Risk Based Inspection of Storage Tanks

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25th California Unified Program Annual Training Conference
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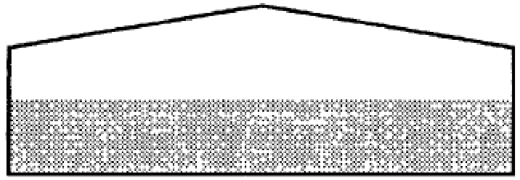
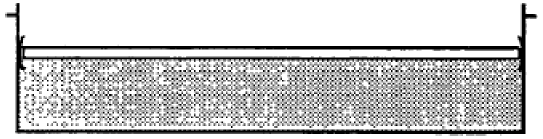
Tank review

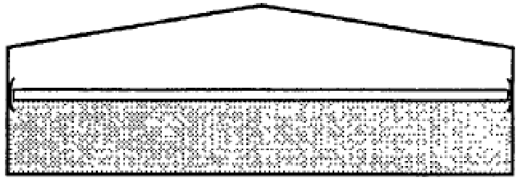
Tank Types



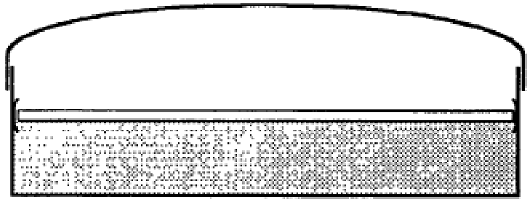
(A) FIXED OR CONE ROOF



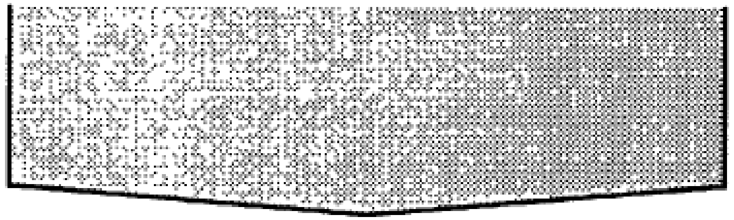
(B) OPEN-TOP FLOATING ROOF



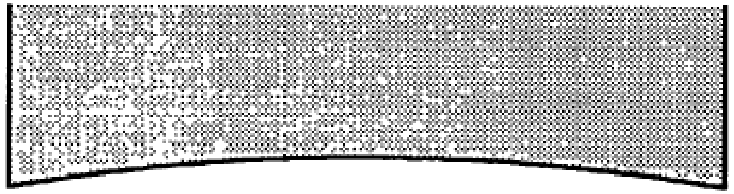
(C) COVERED FLOATER



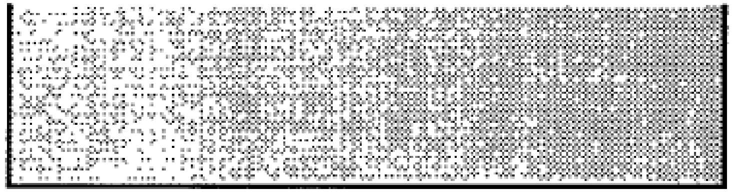
(D) GEODESIC DOME



CONE BOTTOM

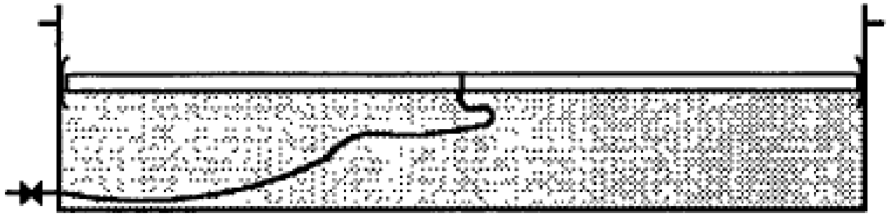


CROWN BOTTOM



FLAT BOTTOM

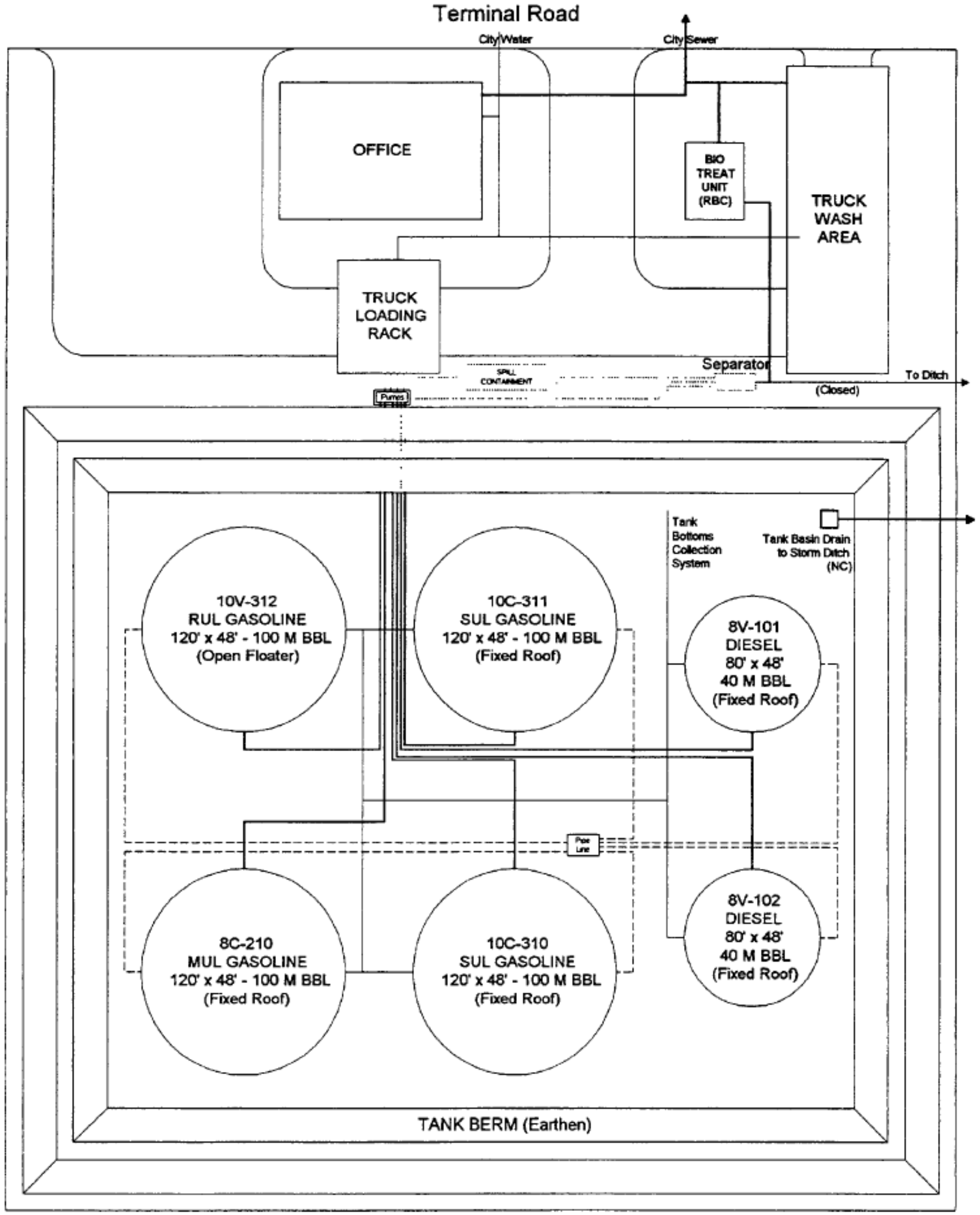
Draining water off of EFRs

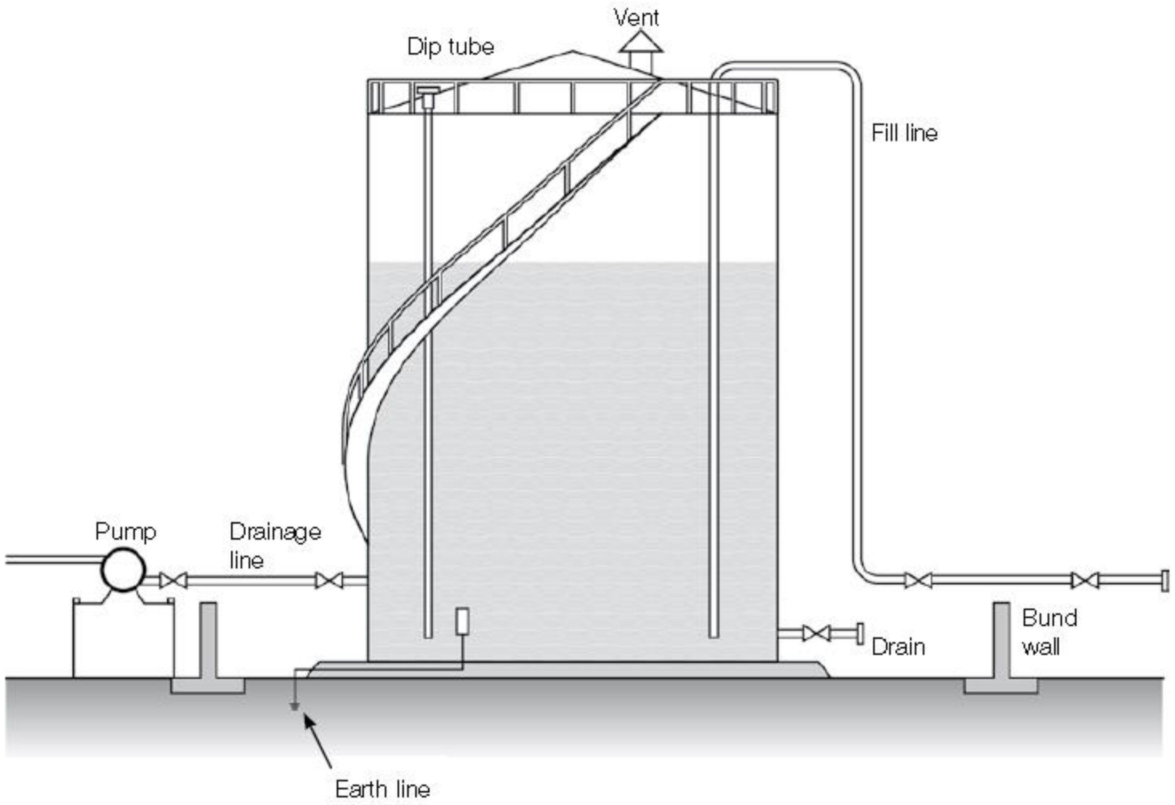


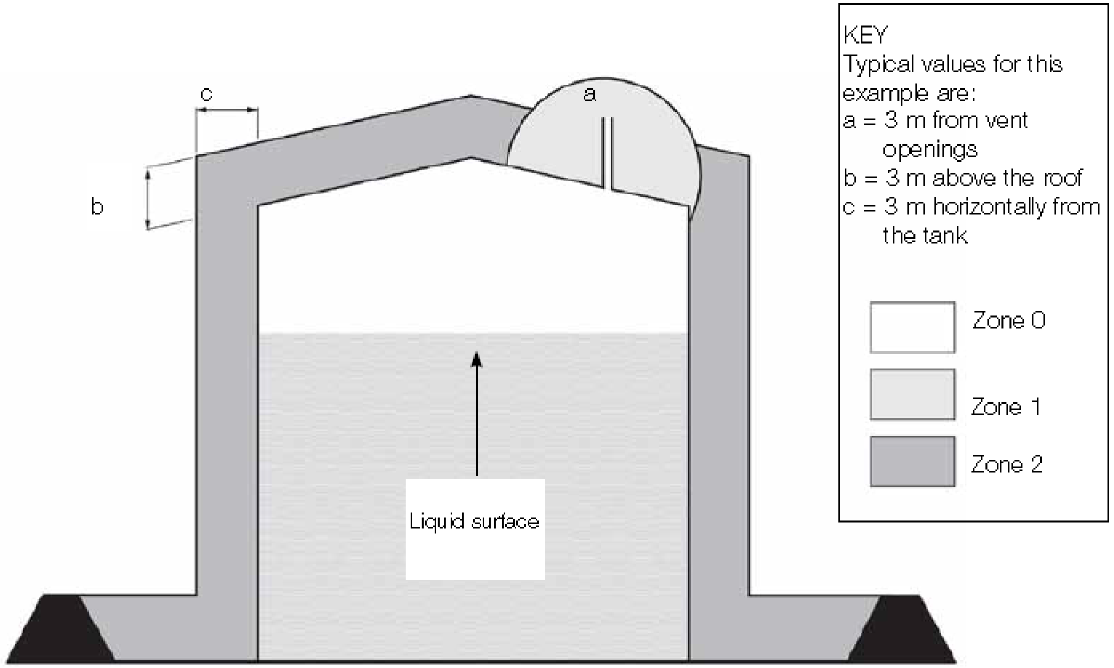
ROOF DRAIN THROUGH HOSE

ROOF DRAIN THROUGH JOINTED PIPE

EXAMPLE OF MARKETING TERMINAL GENERAL ARRANGEMENT PLAN WITH WATER SUPPLY LINES AND WASTEWATER LINES




Vent
Dip tube
Fill line
Pump
Drainage line
Drain
Bund wall
Earth line


c
a
b
Liquid surface
KEY
Typical values for this example are:
a = 3 m from vent openings
b = 3 m above the roof
c = 3 m horizontally from the tank
Zone 0
Zone 1
Zone 2

History of Risk

Year	Who	What
1200	Leonardo Pisano	Introduced Europe to Arabic Numbers, and wrote “Liber Abaci”
1492	Luca Pacioli	Summa de Arithmetic How to split stakes of an unfinished game of chance
1654	Blaise Pascal	Solved Pacioli’s problems and beginning of probility
1654	Pierre de Fermat	Systematic way of computing probability; beginning of probability theory
1703	Jacob Bernoulli	Theory to practice in probability
1750	Rev. Thomas Bayes	Combining new information with old
1738	Daniel Bernoulli	St Petersburg Paradox; combine probability and consequence

Lloyd’s Coffee House

Lombard Street
London

- 1700’s
- Thames River gathering place for voyagers to France
  - Placed “bets” on whether ships would make the journey or not

Risk management

More powerful than the gods!
Clotho spun the “thread” of human fate,
Lachesis dispensed it, and
Atropos cut the thread (thus determining the individual's moment of death).

At a fundamental level – what is risk?

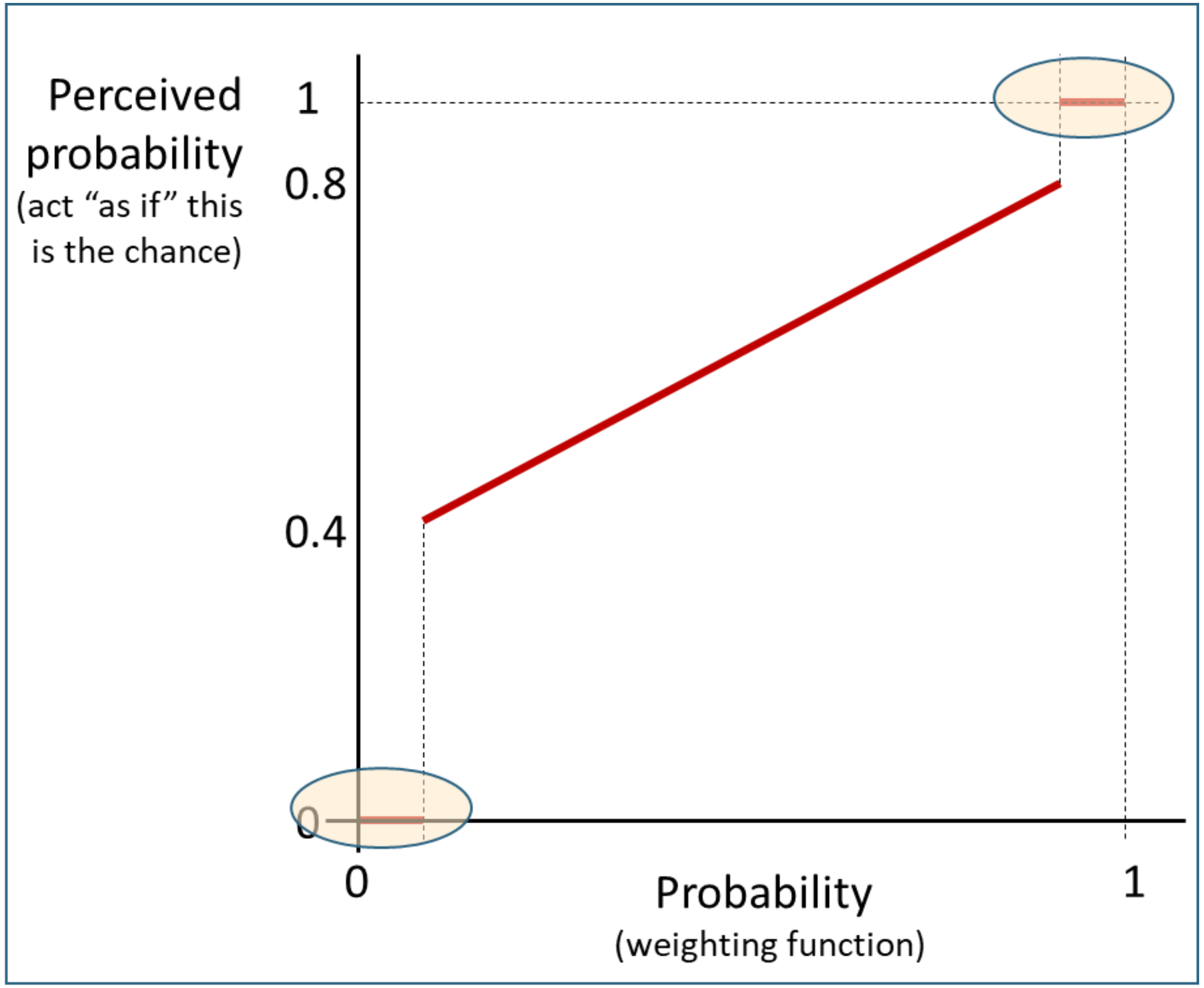
- What can happen?
- How likely is it to happen?
- If it does happen, what would the consequences be?

