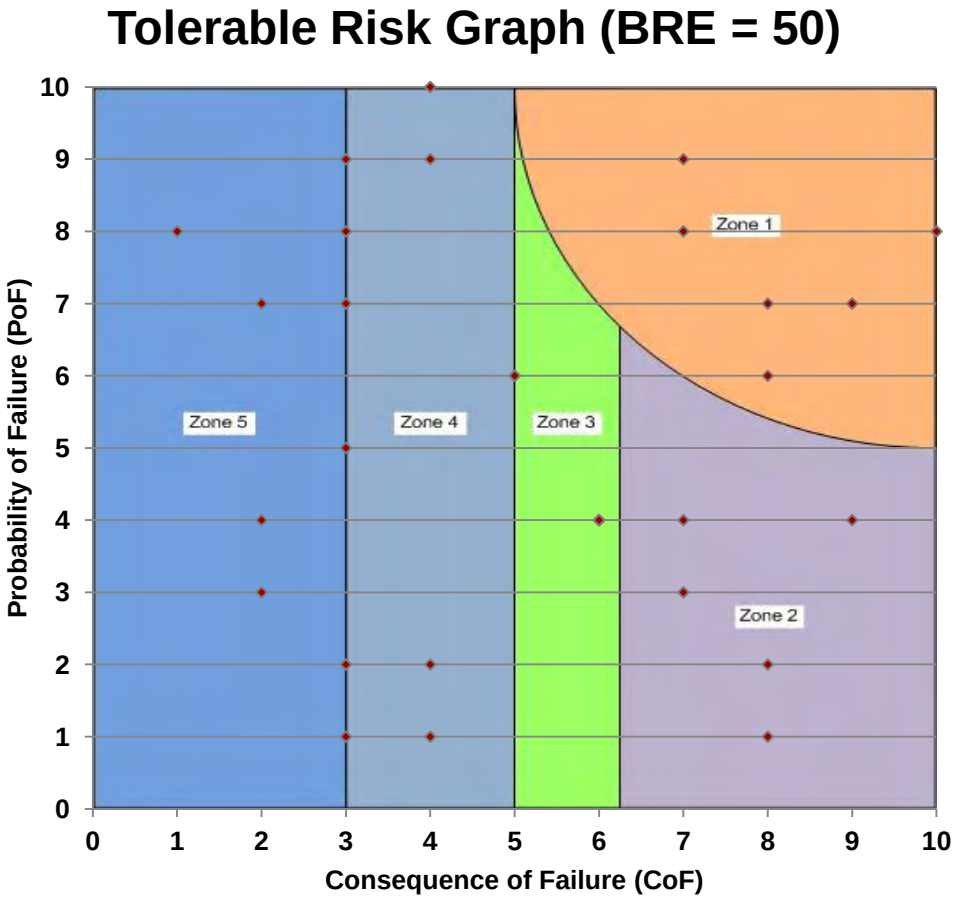
L is low risk, M is moderate risk, S is substantial risk, H is high risk

What is “tolerable risk”?



- As you think of Business Risk Exposure, consider following questions for each asset or asset group:
  - What is a tolerable Consequence of Failure that can happen repeatedly and why?
  - What is a Consequence of Failure that cannot happen even once and why?
  - What do you want to avoid the most and why?
  - What risk score could be acceptable at times and why?
- Categories
  - Tolerable with reactive/PM focused management strategy (“run to failure”)
  - Tolerable with proactive/PdM/monitoring management strategy
  - Not tolerable – “cannot fail”

Tolerable risk mapping



Zone 1: Intolerable Risk

Zone 2: Tolerable and Manageable Risk - Assets with a consequence of failure score that are similar to Zone 1 in terms of the environmental and operational impacts that would be experienced on failure; however failure of these assets is not highly likely at this time; aggressive monitoring is called for.

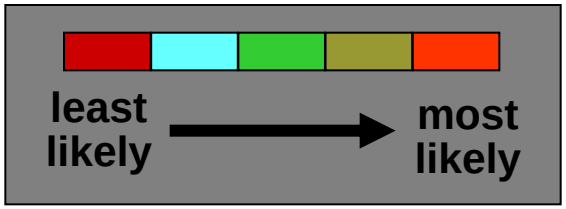
Zone 3: Tolerable and Manageable Risk - Assets in this zone have a consequence of failure and probability of failure that warrant aggressive monitoring and management.

Zone 4: Tolerable and Manageable Risk - Assets in Zone 4 experience failure consequences that are tolerable because they are managed through designed redundancy and operational mitigations such as spares and condition monitoring.

Zone 5: Repeatable Risk - Minor consequences are experienced due to failure of assets in Zone 5. Repeated failures are acceptable in terms of consequence.