And risk assessment?

- Estimating **probability** of a particular scenario happening over the range of scenarios of interest
- Estimating the impact or **consequence** of the loss for each scenario and monetizing it.
- Combining the probability and the consequence or impact of the loss using expected value or utility or some other measure

Uncertainty

Intuition is a poor guide for risk



Deciding how to estimate risk and make decisions is fundamental
to the quality of the decision-making and should be given serious thought.

Function Team Level (PH 3-4)

Descriptions	Indices		6	5	4	3	2	1
Event can reasonably be expected to occur in life of project	1	Likely (>80%)	6	5	4	3	2	1
Conditions may allow the event to occur during the project, or the event has occurred in similar projects within the Business Unit	2	Occasional (80–50%)	7	6	5	4	3	2
Exceptional conditions may allow the event to occur during the project. Has occurred during a similar project in Chevron.	3	Seldom (50–25%)	8	7	6	5	4	3
Reasonable to expect event will not occur during the project. Has occurred several times in the industry, and/or in Chevron projects.	4	Unlikely (25–5%)	9	8	7	6	5	4
Has occurred once or twice within industry	5	Remote (5–1%)	10	9	8	7	6	5
Rare or unheard of	6	Rare (<1%)	10	10	9	8	7	6
	Consequences Indices		6	5	4	3	2	1
			Incidental	Minor	Moderate	Major	Severe	Catastrophic

Decreasing Likelihood

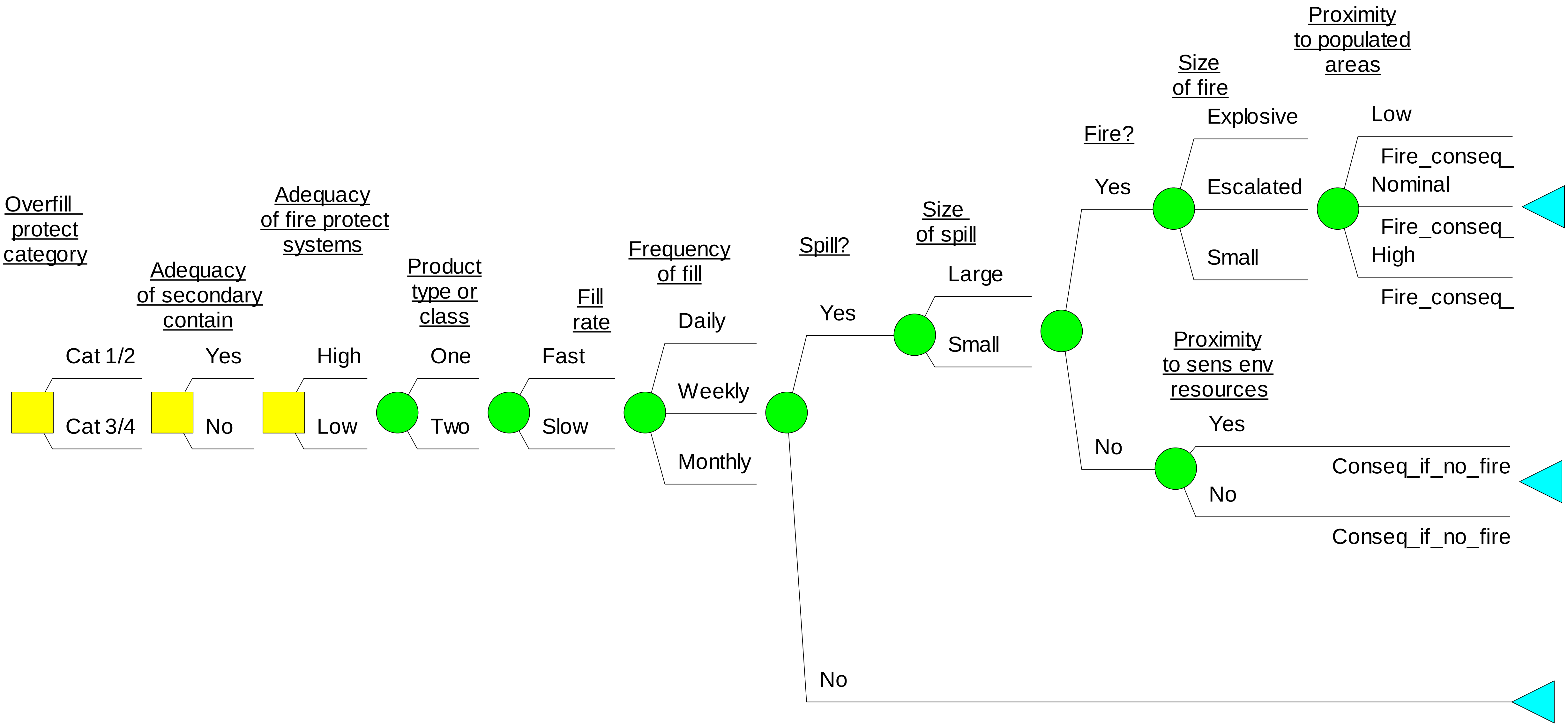
Decreasing Consequence/Impact

Tactical Risks

Significant Risks

Strategic Risks

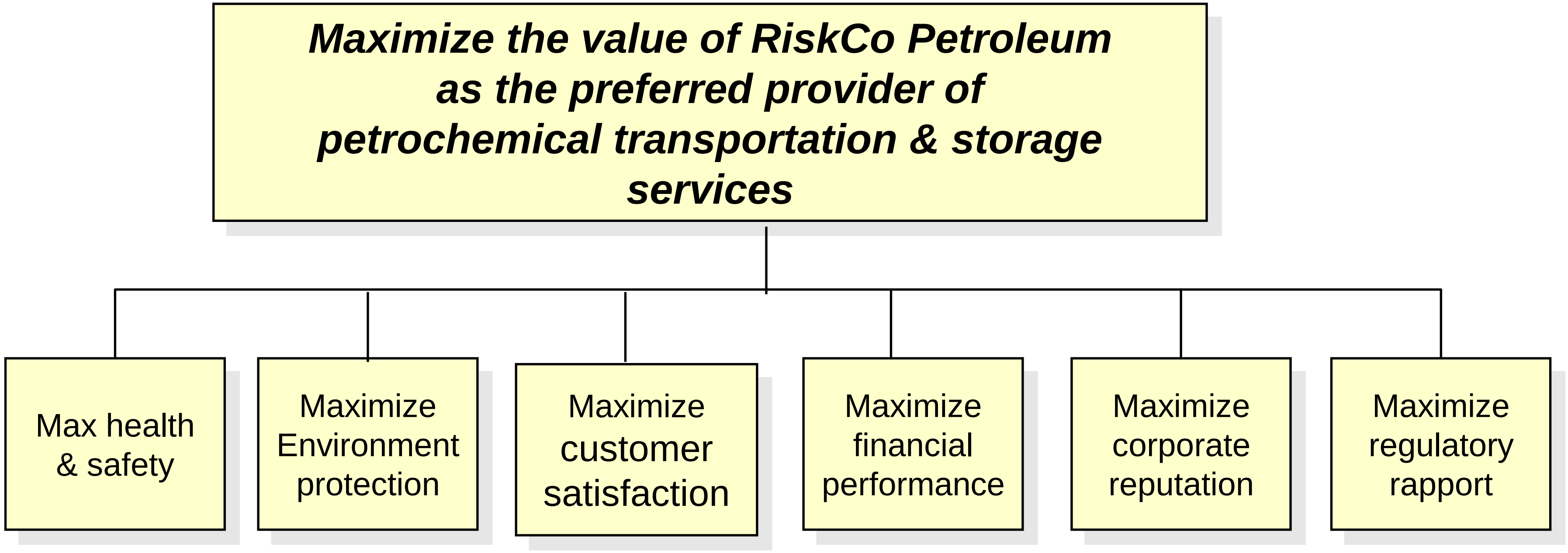
HILP



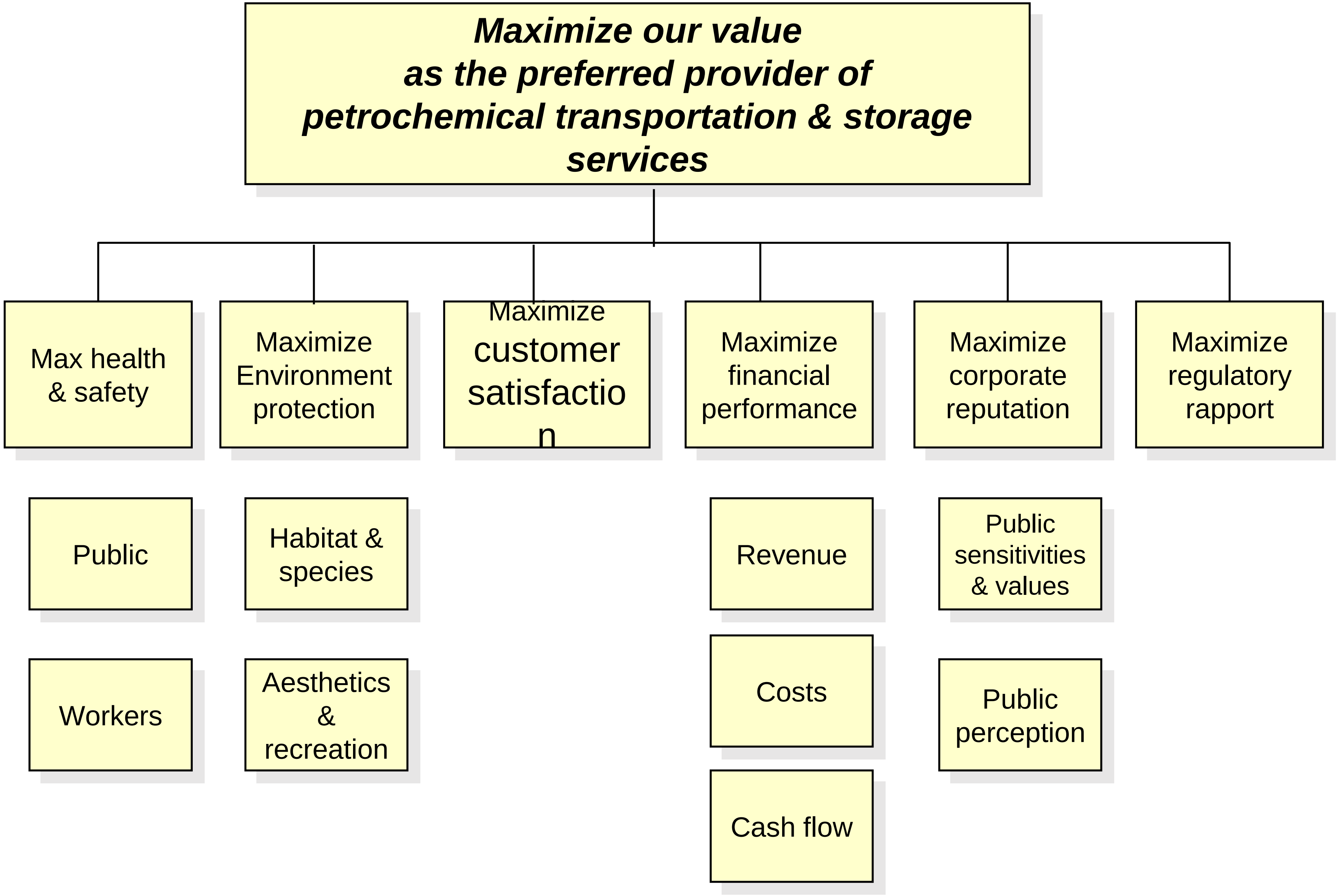
Overfill protect category
Cat 1/2
Cat 3/4
Adequacy of secondary contain
Yes
No
Adequacy of fire protect systems
High
Low
Product type or class
One
Two
Fill rate
Fast
Slow
Frequency of fill
Daily
Weekly
Monthly
Spill?
Yes
No
Size of spill
Large
Small
Fire?
Yes
No
Size of fire
Explosive
Escalated
Small
Proximity to populated areas
Low
Fire_conseq_
Nominal
Fire_conseq_
High
Fire_conseq_
Proximity to sens env resources
Yes
Conseq_if_no_fire
No
Conseq_if_no_fire

Event v Consequence

Defining consequences / impacts

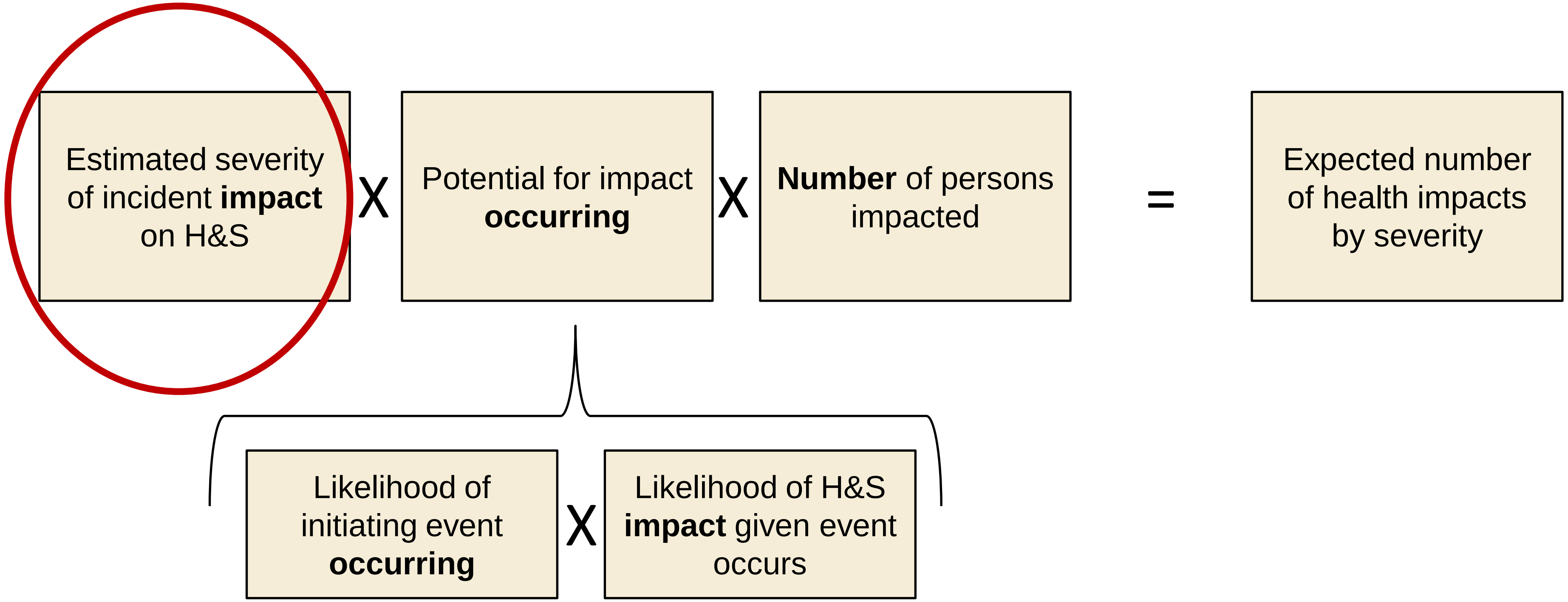


Defining consequences to RiskCo Petroleum



Contents
Layers
Reference
Natural Resource Risks
Protected Lands
SSURGO Soils
USGS Steep Slopes
Human Health Risks
Historic Structures, map service
Cemeteries
County Survey Sites
RATING
Outstanding
Notable
Contributing
Non-Contributing
Demolished
Unknown
Historic Bridges
National Register Sites
Historic Districts
Wind_Speed_50m
Health Services
Schools
County Land Parcels
State Mapped Water_Wells_IDNR
Drinking Water
Other Population Areas

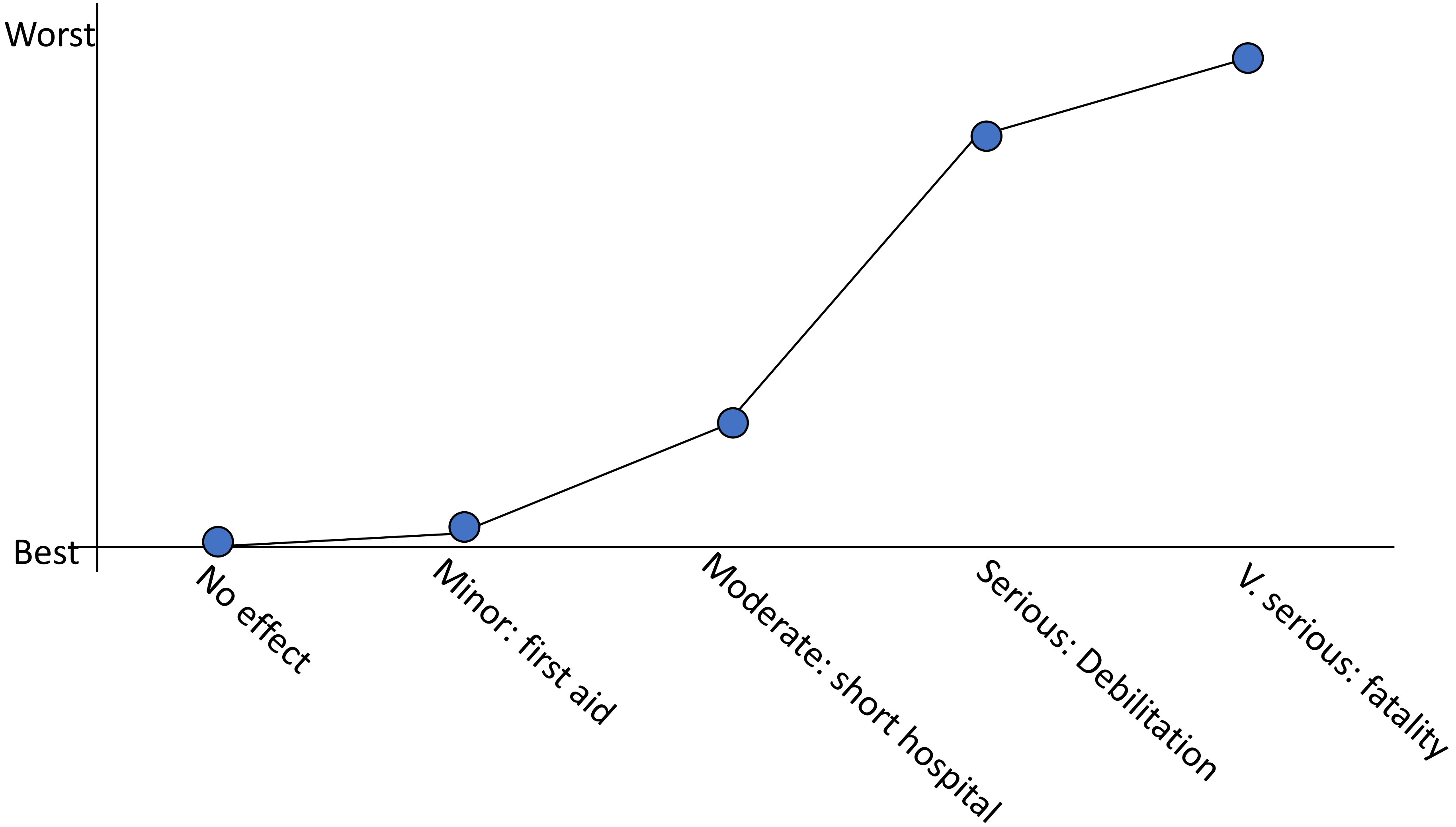
Example: quantifying H&S impact



Scoring H&S severity of impact

Score	Severity of impact
0	No effect
1	Minor: Minor irritation or temporary discomfort; modest first aid needs
2	Moderate: Painful but not long-term or life-threatening; may require short-term hospitalization care
3	Serious: Permanent debilitating injury or serious long-term illness that results in some reduction in quality of life
4	Very serious: Death or permanent debilitation resulting in near total loss of quality of life

How does RiskCo Petroleum mgmt value H&S

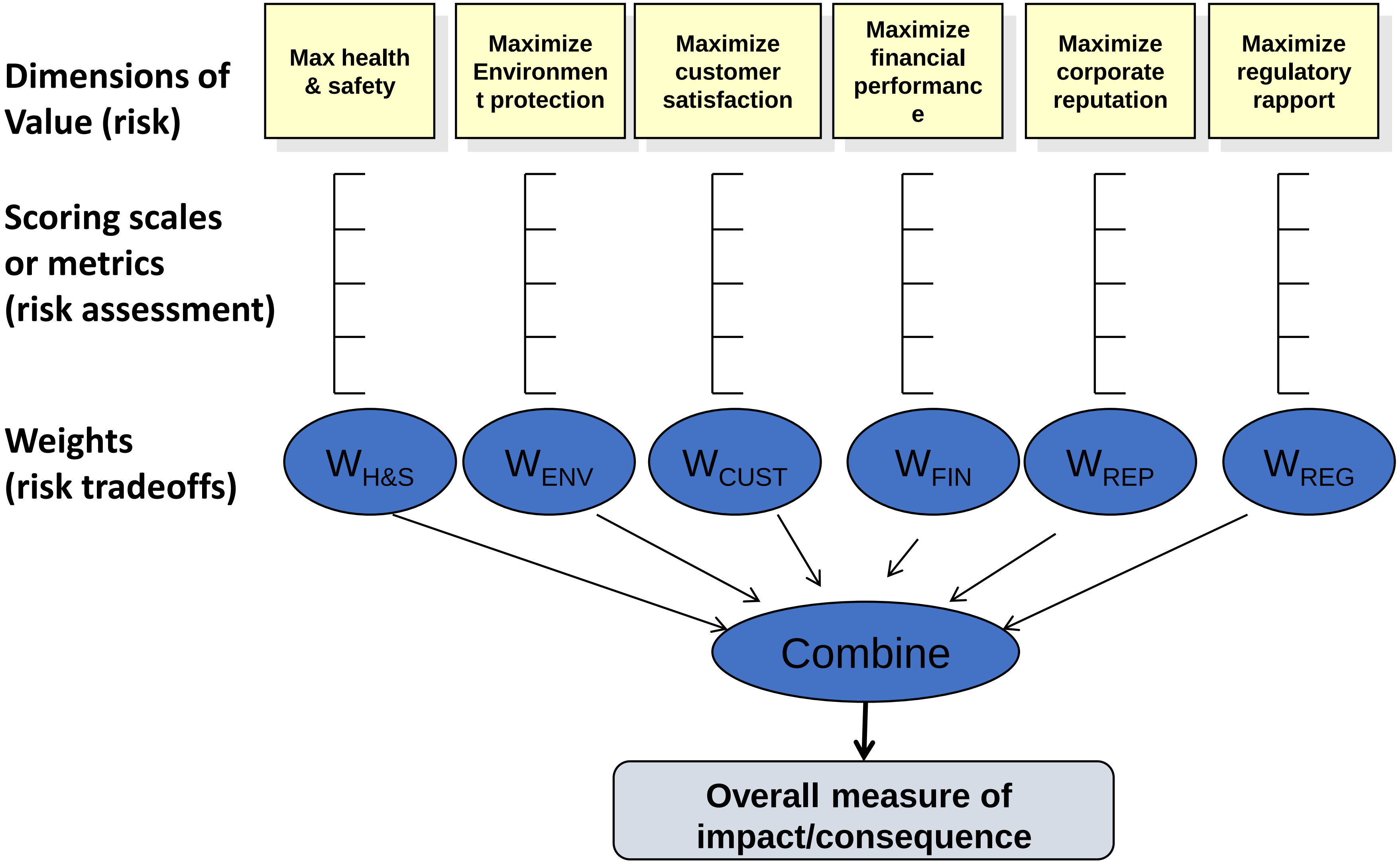


Weights can be monetized (if desired)

Objective	Willingness to pay
Cost:	$1.4 million
Quality:	$2.3 million
Schedule reliability:	$2.0 million
Reputation:	$6.5 million (10% of Mission budget)
Customer satisfaction:	$800,000
Mission focus & support:	$500,000

These values represent the willingness to pay to reduce each adverse impact from its worst level of impact to its best level of impact

Overall (estimated) impact of an incident



Overfill -- Consequences

- Primary consequences of concern:
  - Environmental impact and associated cleanup costs
  - Corporate reputation
- Severity of consequences influenced by:
  - Size of spill
  - Product type
  - Proximity to sensitive environmental resources
  - Regulatory environment
- Equivalent economic impact of an overfill, assuming it occurs:

Site not near sensitive resources	Class 1 product	~$126M
Site not near sensitive resources	Class 2 product	~$107M
Site not near sensitive resources	Class 1 product	~$400M
Site not near sensitive resources	Class 2 product	~$350M

Note: Consequences are the probability-weighted average for large (>100 bbls) and small overfills; about 90% of spills are small

Risk based projects

Identify risks

- Scenario-based risk assessment
- Rank risks from greatest to least
- “Template” scenarios support understanding range of potential consequences

Biggest risks

Identify mitigations

- Use scenario structure to identify mitigations
- Rank mitigations from greatest impact to least
- Mitigations from band-aid/short-term to full elimination of risks

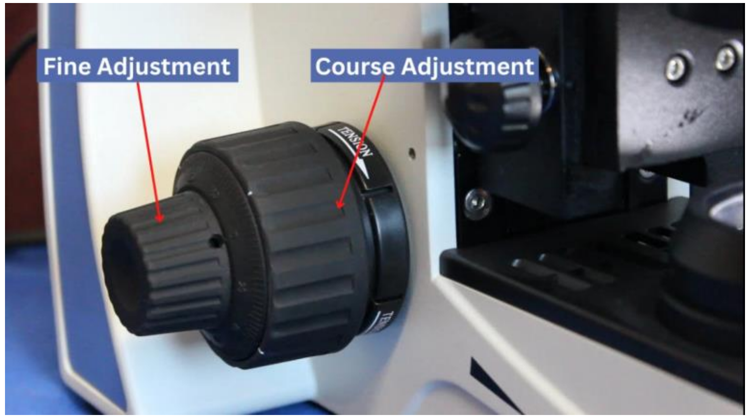
Biggest reducers

Benefit-cost

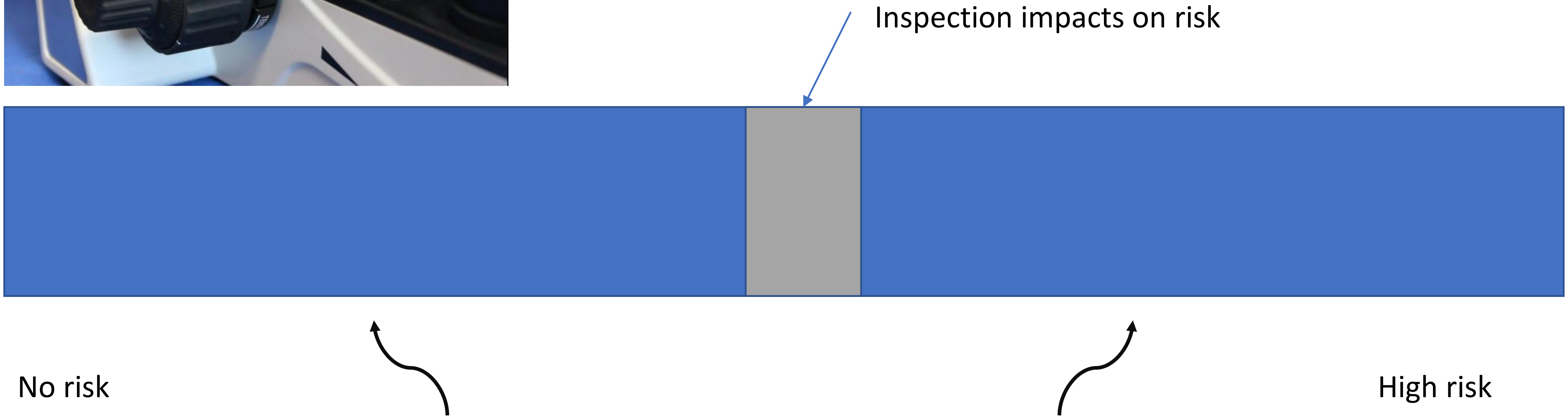
- Rank mitigations by risk-reduction benefit compared to cost
- Ranking shows mitigations that give biggest risk reduction per dollar spent

Most cost effective

Caveats



The risk spectrum



All of the other activities that can impact risk:
Procedures, admin controls, process changes, MOC, risk reduction projects, operations, etc. RBI may not have a significant impact on risk!

Terminology: Risk is not risk

- Probability, Consequence, Risk
- Caution advised
  - Terms like “absolute” and “relative” risk are probabilities, not risks, but pervasive in our industry and the medical industries.
  - Risk combines likelihood and consequence
  - Odds ratios are needed for real world estimation of risks because almost all data for failures will be in the framework of case control studies.

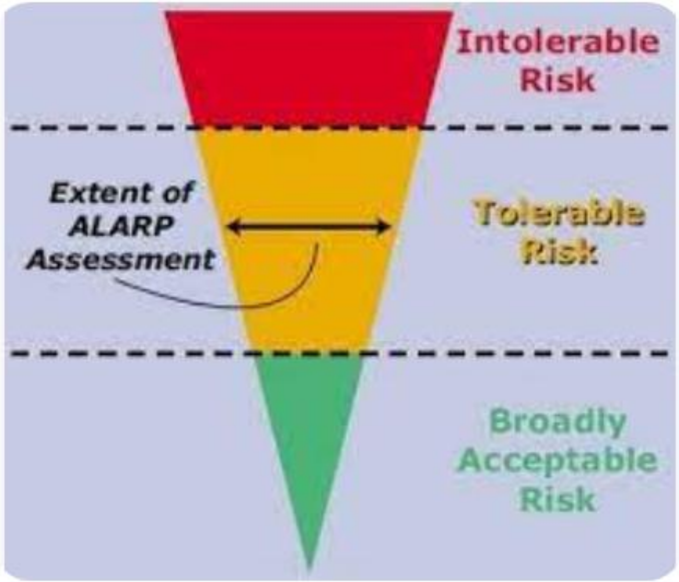
Relative and absolute risk: beware of risk communications

	Heart attack	No heart attack	Total	relative risk	risk ratio	risk diff
Drug	1	99	100	0.01		
No drug	2	98	100	0.02	2	0.01

	Heart attack	No heart attack	Total	relative risk	risk ratio	
Drug	1	99	10000	0.0001		
No drug	2	98	10000	0.0002	2	0.0001

JARGON:
ALARP – "as low as reasonably practicable"

- " a risk is acceptable if the total benefits exceed the total risks"
- ALARP: "is the amount of risk reduction greater than the cost of the risk reduction"
- Basic idea is costs v benefits



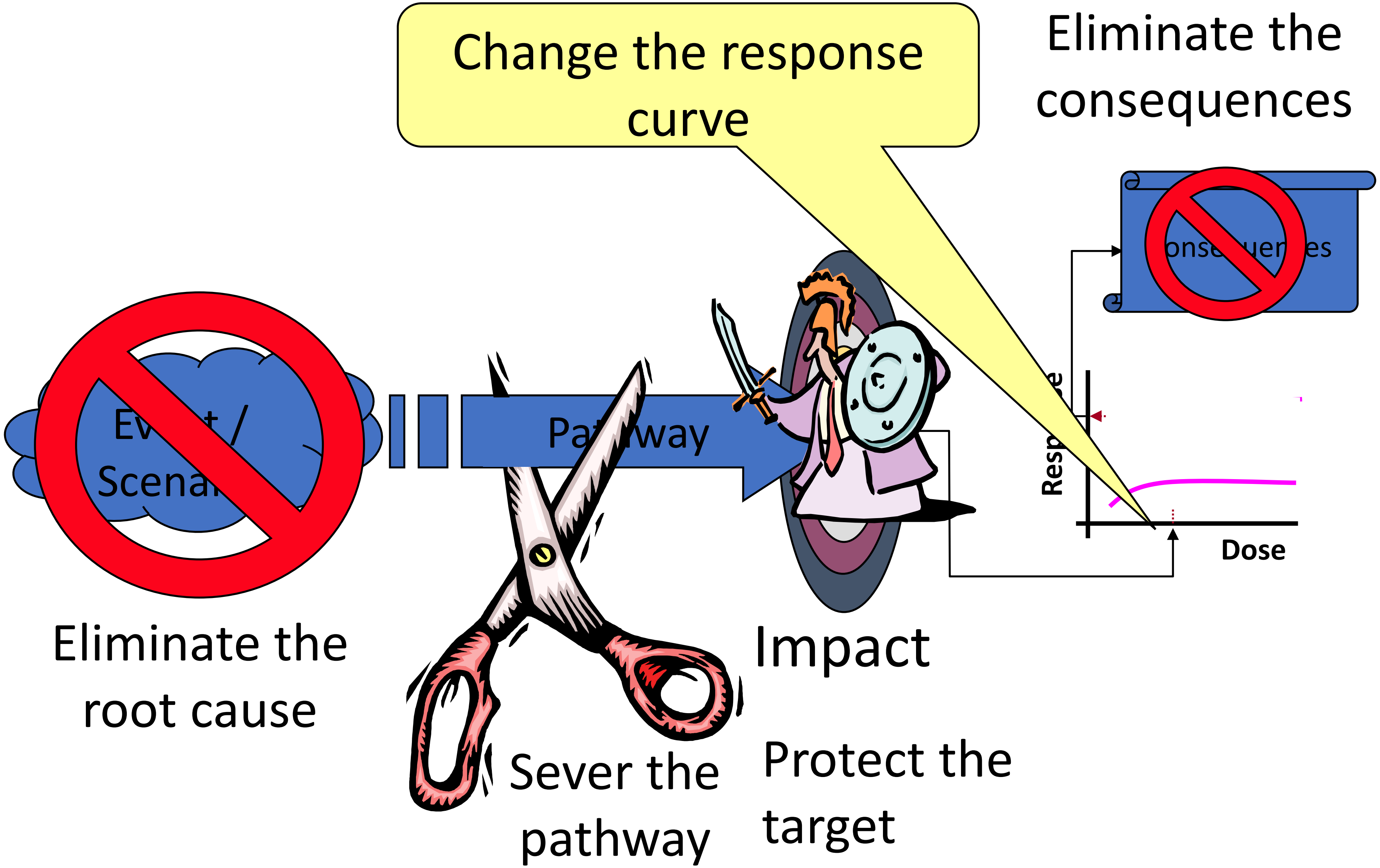
Others: societal v individual risk, FN curves, etc