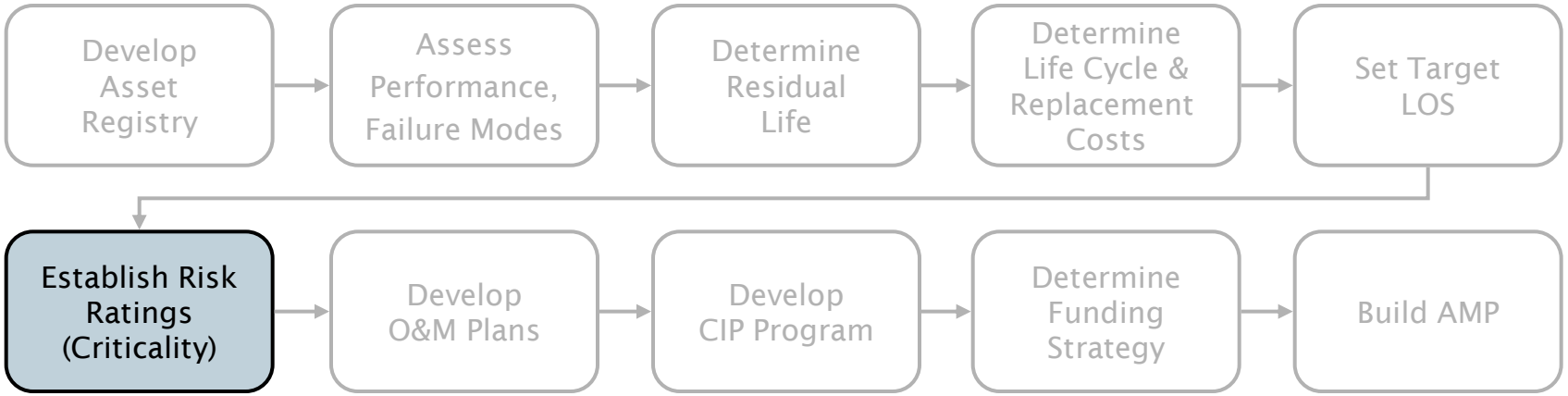
Risk Mapping

Operational Failure

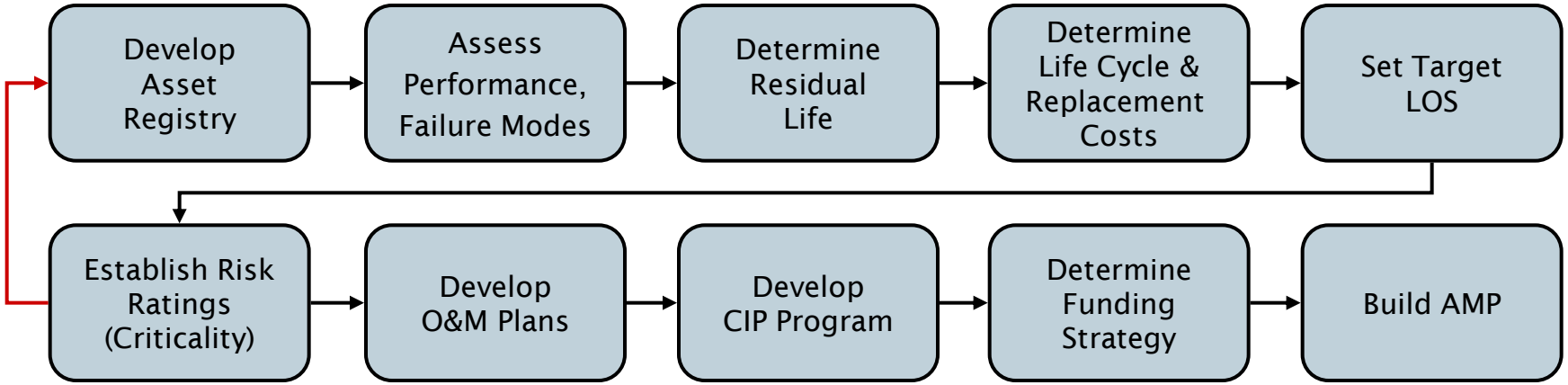


Structural Failure

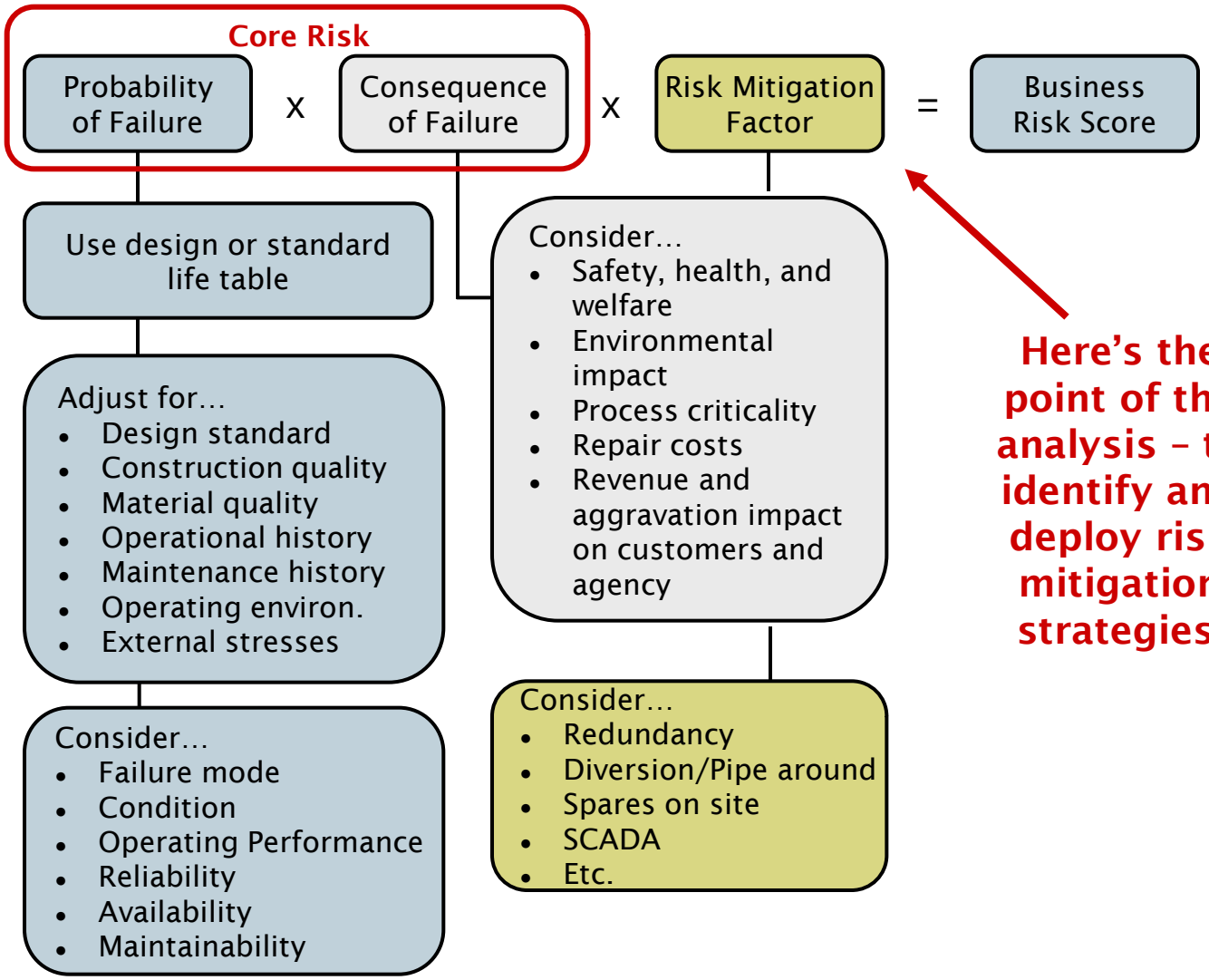