Criteria for evaluating risk assessment techniques

- ☑ Comprehensive
- ☑ Logically sound
- ☑ Practical
  - -- Real problems, real people, real resources
- ☑ Open to evaluation
- ☑ Politically acceptable – internally / externally
- ☑ Conducive to learning

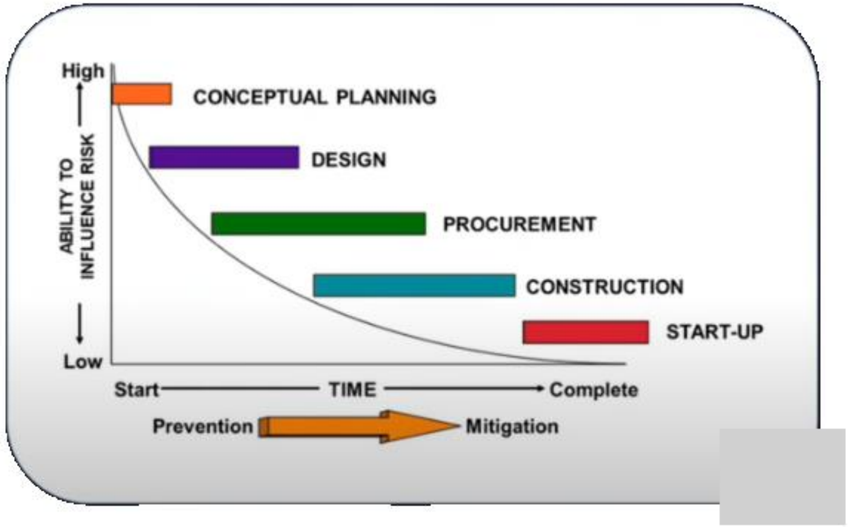
Risk Assessment

Assessment → Management



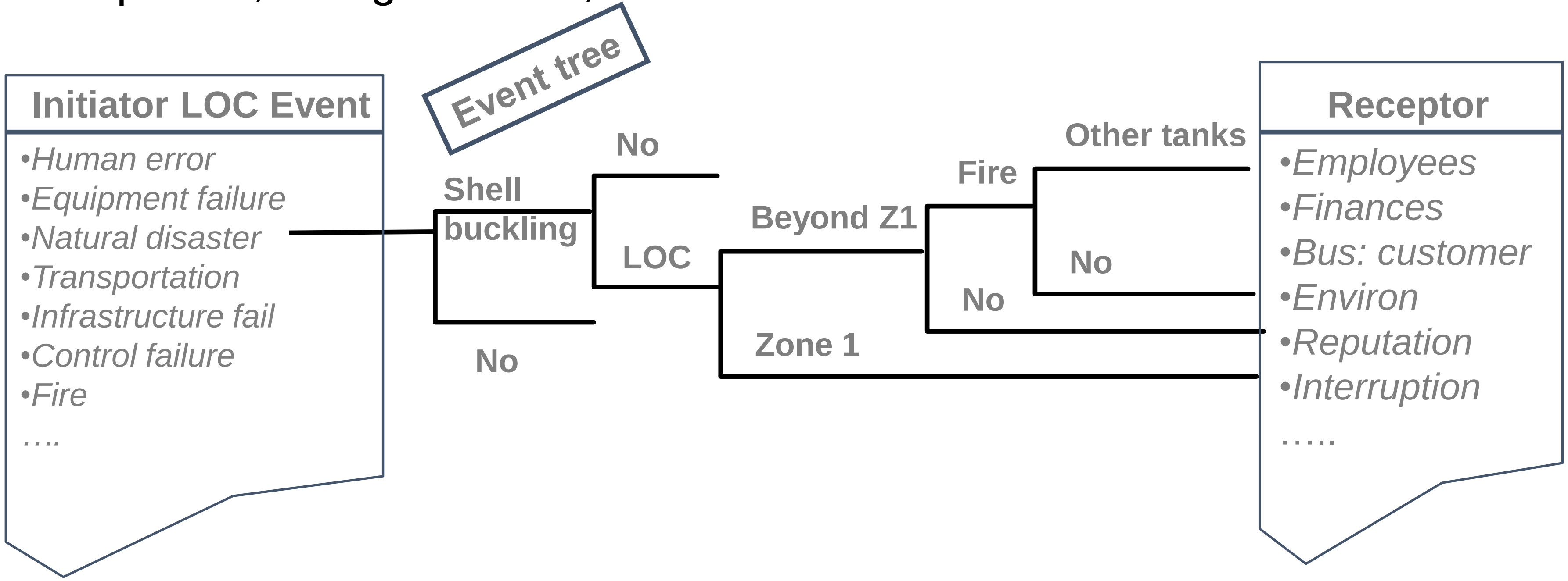
Risk assessment techniques

- HAZOP
- QRA
- Bowtie
- FMEA
- Fault trees
- Event trees
- Checklist and whatif
- LOPA
- Etc.



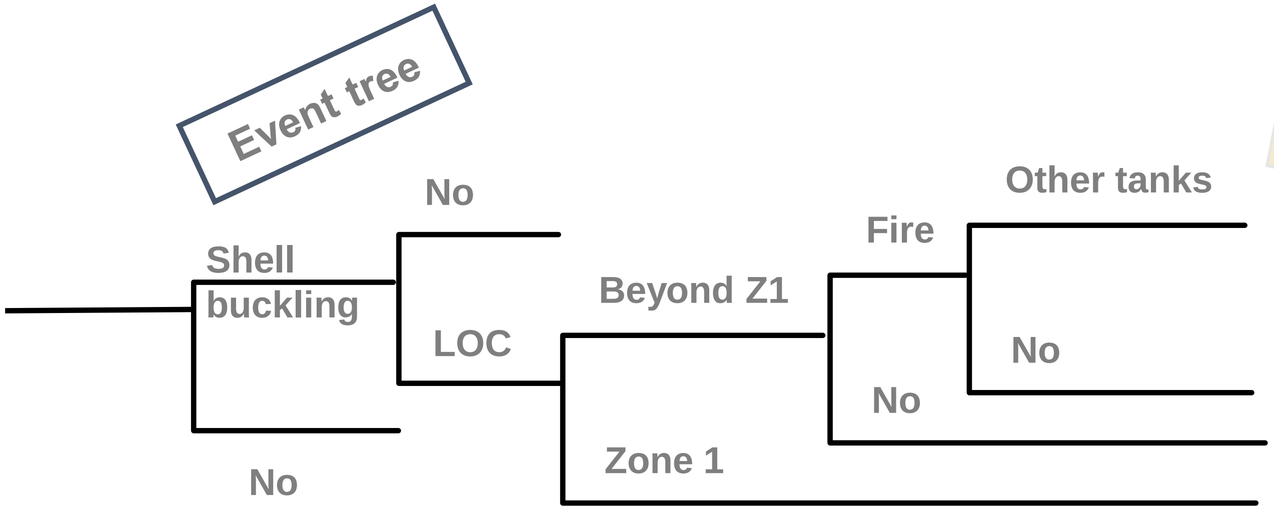
Risk, con't: "Scenario"

- **Scenario planning:**
  - A description of what can happen
  - This is a description of "events"
  - Anchored in reality: event histories, databases, regulations, complaints, ISO guidelines, etc. . .



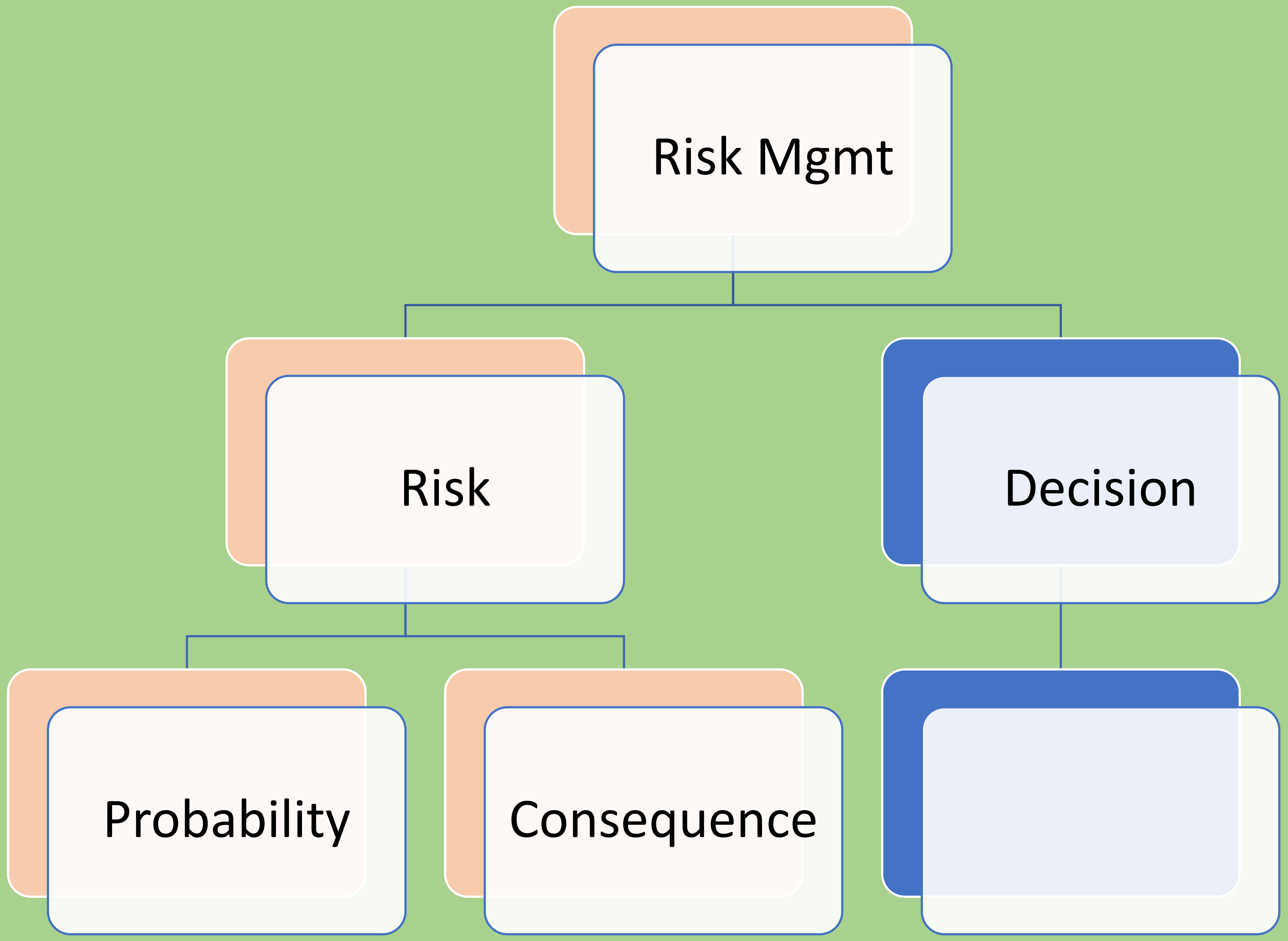
Risk, con't: Scenario construction

- **Developing scenarios: consider**
  - Most likely case
  - Plausible worst case
  - Plausible ripple effects
- **incident histories, "near misses," etc.**



The goal is to be explicit, not perfectly accurate

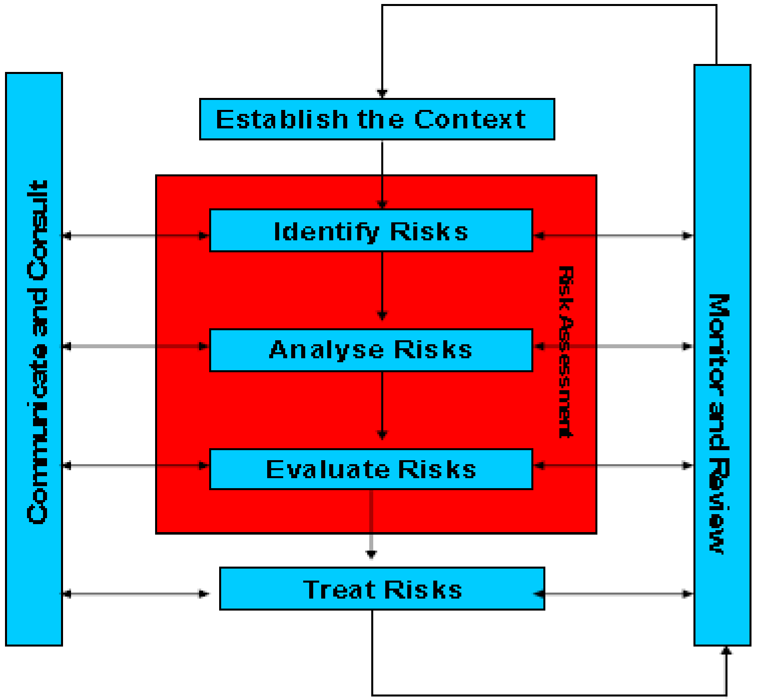
Risk and Decision


Risk Mgmt
Risk
Decision
Probability
Consequence

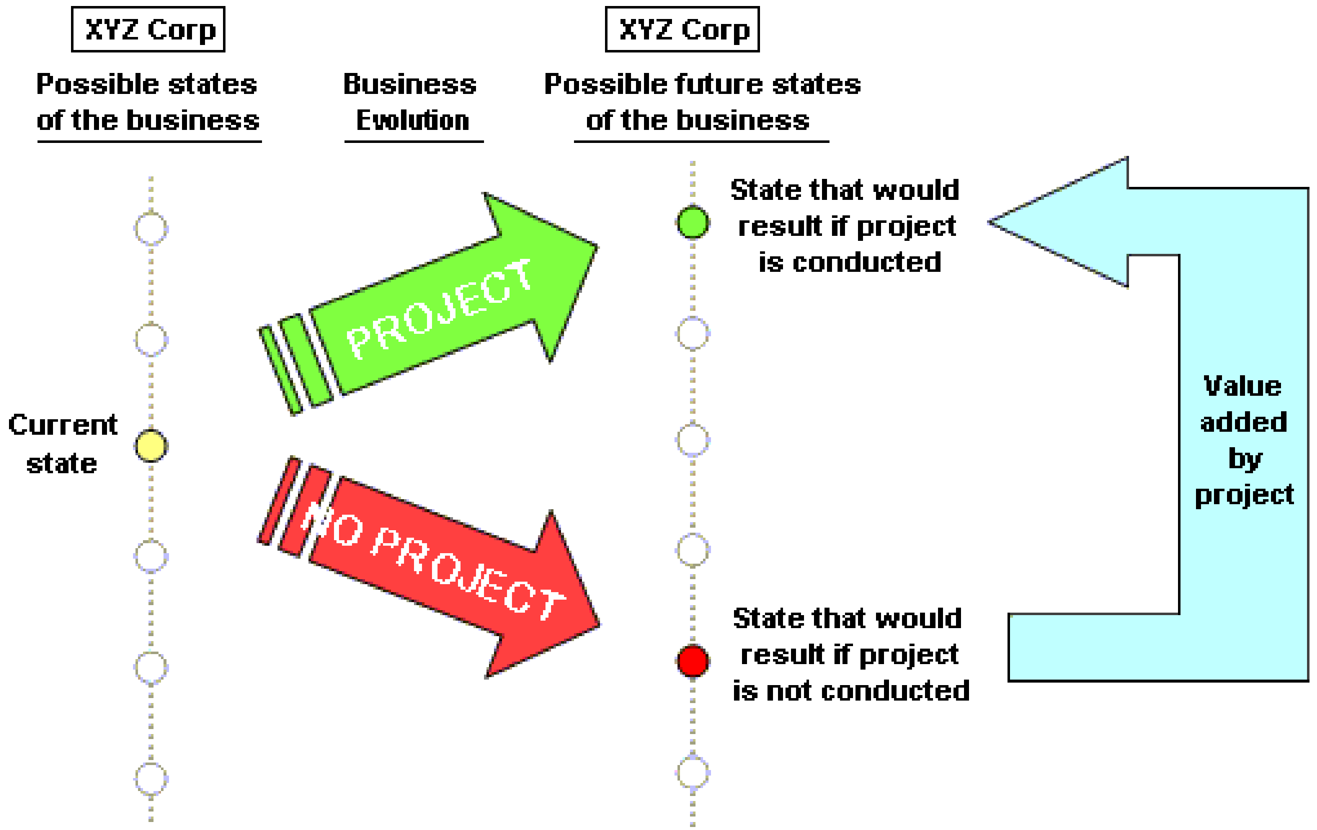
Risk and Decision = Risk Management

- There is no value to risk assessment without decisions to accept or try to change the future.
- Risk assessment information has *value only if* it has the potential to change the mind of the decision makers about how best to protect valued assets. If decisions have already been made and are not going to be changed, then risk assessment information has no value
- Risk assessment – risk management go hand in hand!
- Risk assessment and management is a means to an end
- It aids us in protecting something of value
- It is the foundation for decision making

Risk Management Process – Overview



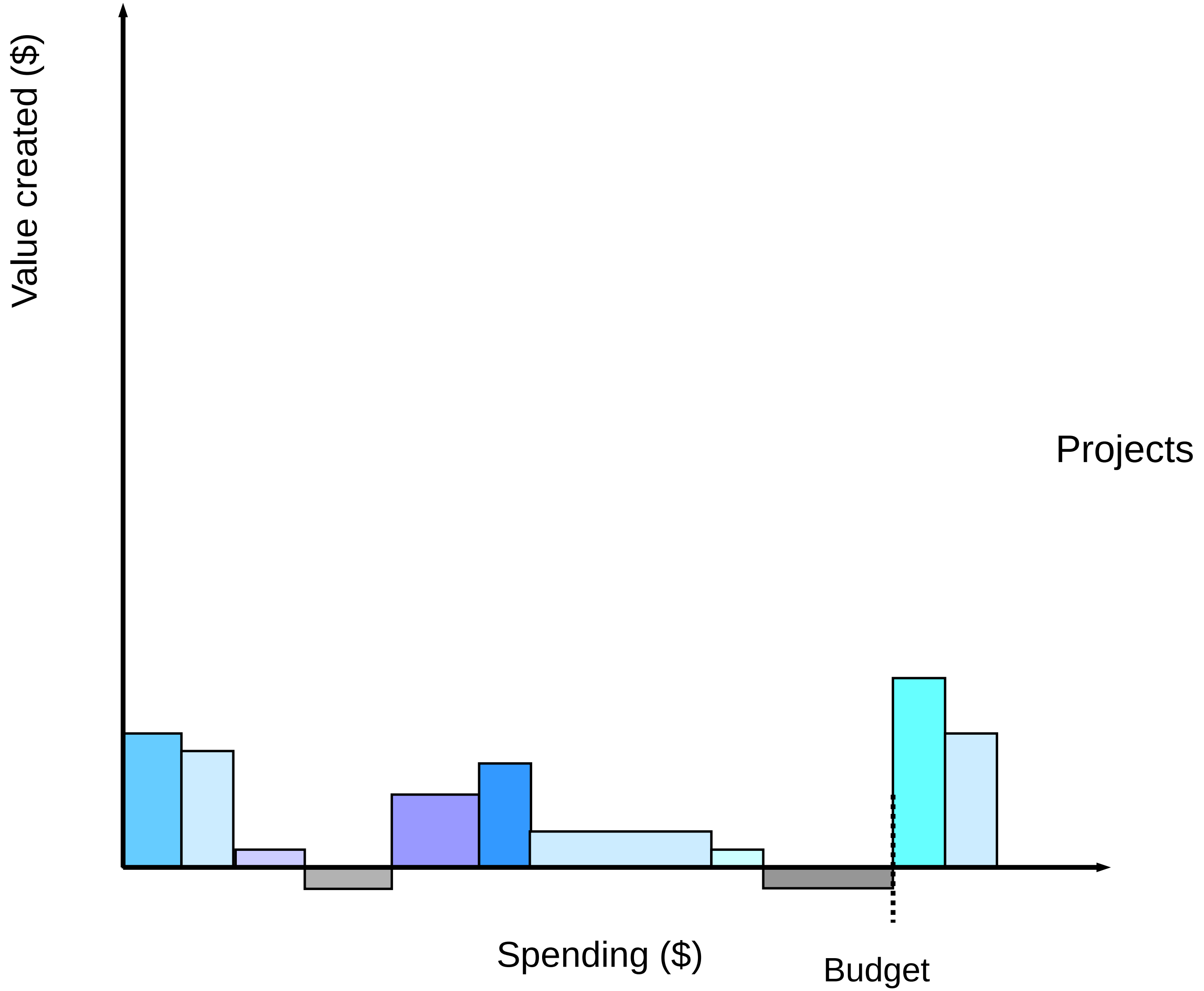
Projects create value by positively transforming the business



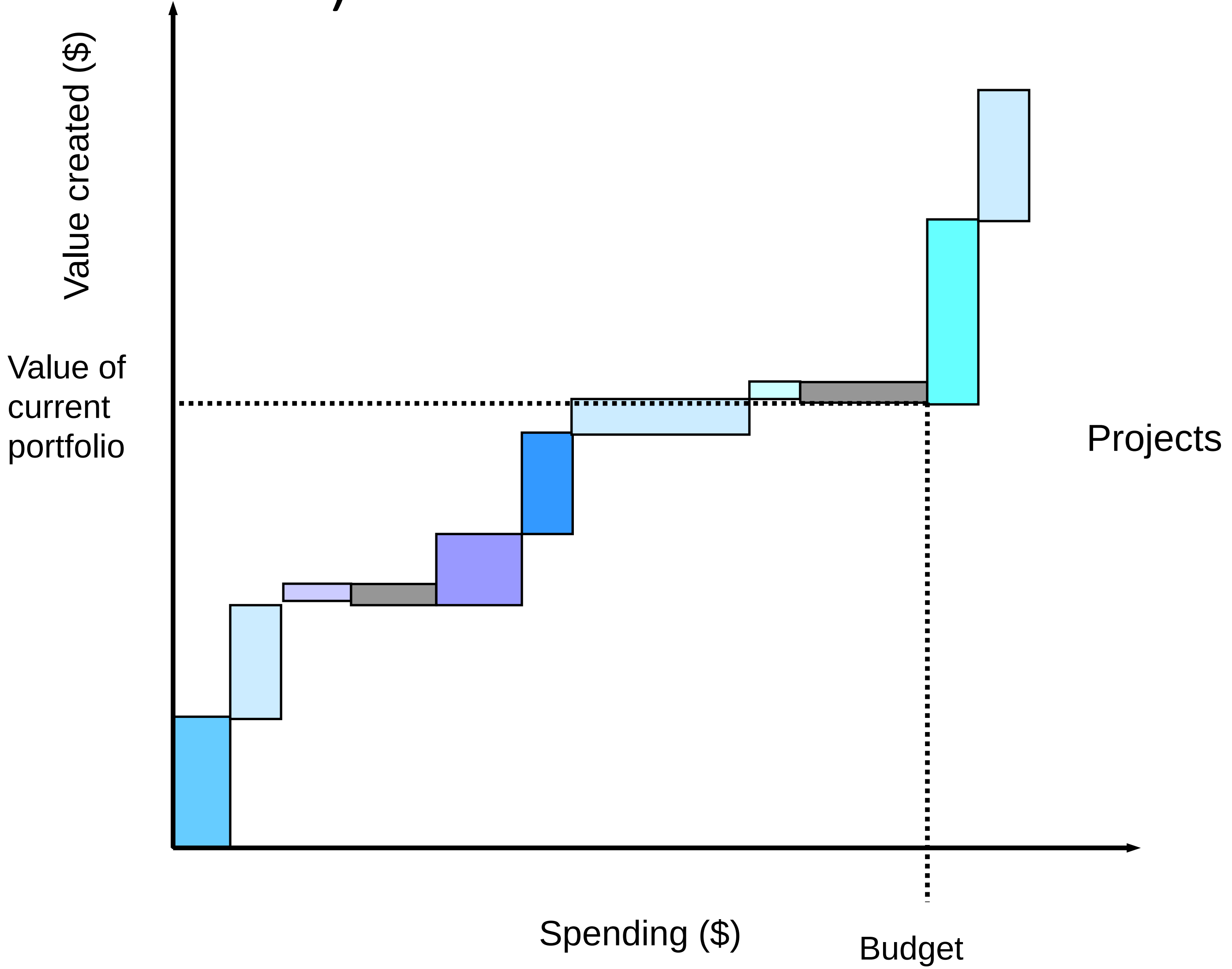
The project value is the difference between the value of the two potential states of the business

Evaluating a project requires estimating what would happen if the project is done and what would happen if the project is not done.

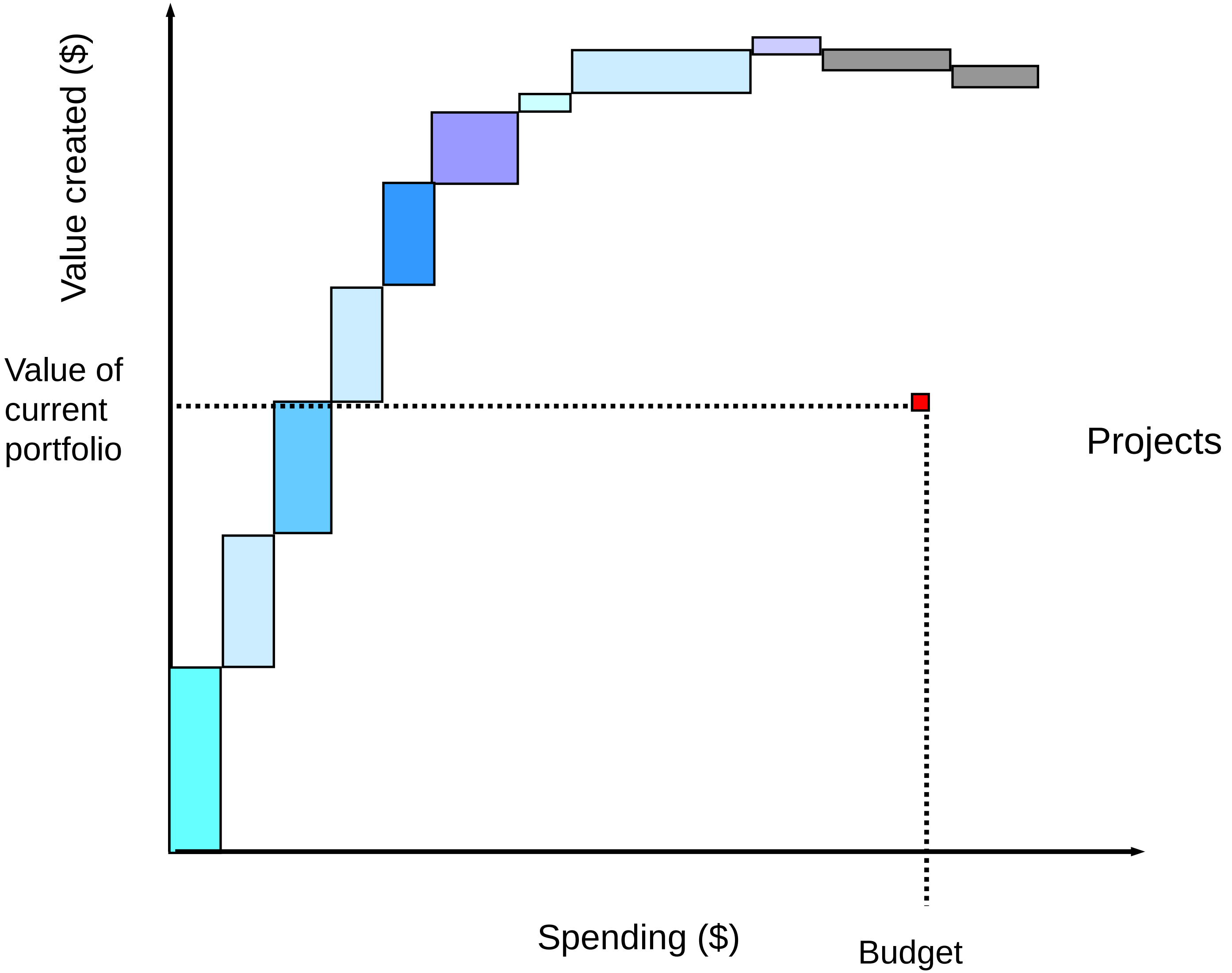
Each project has a cost and value…



The projects included within the portfolio determine the total (cumulative) value…