Modifying the 10-step process



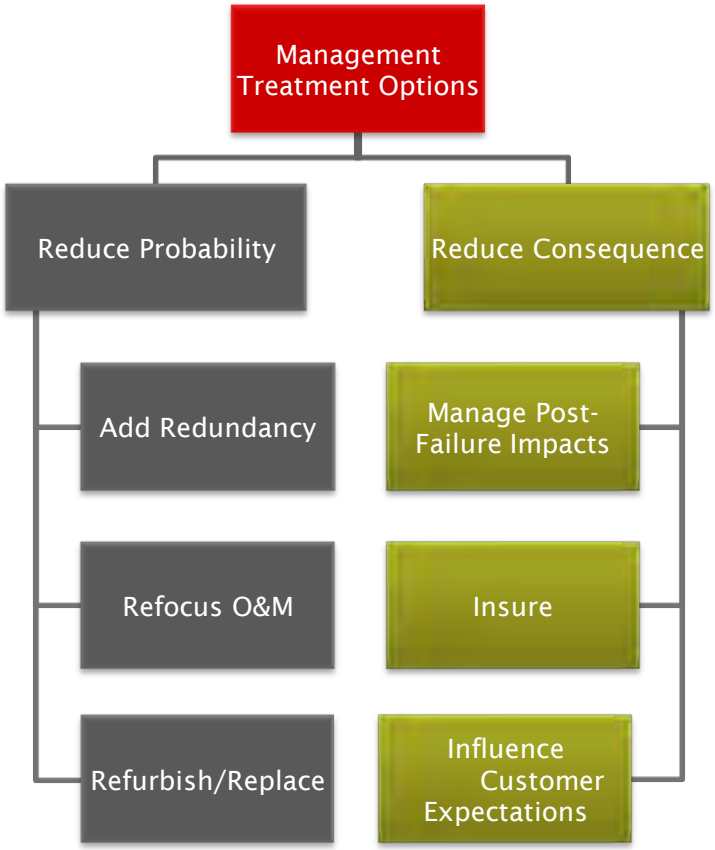
Modifying the 10-step process



Putting it all together—calculating business risk