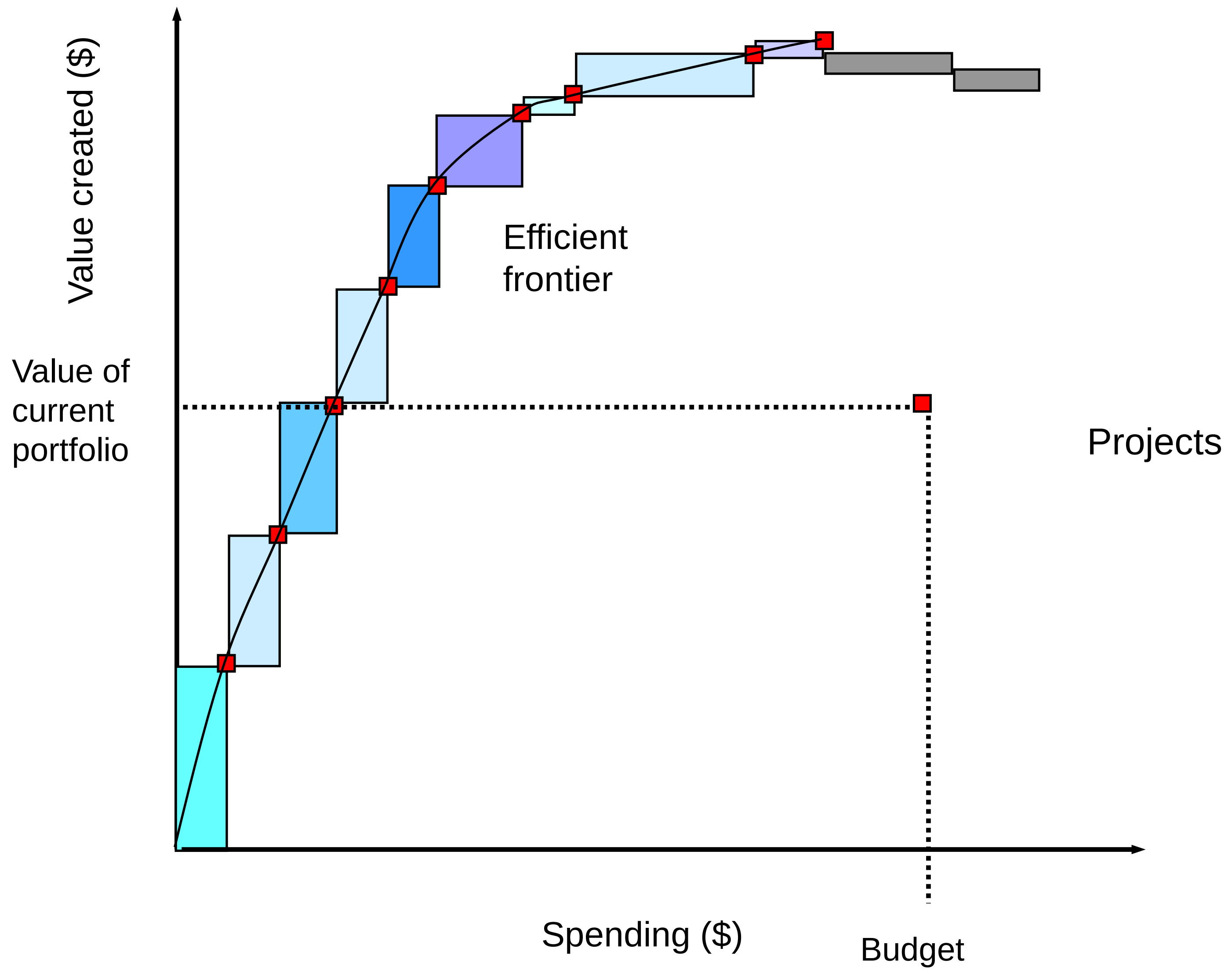
If you order projects by B/C…



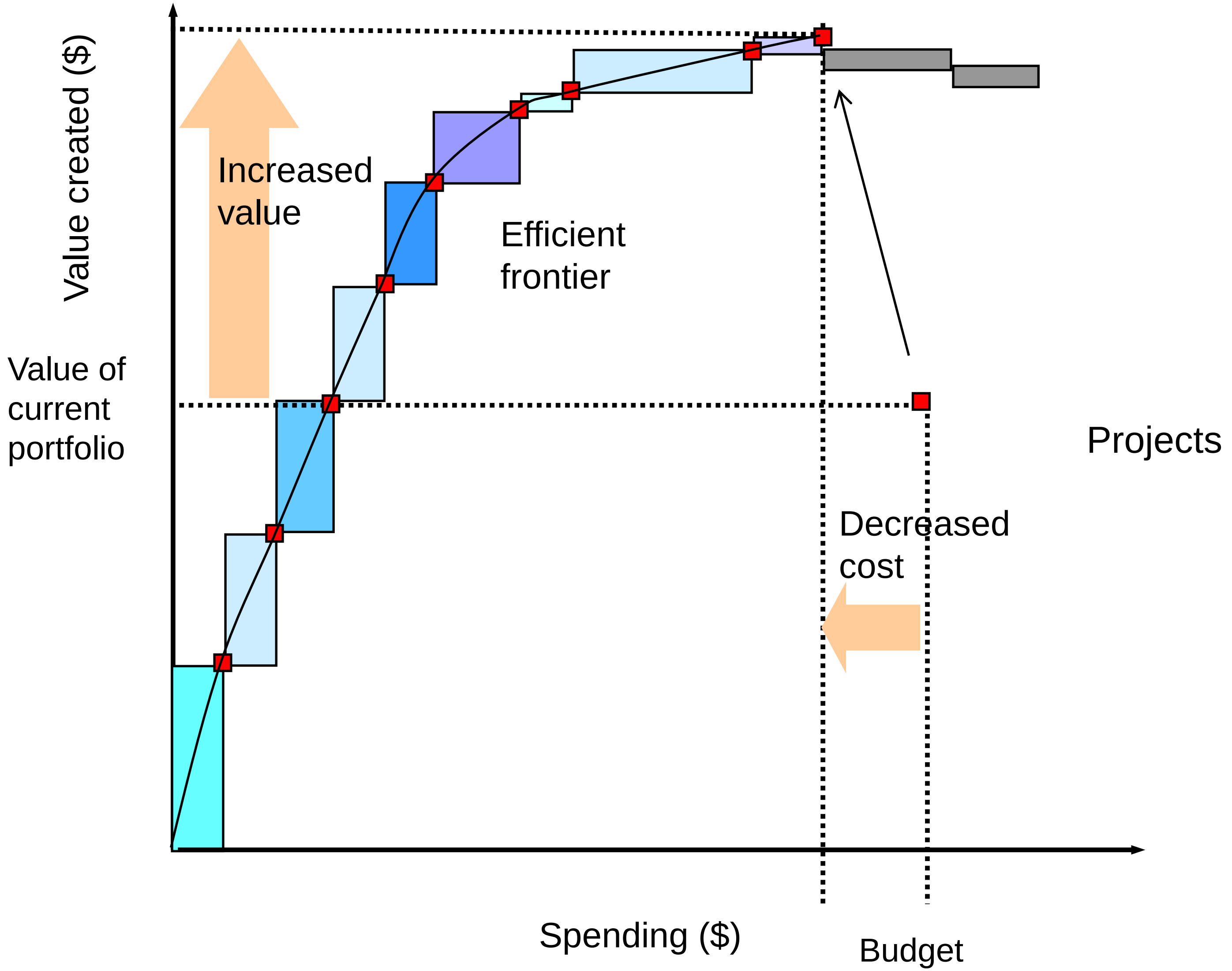
The “efficient frontier”

- 1952 Nobel prize awarded to Harry Markowitz for investment portfolio theory
- Today it is the cornerstone of portfolio theory
- It can be applied to a portfolio of risk reducing projects
- The efficient frontier shows those portfolios that maximize returns (maximum risk reduction) giving the best possible slate of risk reduction activities

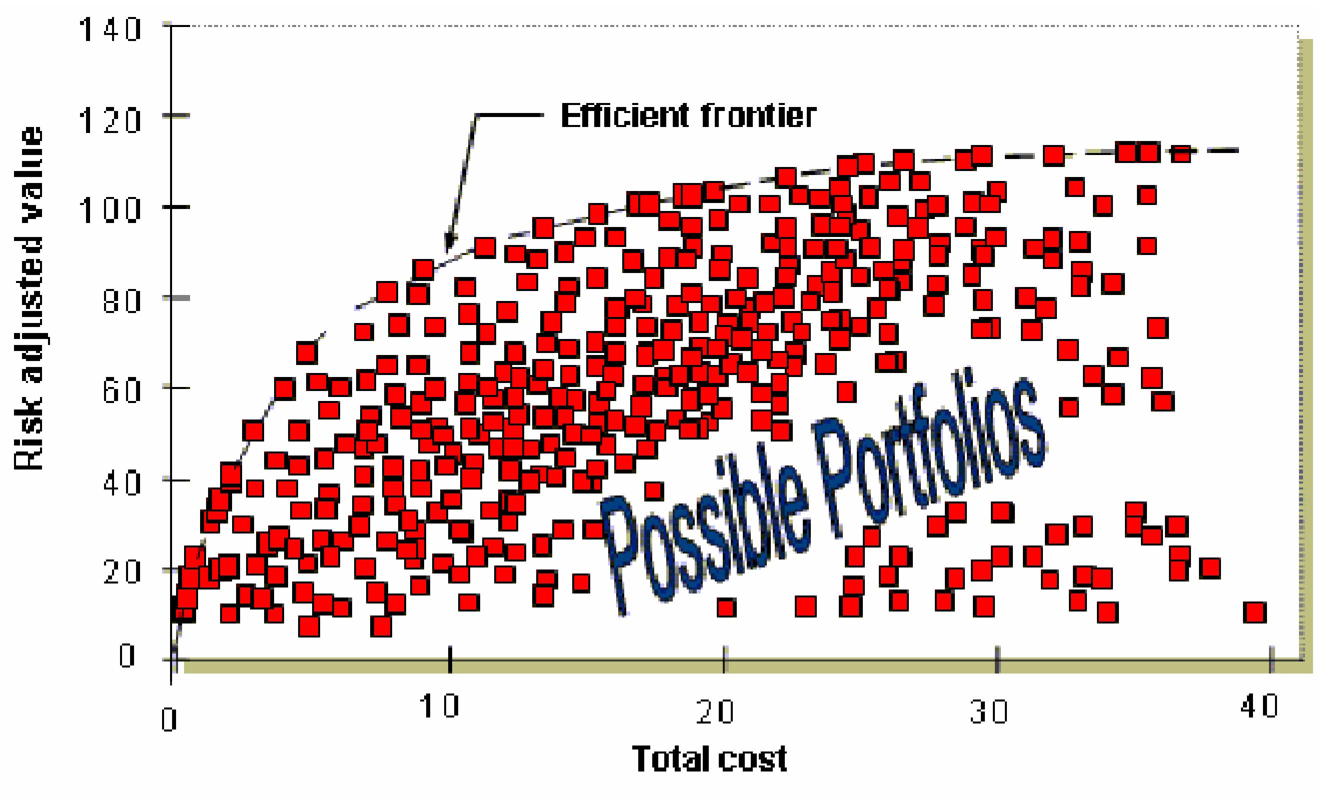
…you get the efficient frontier



…which shows how to increase value while minimizing cost…it's the best that can be done



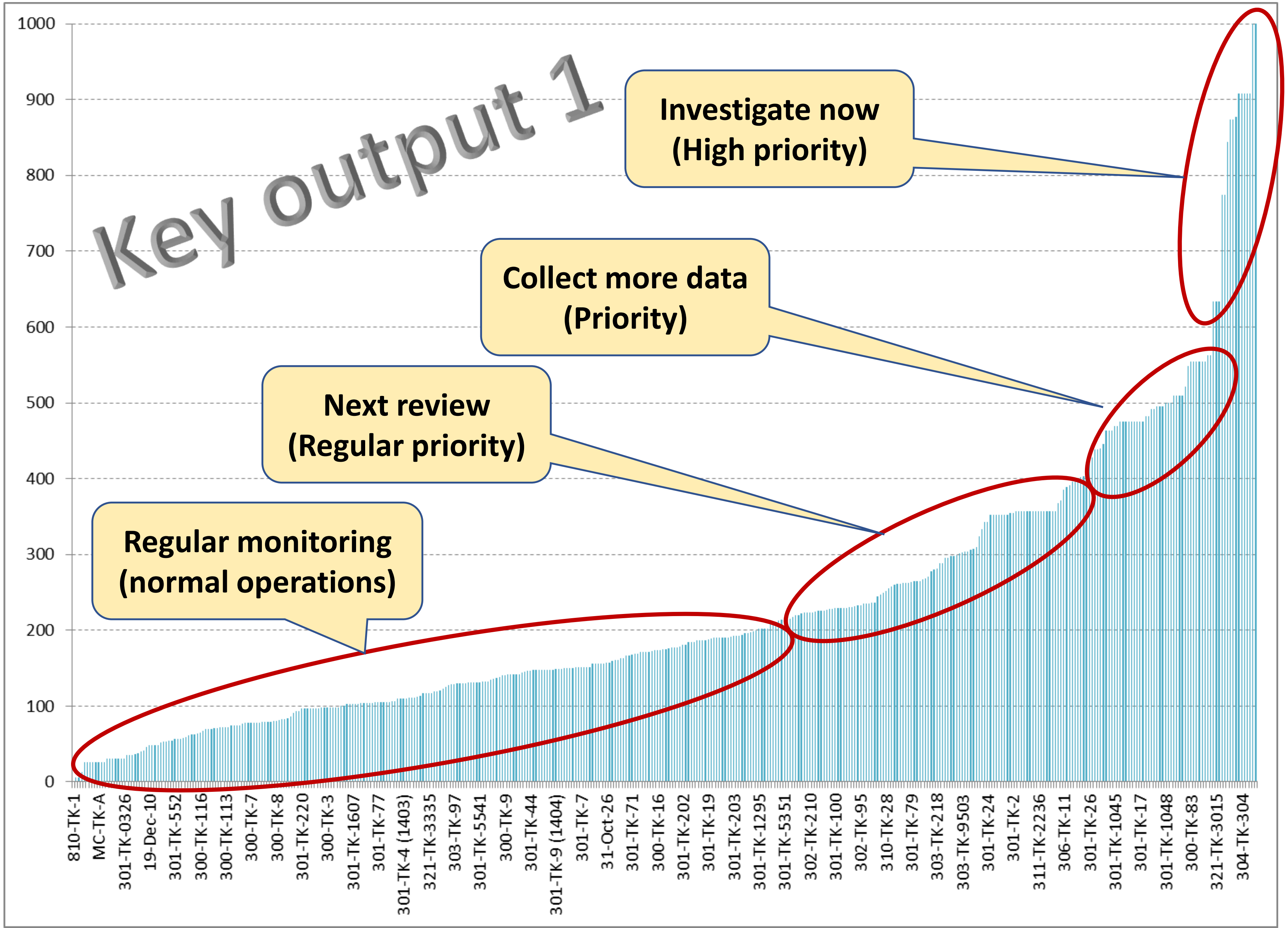
The efficient frontier identifies the project portfolios that create the most value for the least cost



Scaled Risk Factors

(0 to 1000)

This initial RBITIP prioritization/ranking Model provides basis for setting intervals, establishing risk reduction projects (i.e. tank repair projects), and scheduling/budgeting as well as answer key management questions



API Standards and Pubs

API standards and publications relevant to RBI for tanks

- PEMY Consulting
- Philip Myers
- 2023

What are the standards for RBI

- API 340 Liquid Release Prevention and Detection Measures for Aboveground Storage Facilities
- API 353 Managing Systems Integrity ofTerminal and Tank Facilities
- API 580 Risk Based Inspection
- API 581 Risk-based Inspection Methodology

API 340 Liquid release prevention and detection measures for aboveground storage facilities

- A summary of the potential causes of liquid petroleum releases
- An overview of the procedures and equipment available to operators to prevent, detect or provide environmental protection from such releases; and
- The advantages and disadvantages of various control measures including relative costs, as well as maintenance and operating parameters.

Covers petroleum terminals

- Tanks
- Piping systems
- Loading/unloading
- Ancillary equipment
- Operational

Table 4-2 Aboveground Storage Tank Control Measures

Item	Control Measure / Type	Reference	Advantages	Disadvantages	Operation & Maintenance Comments
1A	Impressed Current Cathodic protection of Tank Bottom **(Prevention)**	API RP 651	• Provides protection of bare steel or coated steel on or in soil • Easily checked for proper function • Increases tank bottom life • Provides protection over a wide range of soil conditions • Able to provide protection to groups of tanks	• Requires a current source • Effectiveness can be compromised by hydrocarbon contamination, soil conditions, stray currents	• Maintain power supply; record rectifier readings periodically • Periodically measure soil potentials • Perform annual survey and evaluation • To ensure proper performance potential must be checked under the tank
1B	Galvanic Cathodic protection of Tank Bottom **(Prevention)**	API RP 651	• Provides protection of bare steel or coated steel on or in soil • Easily checked for proper function • Increases tank bottom life • Electrical power not required	• Effectiveness limited to soils of high resistivity • Effectiveness can be compromised by hydrocarbon contamination • Applicable to relatively small tanks	• Periodically measure soil potentials • Perform annual survey and evaluation • To ensure proper performance potential must be checked under the tank
2A	Steel tank product side coating or lining **(Prevention)**	API RP 652	• Protects the steel bottom product side • Provides a corrosion resistant barrier • Provides additional protection for welded seams • Reinforced coatings provide additional support for tank base, allowing for lower minimum remaining thickness (MRT) of floor	• Special preparation, installation & curing required • Must be compatible with product and temperature stored • Rigorous inspection of coating application required • Limits inspection of both surfaces	• Coating / lining should be visual inspected when tank is taken out of service • Coating / lining should have low voltage holiday test performed after major tank repair or alteration • Rigorous inspection during installation • Not suitable for all tanks • Reinforced coating may limit floor scanning and ultrasonic test results • Appropriate voltage must be used for holiday test • Refer to API STD 652 for thick & thin film discussion
2B	External coating of steel tank shell **(Prevention)**	SSPC Surface Prepar-ation	• Protects the steel tank shell • Provides a corrosion resistant barrier • Provides additional protection of riveted seams	• Special preparation, installation & curing required • Rigorous inspection & QA/QC of coating required	• Coating should be periodically inspected

Table 4-1 Aboveground Storage Tank Release Scenarios[1]

Release Category	Cause	Control Measure Options	Type of Control Prevention Detection Protection	Control Measure Reference (see Table 2)	Retrofit Cost	O & M Cost
Overfill releases / Spill through tank vents	Human error	• Written operations procedures / schedule • Operator training • Overfill protection system alarms and instrumentation[2] • Manual product level verification before & during receipt • Automatic product level verification before & during receipt • Tank farm secondary containment dike / berms • Tank farm dike yard liners	P P P P P Pro Pro	5A 5A 3B 3A 3B 28 29	Low Low Medium-High Low-Medium Medium-High High Very High	Medium Medium Medium-High Low-Medium Medium-High Low Medium-High
	Equipment failure	• Planned and documented inspections in accordance with API STD 653 • Automatic tank gauging system • Manual product level verification before & during receipt • Overfill protection system alarms and instrumentation • Programmed, preventative maintenance and testing • Tank farm secondary containment dike / berms • Tank farm dike yard liners	P P D P P P Pro Pro	13A 13B 21B 3A 3B 5B 28 29	N/A N/A Medium Low-Medium Medium- High Medium-High High Very High	Low Medium Medium Low-Medium Medium-High Medium Low Medium-High
Slow Releases /Shell release	1. External corrosion 2. Corrosion under insulation 3. Internal corrosion	• External coating of steel tank • Planned and documented inspections in accordance with API STD 653 • Steel tank product side lining or coating • Routine walk around inspections • Tank farm dike yard liners • Internal cathodic protection for internal corrosion	P P P P D Pro P	2B 13A 13B 2A 25 29 35	Medium N/A N/A Medium-High N/A Very High High	Medium Low Medium Low-Medium Low Medium-High Low-Medium
	Weld crack	• Planned and document inspections in accordance with API STD 653 • Routine walk around inspections • Tank farm secondary containment dike / berms	P P D Pro	13A 13B 25 28	N/A N/A N/A High	Low Medium Low Low

Pros and cons of API 340

- Understandable, simple, and transparent
- Great checklist
  - Tanks
  - Piping
  - Loading
  - Ancillary
  - operating
- Covers most terminals
- Provides scenarios for release mechanisms
- Lists control measures
- Has relative costs for control measures

- No quantitation
- Does not cover retail, refineries, oil and gas producing, natural gas processing, or cross country pipelines
- Has not been updated since 1997

API 353
Managing Systems Integrity of Terminal and Tank Facilities
Managing the Risk of Liquid Petroleum Releases

- Covers tanks, piping, and transfer systems
- Addresses environmental risks
- A structured approach to risk assessment
- Ranking and prioritizing risks
- Examples of risk ranking and prioritizing
- Uses factors as multipliers similar to API 581