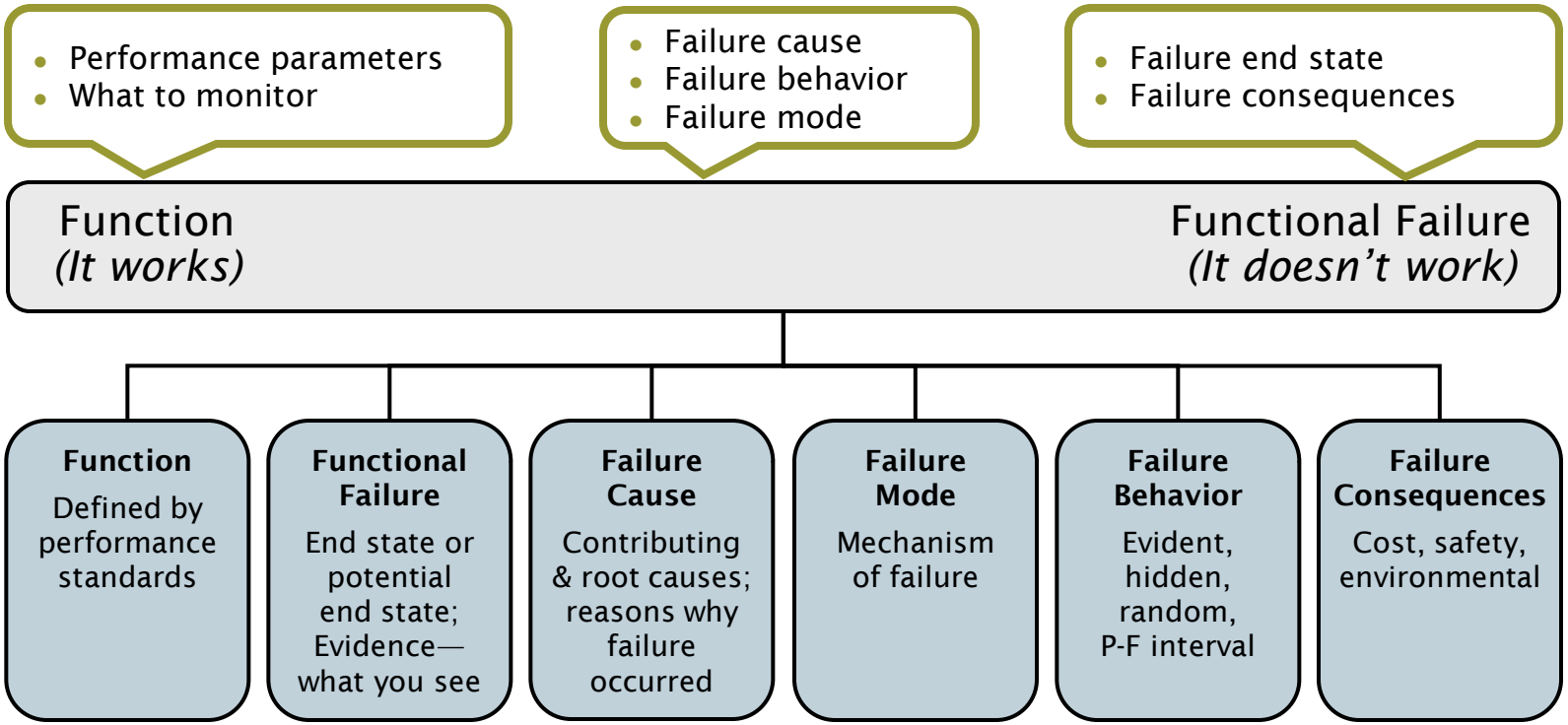
Managing risk—reduction options



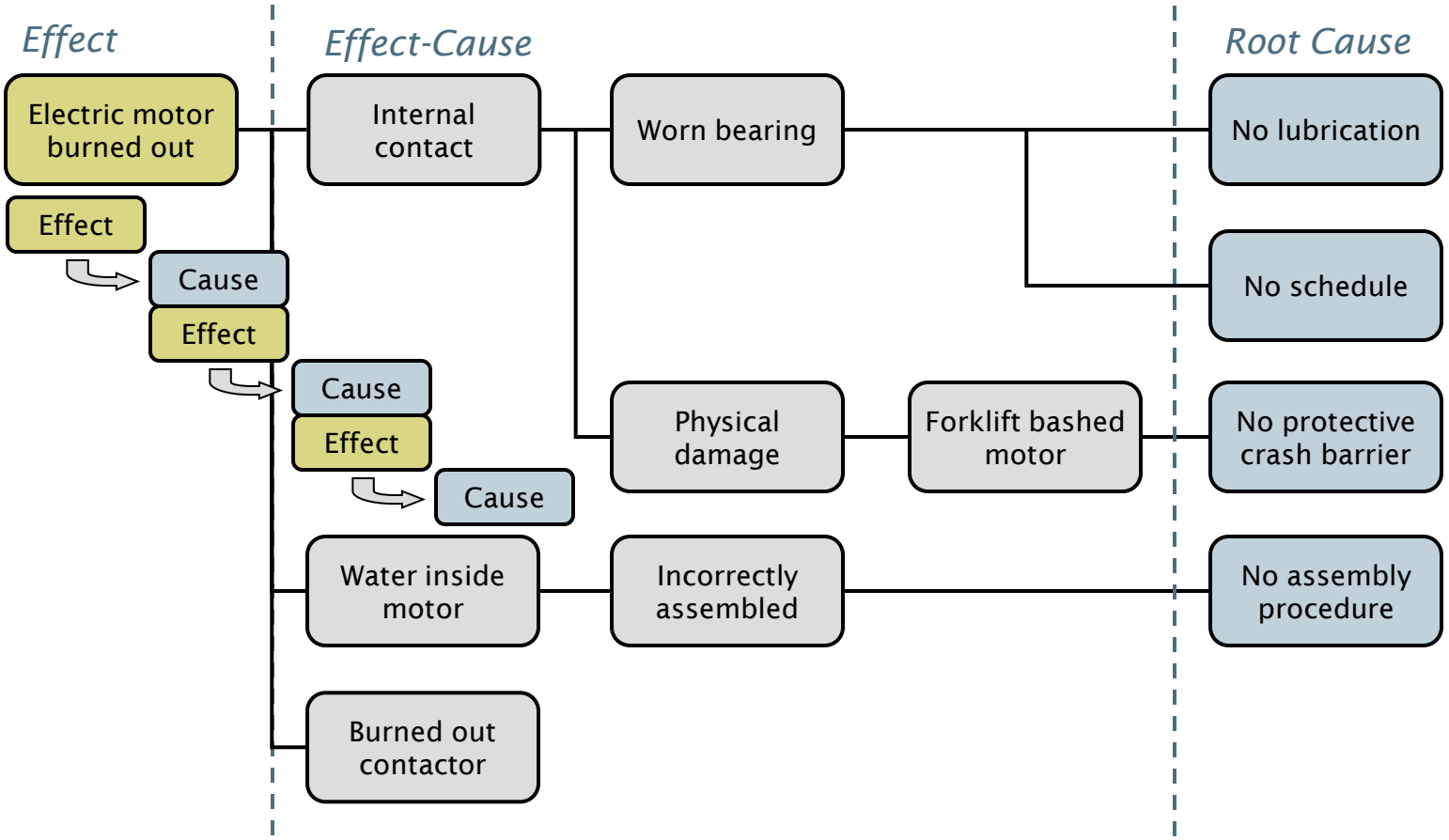
What caused the Jones Street power station to fail?

- Truck hits pole and causes power failure
- June’s incident report

Let's apply failure analysis techniques with Tom



Recall the cause and effect diagram



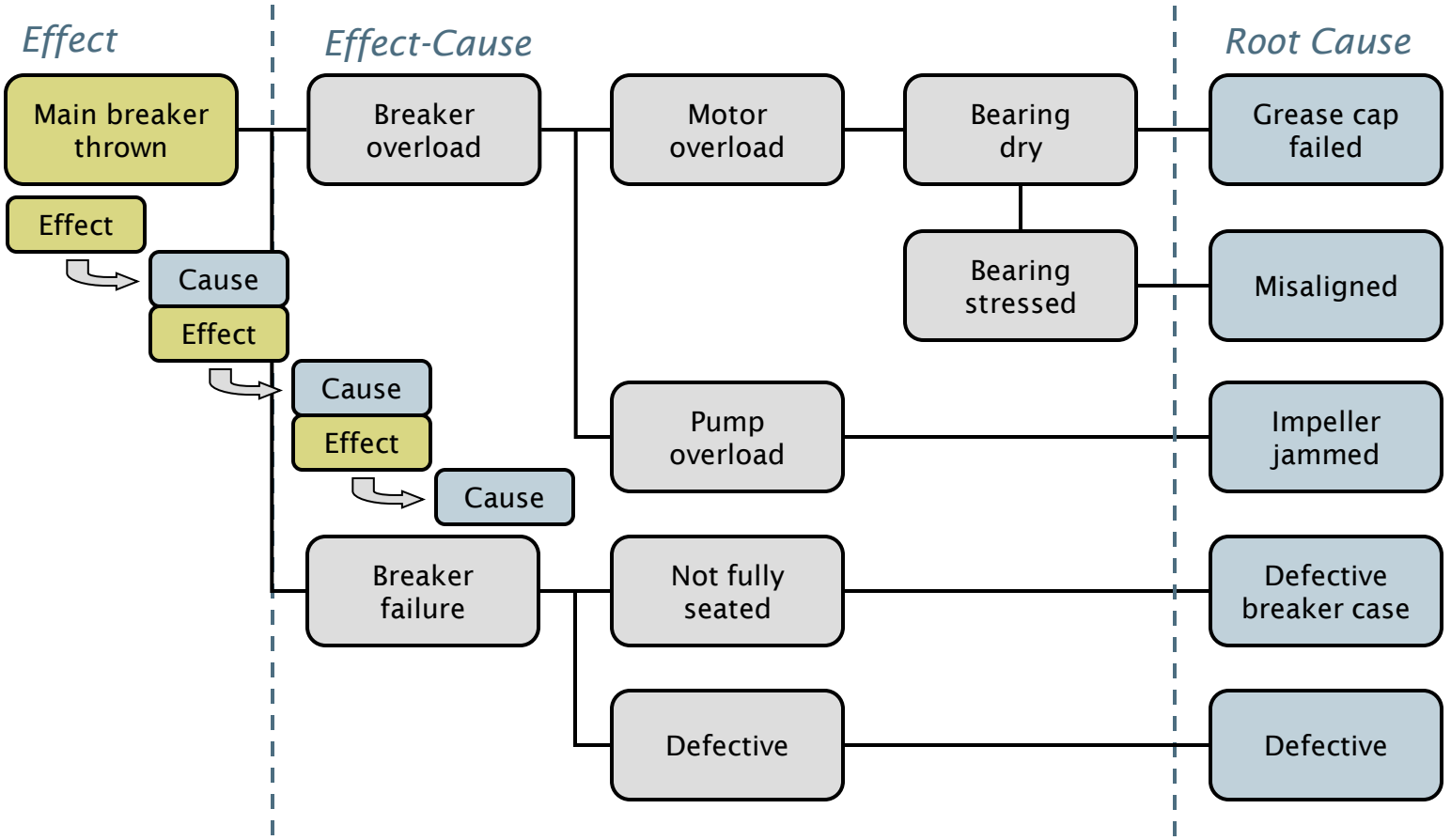
June's incident report notes

Hour	*Notes*
19:35	Entered superstructure to shut off power breakers before power-up. The main breaker had been thrown. No immediate clue as to what caused it to trigger. No sign of arcing or flash explosion around the box. That means neither Motor-pump 1 or Motor-pump 2 could run. No wonder the overflow. Why both down?
20:25	Power temporarily restored by Costly Electric & Illumination. Will return in am to install permanent pole. (Shouldn't we ask them to move it back from the road?)
20:30	Mac and I turned on main breaker to Motor 1. Immediately heard loud screeching. Seems to be from Motor 1. Immediately shut main down. Turned off breaker to Motor 1. Turned on main. Good news—Motor 2 ran fine. No unusual noise. Nice to have lights. Wonder if coffee pot works!
20:40	Noted that motor mounts on Motor 1 appear loose—black skid marks up to half inch from front feet. Back shows movement, but not as bad.