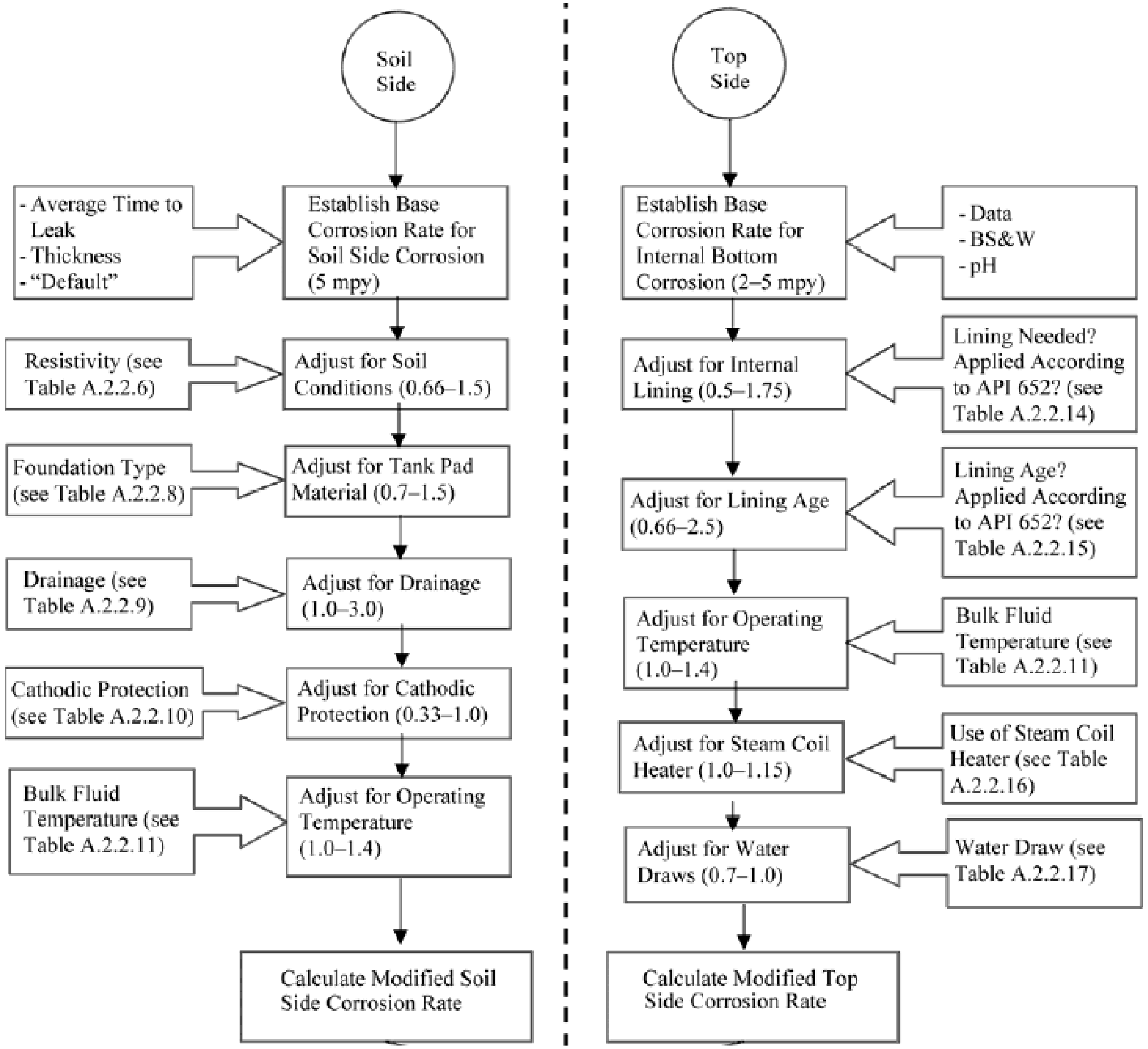


Table A.2.2.6: Native Soil Resistivity Adjustment

Resistivity (ohm-cm)	Potential Corrosion Activity	Adjustment Factor
<500	Very Corrosive	1.5
500–1000	Corrosive	1.25
1000–2000	Moderately Corrosive	1
2000–10000	Mildly Corrosive	0.83
>10000	Progressively Less Corrosive	0.66
Tank with RPB		1

Table A.2.2.9: Tank Drainage Adjustment

Type of Drainage	Adjustment Factor
More than one-third of the bottom edge of the tank is frequently under water.	3
Storm water usually collects around the base of the tank.	2
Storm water does not usually collect around the base of the tank.	1

Pros and cons of API 353

- Procedure for estimating corrosion leak frequencies clear (very similar to API 581)
- Provides some useful ordinal data about factors that affect corrosion rates.

- Basis of factors not given
- No uncertainty analysis provided
- Underlying probability and data analysis yielding the methodology is not given (black box)
- Only covers liquid releases
- Is basically duplicative with API 581
- Last updated in 2006

API 580 Risk Based Inspection

- Inspection focus and intensity (e.g. inspection intervals beyond “1/2 life”)
- Documented management system to implement and sustain an RBI program
- Data to support POF and COF
- Damage mechanisms and failure modes (e.g. corrosion)
- Reassessment
- Pressure vessels, piping, stanks, rotating machinery, fired equipment, PRVs but not electrical, I&E, structural

API 580 Contents Summary

- Scope
- Normative References
- Terms, Definitions, Acronyms, and Abbreviations
- Basic Risk Assessment Concepts
- Introduction to Risk-Based Inspection
- Planning the RBI Assessment
- Data and Information Collection for RBI Assessment
- Damage Mechanisms and Failure Modes
- Assessing Probability of Failure
- Assessing Consequence of Failure
- Purpose
- Risk Management with Inspection Activities
- Other Risk Mitigation Activities
- Reassessment and Updating RBI Assessments
- Roles, Responsibilities, Training, and Qualifications
- RBI Documentation and Recordkeeping
- Summary of Risk-Based Inspection Pitfalls
- Bibliography

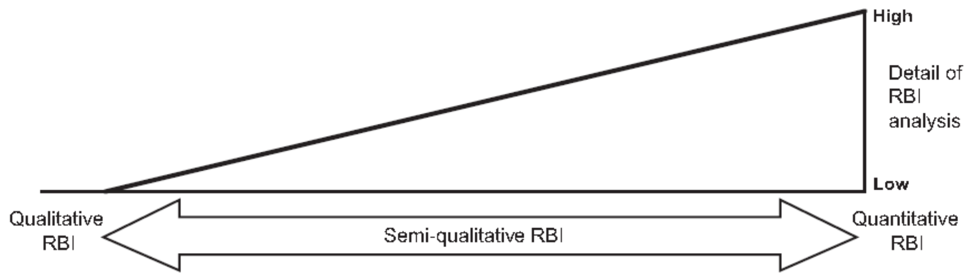


Figure 3—Continuum of RBI Approaches

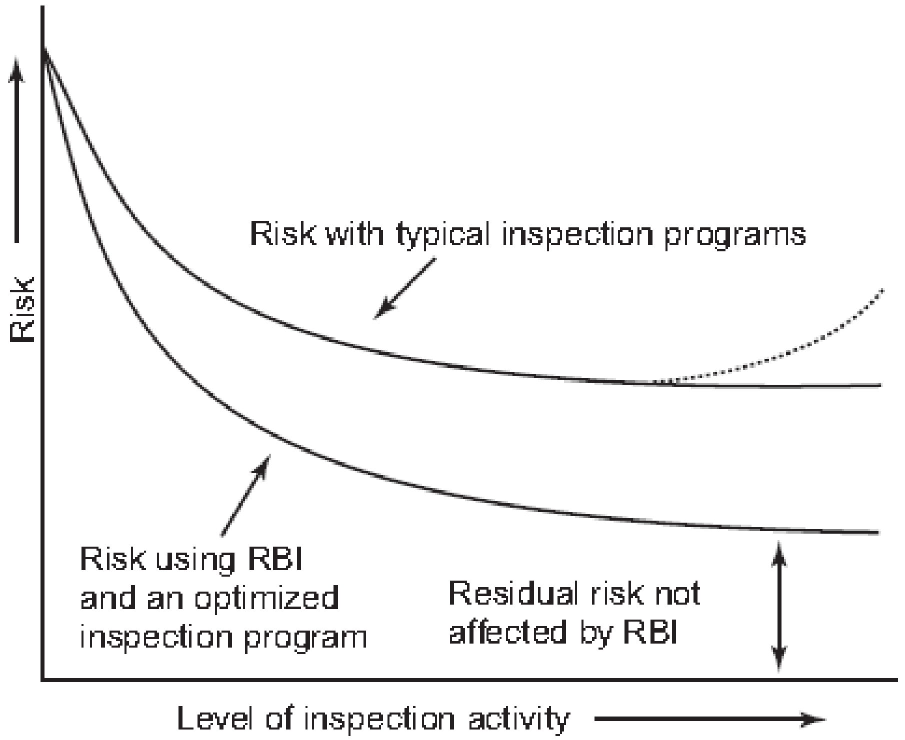


Figure 1—Management of Risk Using RBI

Pros and cons of API 580

- Good tutorial on risk
- Shows RBI as a process and not a task
- Lists the management systems required to run RBI

- Somewhat general and vague with few examples
- Does not emphasize or quantify how much effect the fine tune knob has relative to overall risks
- Does not quantify the benefit so that cost-benefit is unknown
- Does not provide any benchmarks or studies showing the cost benefit

API 581Risk-based Inspection Methodology

1.4 Organization and Use

The API RP 581 methodology is presented in a three-part volume:

a) Part 1 – Inspection Planning Methodology

b) Part 2 – Probability of Failure Methodology

c) Part 3 – Consequence of Failure Methodology

It is important to note that the methodology presented in API 581 is NOT the only methodology nor even the best methodology depending on the specific issues involved.
Other methodologies should be used and applied if found to be more appropriate.
An expert in probability and statistics is recommended to review the methodological approach of all RBI work.

Contents

API 581 approach to tank bottom corrosion rates

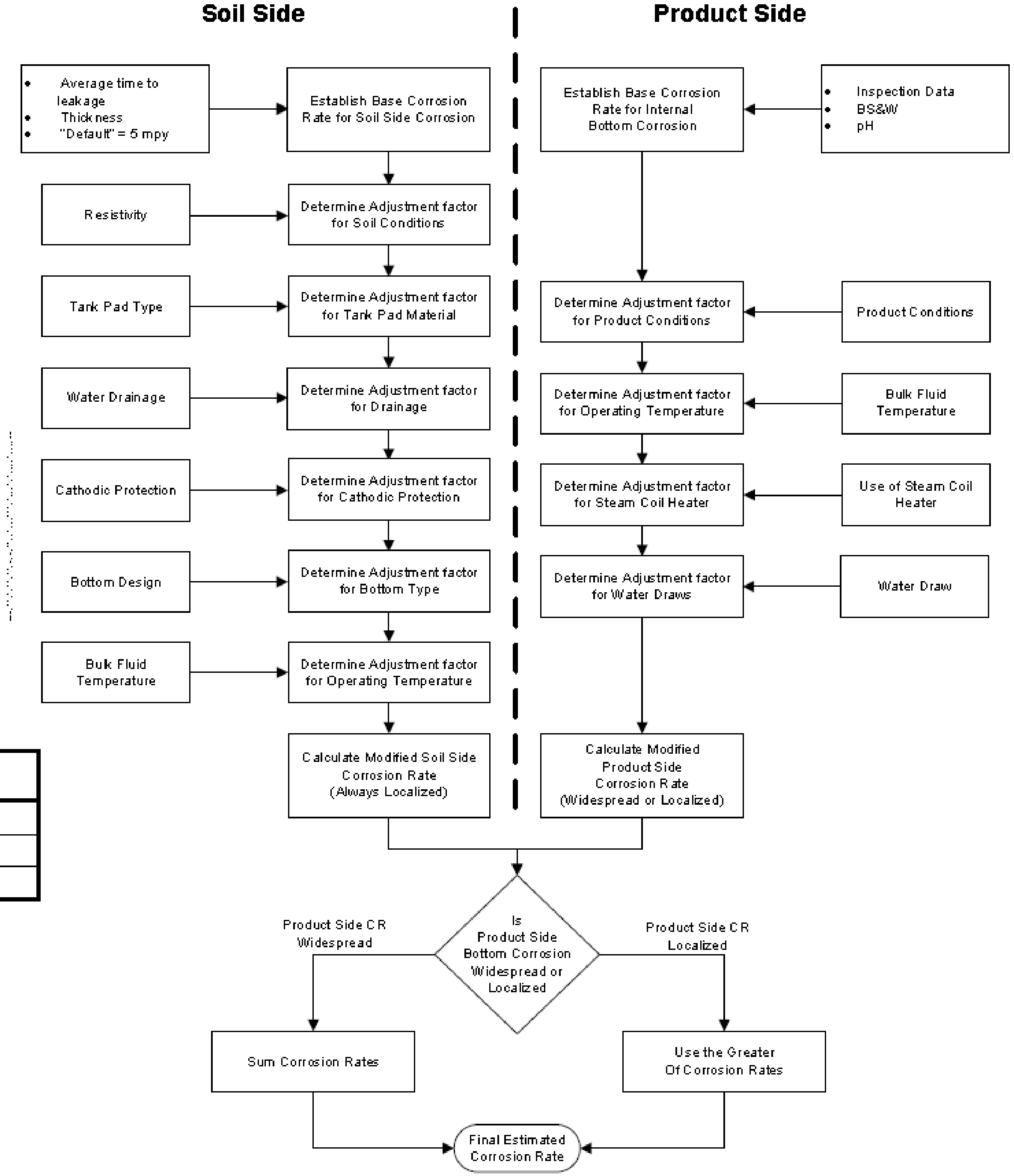
$$CR_p = CR_{PB} \cdot F_{PC} \cdot F_{PT} \cdot F_{SC} \cdot F_{WD}$$

Table 2.B.14.4 – Soil Side Soil Resistivity Adjustment Factor

Resistivity (ohm-cm)	Potential Corrosion Activity	Multiplying Factor – F_{SR}
< 500	Very Corrosive	1.5
500 – 1000	Corrosive	1.25
1000 – 2000	Moderately Corrosive	1.0
2000 – 10000	Mildly Corrosive	0.83
> 10000	Progressively Less Corrosive	0.66
AST with RPB		1.0

Table 2.B.14.7 – Soil Side Cathodic Protection Adjustment Factor

Cathodic Protection Type	Multiplying Factor – F_{CP}
None	1.0
Yes Not Per API 651	0.66
Yes Per API 651	0.33



Pros and cons of API 581

- Lots of useful data for equipment used in refinery processes – but most irrelevant to storage tanks
- Some data for storage tanks and failure frequencies
- Shows RBI a process and not a task
- Is an RP not a standard!

- A cookbook without transparency for basis of equations and tables used to estimate risk
- Corrosion model for tanks is not consistent with formal statistical and probabilistic methods.
- Methodology is a cookbook and black box which is very difficult to trace or understand without an inordinate amount of work and time
- Has had mixed success in the industry
- No body of literature that really supports the impact it has on overall risk
- It only impacts the fine tuning knob on risk

How valuable are these standards (my opinion only)

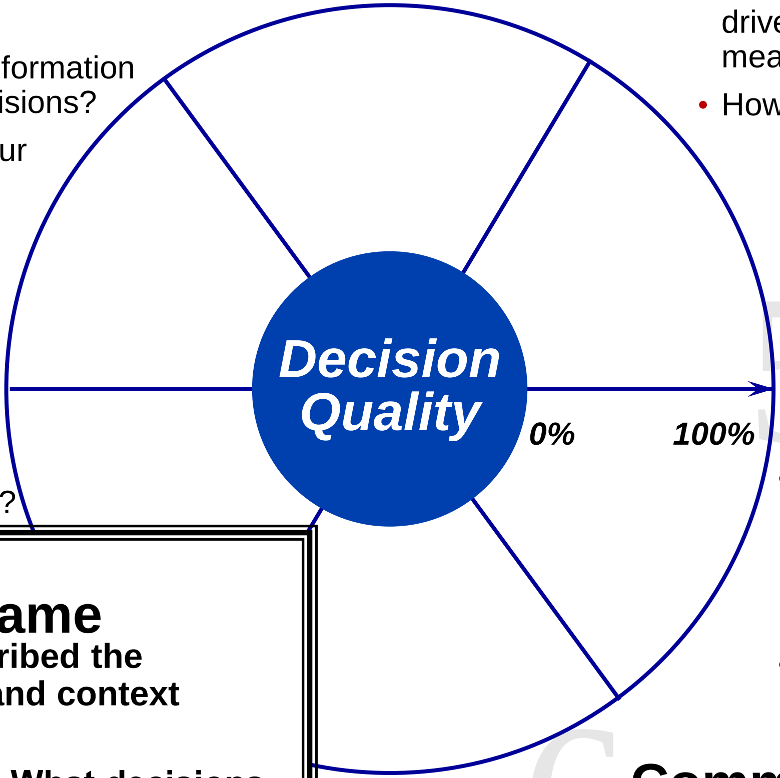
- API 340 
- API 353 
- API 580 
- API 581 

BREAK TIME!

RBI v Tank Integrity Programs (RBITIP)

What is framing?

A Well-Defined Frame is the Foundation for Decision Quality and helps RBITIP be a success



3 Meaningful Reliable Information

- What do we know? What don't we know?
- Do we have sufficient information to make fact-based decisions?
- Do we know and trust our sources of information?

4 Clear Values and Trade-Offs

- What do we want?
- Do we understand our value drivers? Value / Success measures?
- How do we make trade-offs?