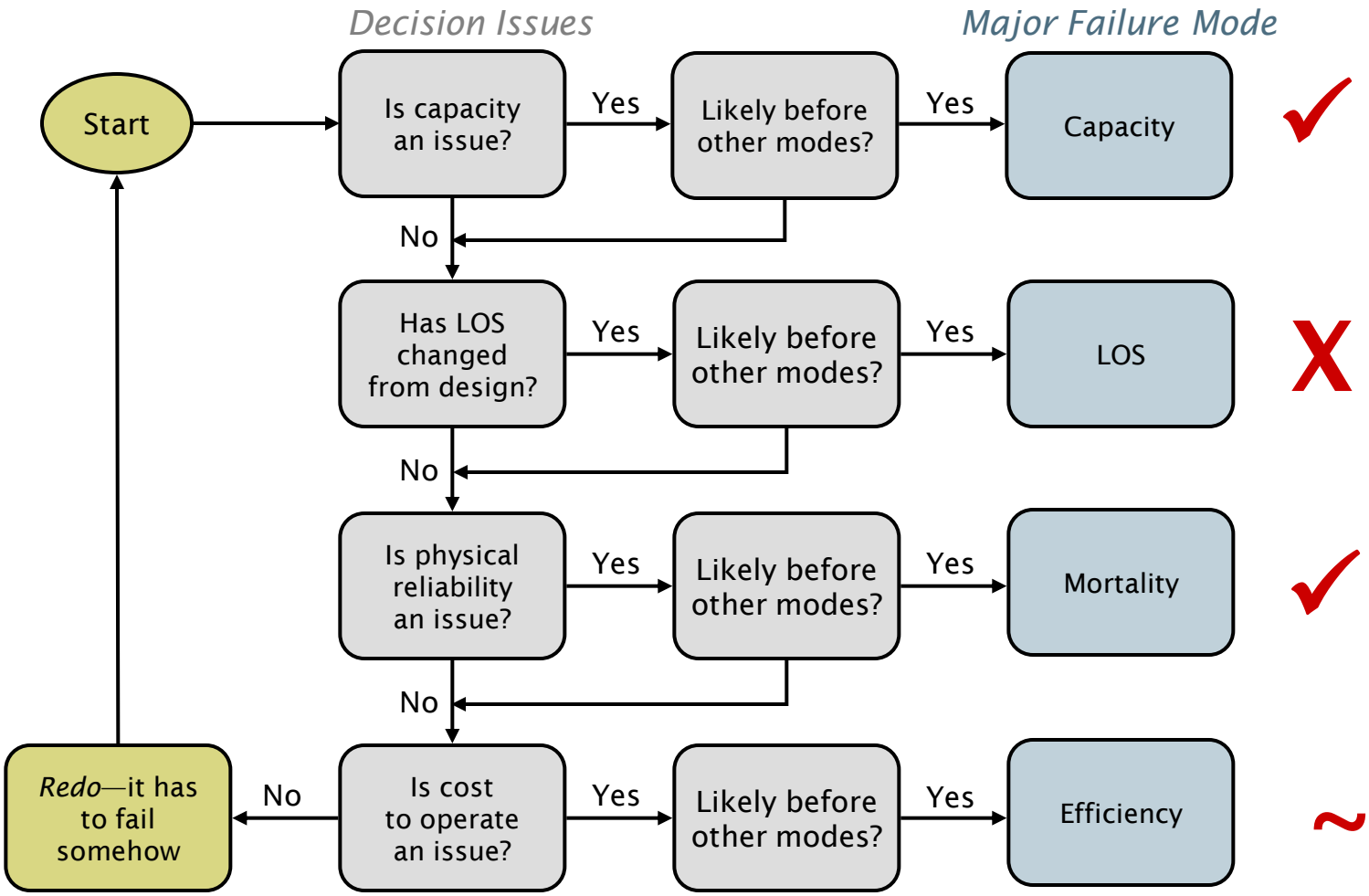
June's incident report notes, continued

Hour	*Notes*
20:45	I entered wet well and dry well with Motor 2 running. Mac stayed top. Noted that the two shaft guides on the wall for Motor-pump 1 was completely loose, one side pulled off wall. Bolts pulled clear from wall too. Noticed substantial play in pump shaft at the coupler to the shaft. Way too much play here. See photos.
05:15	My guess at this point—looks like vibration worked the shaft guides loose, increasing strain on the motor, working the motor loose, which strained bearings to point of break down.
05:30	Sent crews home with Motor-pump 2 running alone. What to do with Motor-pump 1? Repair? Refurbish? Replace? Will discuss with you after I get some shut eye.

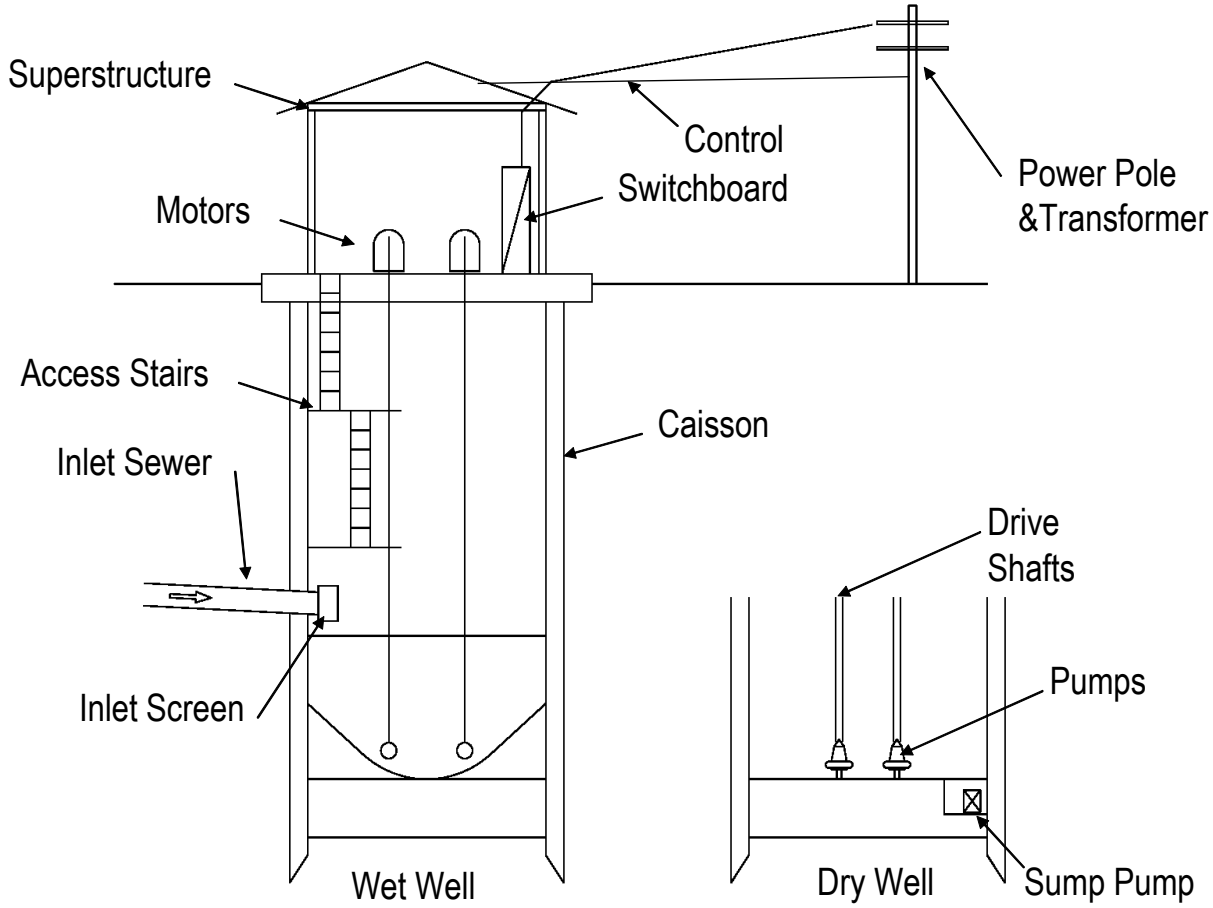
Tom's cause and effect diagram



Which major failure modes are at work?



Risk mitigation: does Tom have redundancy? If so, how much?



Tom's risk mitigation tactical options

- Store key spares on site
- Modify piping to accommodate bypass pumping
- Provide proper electrical interface for generator
- Upgrade alarm system to real time SCADA
- Bury power line
- Build berm containment
- Increase redundancy (full)
- Other

Applying business risk to the organization

A *business risk* is the threat that an event—*action or inaction*—will adversely affect an organization's ability to achieve its business objectives and execute its strategies successfully.

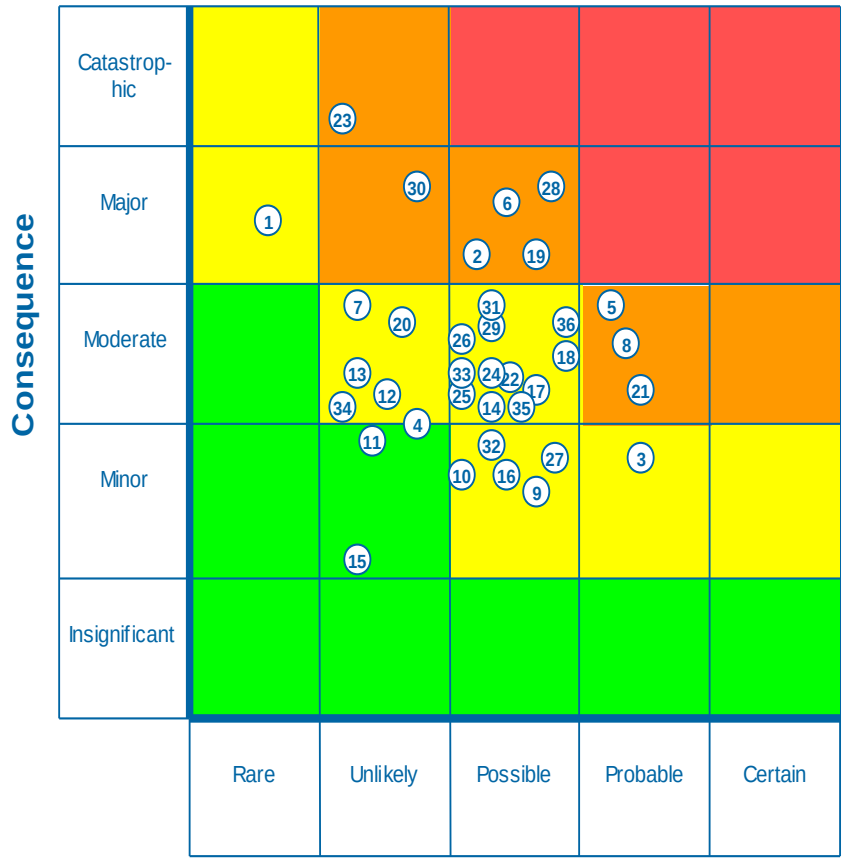
Management of these risks has the twofold advantage of both *avoiding* and *minimizing* the risk itself, and *enabling informed business decision-making* based on an understanding of where the business vulnerabilities lie.

Mapping organizational risk: List risk elements

1. Terrorist attack on OCSD asset (e.g. treatment plant)
2. Regional power outage (up to 24 hours)
3. Safety incident on OCSD project
4. Internal security breach of IT systems
5. Increase in regulatory requirements
6. Finding places to put our biosolids
7. Potential loss of property tax revenue
8. Internal labor unrest at OCSD
9. Consultants ability to meet stakeholders expectations
10. Level of service change for environmental stewardship (constituents of concern)
11. Loss of public confidence in OCSD ability to perform core services
12. Exceedance of pollutants of concerns in groundwater related to GWRS
13. Internal business fraud (e.g. malfeasance)
14. Non compliance by OCSD that result in fines by regulators and legal activities by NGO's
15. Lack of incentives for early retirement of ageing staff that perform physical activities
16. Poor two way communications across OCSD levels
17. Lack of a leadership model in EMT and management level
18. Changing technology vs. CIP decisions
19. Board not supporting the funding required to support CIP/O&M (Full Cost Pricing)
20. Ability to accurately forecast growth of county
21. Loss of Board institutional knowledge
22. Not sustaining effective plant operations during construction
23. Disasters that destroy collection system or plant
24. Inability to appropriately fund staff at required technical strength
25. Inability to balance strategic initiatives that support GWRS (Groundwater Replenishment System) with plant operations
26. Emergency (operations level) communication among response teams and management for emergencies
27. Lack of alignment of organizational structure with requirements for strategic initiatives
28. Unable to put into effect funding agreement for SARI (Santa Ana River Interceptor)
29. Unable to negotiate new operating agreement with SAWPA (Santa Ana Watershed Project Authority)
30. Public ceases support for GWRS after investment is in place
31. Inability to meet new air emission standards for generating facility
32. Inability to balance impacts on neighbors with desire by public to reduce cost
33. Cost to meet odor and air emissions standards from facilities
34. Privatization of OCSD
35. Recruiting and retention of staff in face of local cost of living
36. Lack of succession planning at OCSD

Mapping organizational risk: BRE map

Sanitation Utility Risk Profile



Schematic represents allocation of risk rather than absolute values

Critical Risks: None categorized as Critical

High Risks:

2 Regional power outage (up to 24 hours)
5 Increase in regulatory requirements
6 Finding places to put our biosolids
8 Internal labor unrest
9 Consultants ability to meet stakeholders expectations
19 Board not supporting the funding required to support CIP/O&M (Full Cost Pricing)
21 Loss of Board institutional knowledge
23 Disasters that destroy collection system or plant
28 Unable to put into effective funding agreement with key customer
30 Public ceases support for potable water after investment is in place

Medium Risks:

1 Terrorist attack on assetS (e.g. treatment plant)
3 Safety incident on major projects
7 Potential loss of property tax revenue
10 Level of service change for environmental stewardship (constituents of concern)
12 Exceedance of pollutants of concerns in groundwater
13 Internal business fraud (e.g. malfeasance)
14 Non compliance that result in fines by regulators and legal activities by NGO's
16 Poor two way communications across department levels
17 Lack of a leadership model in EMT and management level
18 Changing technology vs. CIP decisions
20 Ability to accurately forecast growth of county
22 Not sustaining effective plant operations during construction
24 Inability to appropriately fund staff at required technical strength
25 Inability to balance strategic initiatives that support groundwater replenishment with plant operations
26 Emergency (operations level) communication among response teams and management for emergencies
27 Lack of alignment of organizational structure with requirements for strategic initiatives
29 Unable to negotiate new operating agreement with key customers
31 Inability to meet new air emission standards
32 Inability to balance impacts on neighbors with desire by public to reduce cost
33 Cost to meet odor and air emissions standards from facilities
34 Privatization of organisation
35 Recruiting and retention of staff in face of local cost of living
36 Lack of succession planning

Low Risks:

4 Internal security breach of IT systems
11 Loss of public confidence in organisation to perform core services
15 Lack of incentives for early retirement of ageing staff that perform physical activities

The risk register – building an action plan

Risk Identification and Analysis									Plan		
#	Risk Issue	Causes and Notes	Potential Impact / Consequence	Current Mitigation Measures	Initial Risk			Proposed Mitigation Measures	By Whom	By When	Complete
					Consequence	Likelihood	Risk				
30	Public ceases support for GWRS after investment is in place	Public perception, rate resistance	Loss of $200m. Political tension.	Active public relations outreach program. Lobbyists. Public relations plan. Blue Ribbon Panel (academics, regulators and environmentalists) Enhanced source control (pollution concerns).	Major	Unlikely	High	Increase source control to non-industrial base. Design more flexibility into design process. Second outfall design as backup (need to confirm maximum capacity of outfall).	Human Resources - Public Relations		
31	Inability to meet new air emission standards for generating facility	Regulations.	Unable to run cogeneration plant. Power cost increase. What to do with gas.		Moderate	Possible	Medium				
32	Inability to balance impacts on neighbors with desire by public to reduce cost	Competing interests. Turnover of Board.	Political tension. Replacement of Board. Unhappy consequences.		Minor	Possible	Medium				
33	Cost to meet odor and air emissions standards from facilities	Increasing regulation. Rate resistance. High public expectations. Growth. Increasing cost of inputs.	Political tension. Declining LOS. Increasing failures.		Moderate	Possible	Medium				
34	Privatization of OCSD	Rate resistance.	Political tension. Organizational tension.		Moderate	Unlikely	Medium				
35	Recruiting and retention of staff in face of local cost of living	High cost of living, especially housing. Declining pool of resources available.	Increased cost.		Moderate	Possible	Medium				

Key points from this session

Given my system, which assets are critical to sustained performance?

Key Points:

- Not all assets fail the same way
- Not all assets have the same likelihood of failure
- Not all assets have the same consequence of failure
- Understanding failure drives acquisition, maintenance and renewal management decisions.

Associated Techniques:

- Failure analysis (“root cause” analysis; failure mode, effects and criticality analysis; reliability-centered analysis)
- Failure codes
- Probability of failure
- Consequence of failure
- Business risk exposure
- Asset list by business risk exposure level
- Asset functionality statements

Tom's spreadsheet