2 Creative, Doable Alternatives

- What are the options or choices?
- Are our alternatives doable?

5 Logically Correct Reasoning

- Are we using good logic to evaluate our options, using available information, and keeping in mind what we want?
- Have we applied appropriate decision-making tools?

1 Appropriate Frame

- **Have we clearly described the correct background and context for the decision?**
- **What's the problem? What decisions are we trying to make?**
- **Do key stakeholders clearly understand the frame?**

6 Commitment to Action

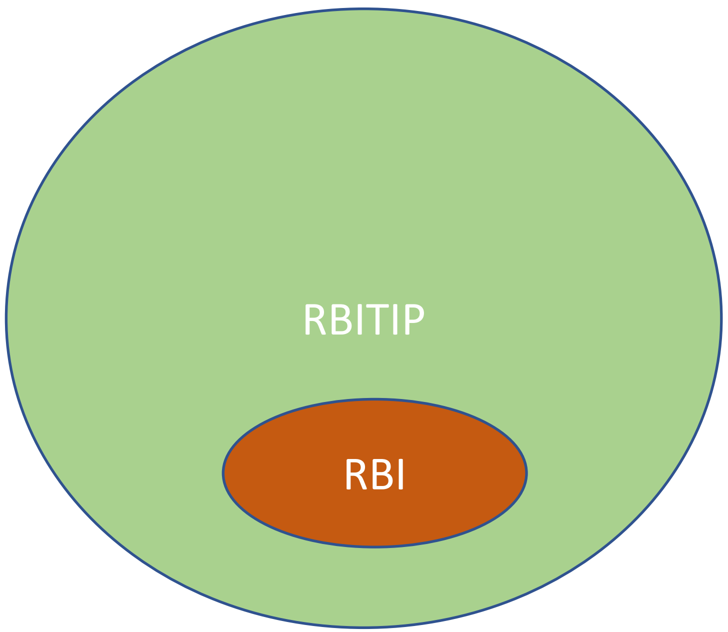
- Are we ready to make the decision and take action?

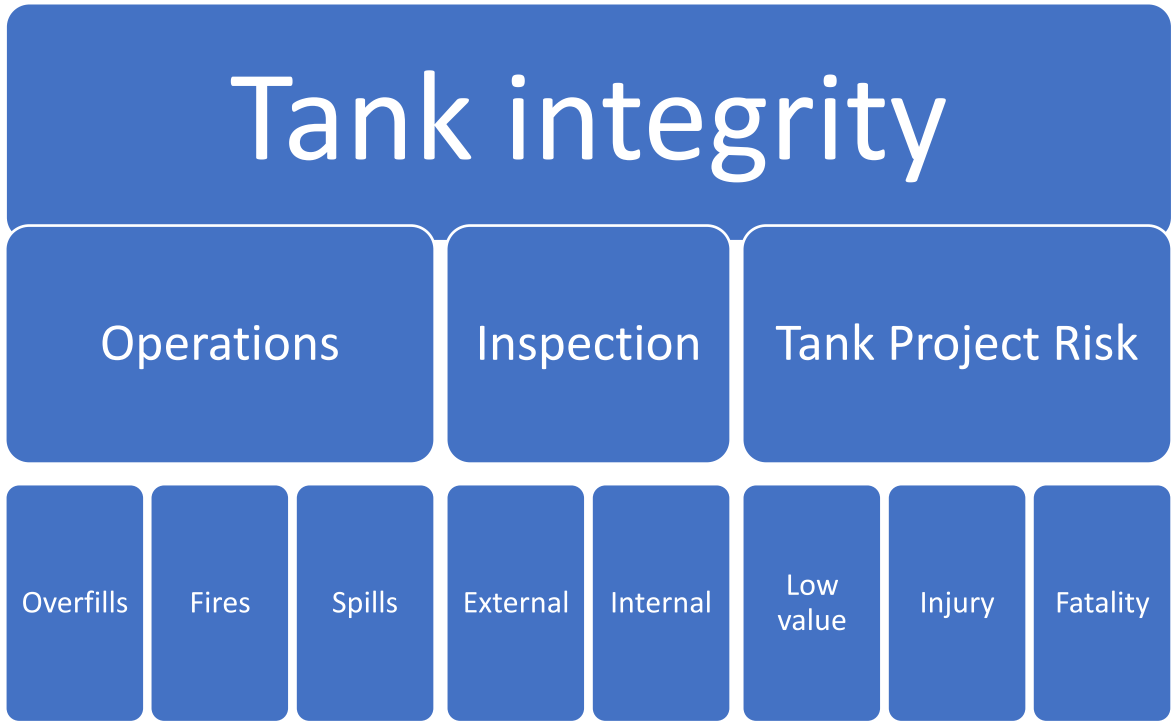
Risk Based Inspection or Risk Based Tank Integrity Programs - Evergreen processes

- Because the organization changes – the physical assets, ways of doing business, the changing nature of societal values – its important to make sure that the RBI process stays evergreen.
- RBI is a process – not a task
- Optimization of value from risk is only possible with a long term perspective and process
- Risk management is fragile

RBI v RBITIP

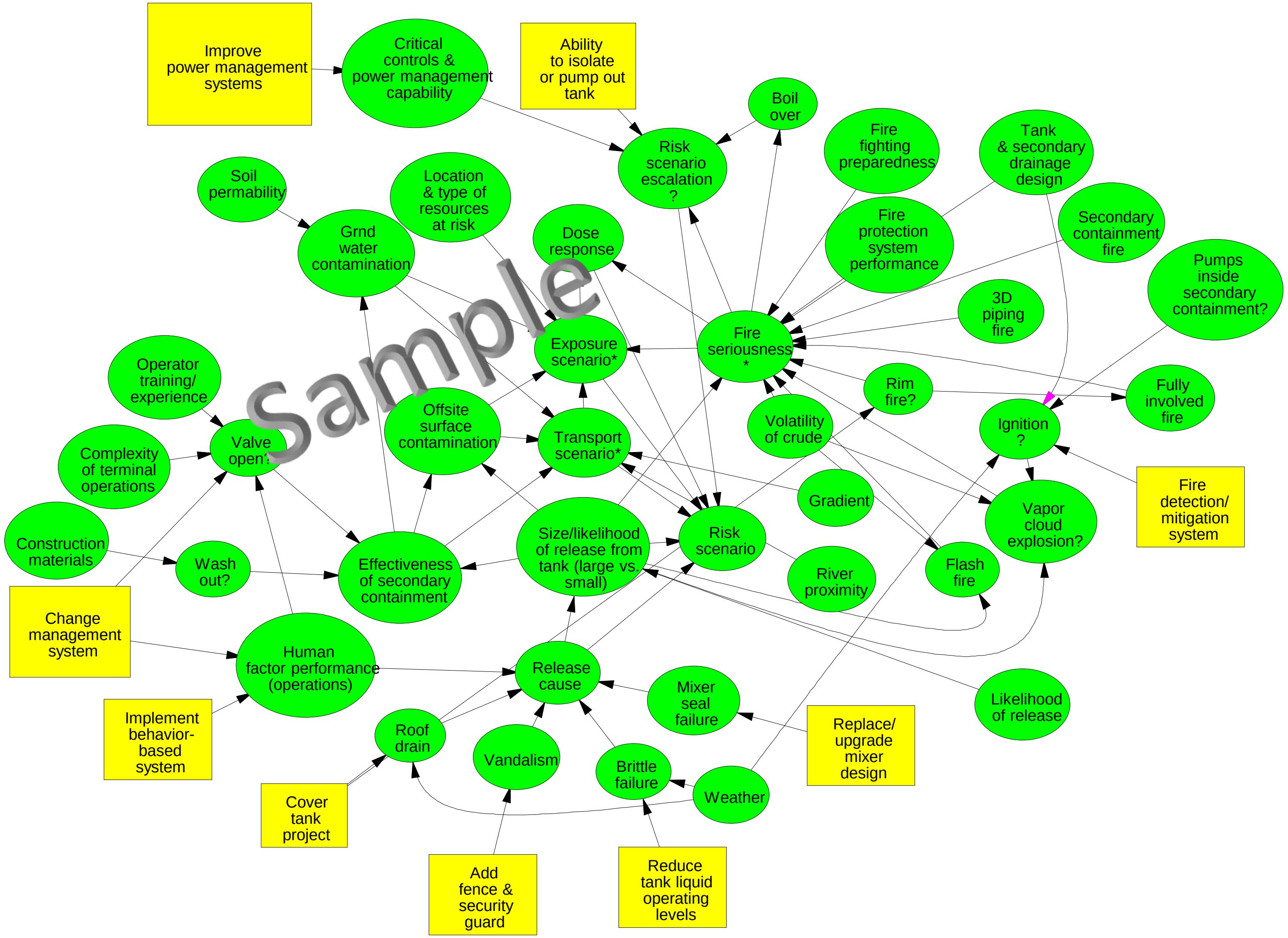
- Risk Based Inspection (fine tuning knob)
- RBITIP Tank Integrity Program (coarse tuning knob)





Adding sample RBTIP projects shows how specific types of projects impact factors that ultimately impact environmental risk

Influence diagrams and cause and effect can be probabilistically related to quantify likelihoods, consequences, and issues for the RBITIP.

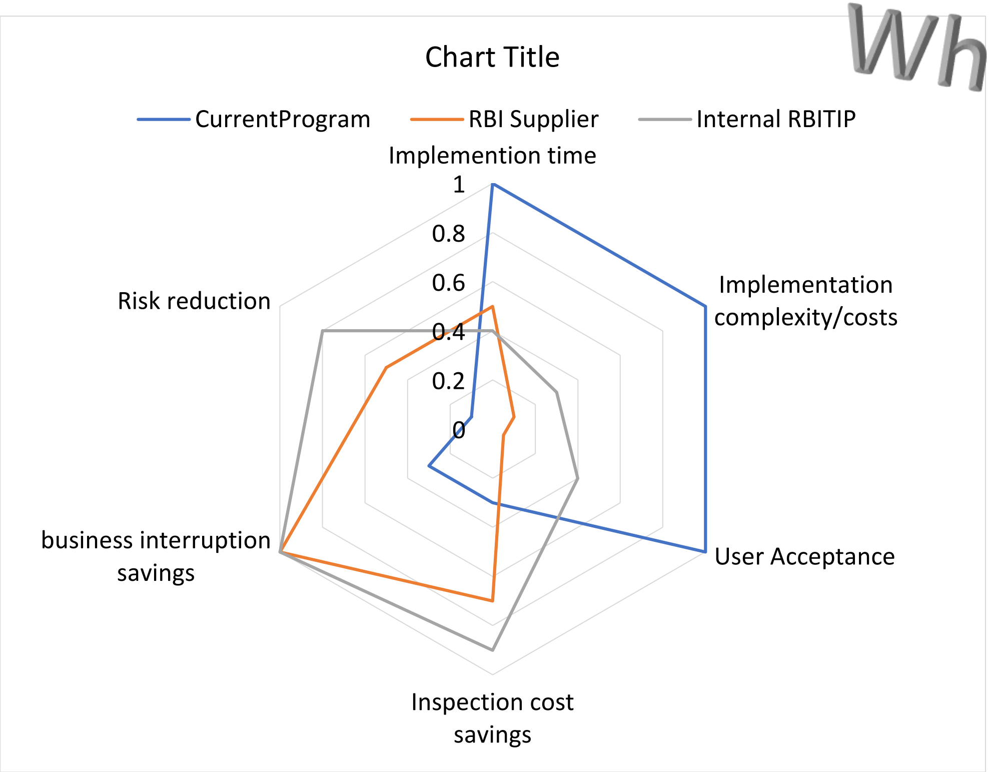


RBI Programs for Tanks

Framing Some Typical Implementation Alternatives for RBI

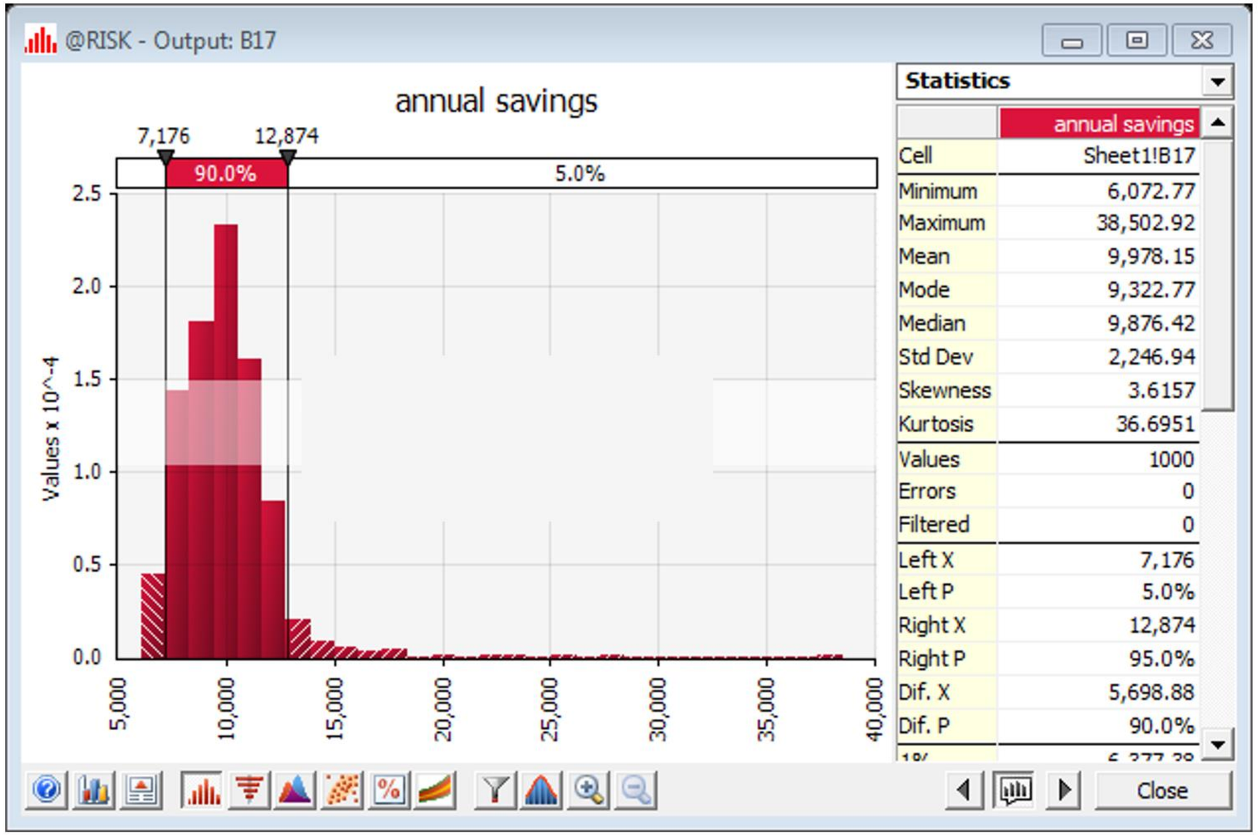
- Case 1 – API 653: Standard Tank Inspection Program
- Case 2 – API 653 & Sim Service (corrosion rate estimation)
- Case 3 – API 653 & Vendor supplied RBITIP
- Case 4 – API 653 & Internally Developed RBITIP

What's the best alternative for a company



			Input scores			Weighted scores		
	raw	normalized	Alternate 1	Alternate 2	Alternate 3	Alternate 1	Alternate 2	Alternate 3
Evalutation Criterion	weights	wt factors	Status quo	RBI supplier	RBI internal	Status quo	RBI supplier	RBI internal
Data loading	2	0.05714	1	0.4	0.7	0.057	0.023	0.040
Implementation time	3	0.08571	1	0.7	0.5	0.086	0.060	0.043
Software costs	1	0.02857	1	0.5	0.5	0.029	0.014	0.014
User acceptance	5	0.14286	1	0.4	0.8	0.143	0.057	0.114
Inspection costs savings	8	0.22857	0.4	0.7	0.9	0.091	0.160	0.206
Business interruption cost savings	6	0.17143	0.5	0.8	0.8	0.086	0.137	0.137
Reduced spare tankage	1	0.02857	0.5	0.8	0.8	0.014	0.023	0.023
True risk reduction	9	0.25714	0.7	0.8	0.9	0.180	0.206	0.231
	35					0.69	0.68	0.81

The Overall Savings may look like this!



Annually in $K

minimum savings 6072

maximum savings 38502

average savings is 9978

Simulations can and should be run on the costs of tank outages, for inspection, numbers of additional tanks needed to keep operating due to inspection/cleaning/repair outages, business costs, etc. This can be used to estimate the savings from an RBITIP program

Why Bother with all this – instead of jumping right into RBI?

- Framing the project is like any other. A poor job up front leads to major problems later. Applying an RBITIP program is no exception. *There are many sad stories of failed RBI programs!*
- If nothing else, owner companies should decide if RBI suppliers can live up to the task.
- RBI can provide more than just reduced costs for inspection; it can identify where risks are significant.
- It has many other benefits such as risk communication, auditability and justification for actions, costs, schedules, etc.
- It forces the examination of internal values and gets management on the same page and builds consensus for what is important to the company

Finally, how does RBITIP meet Senior Management Goals

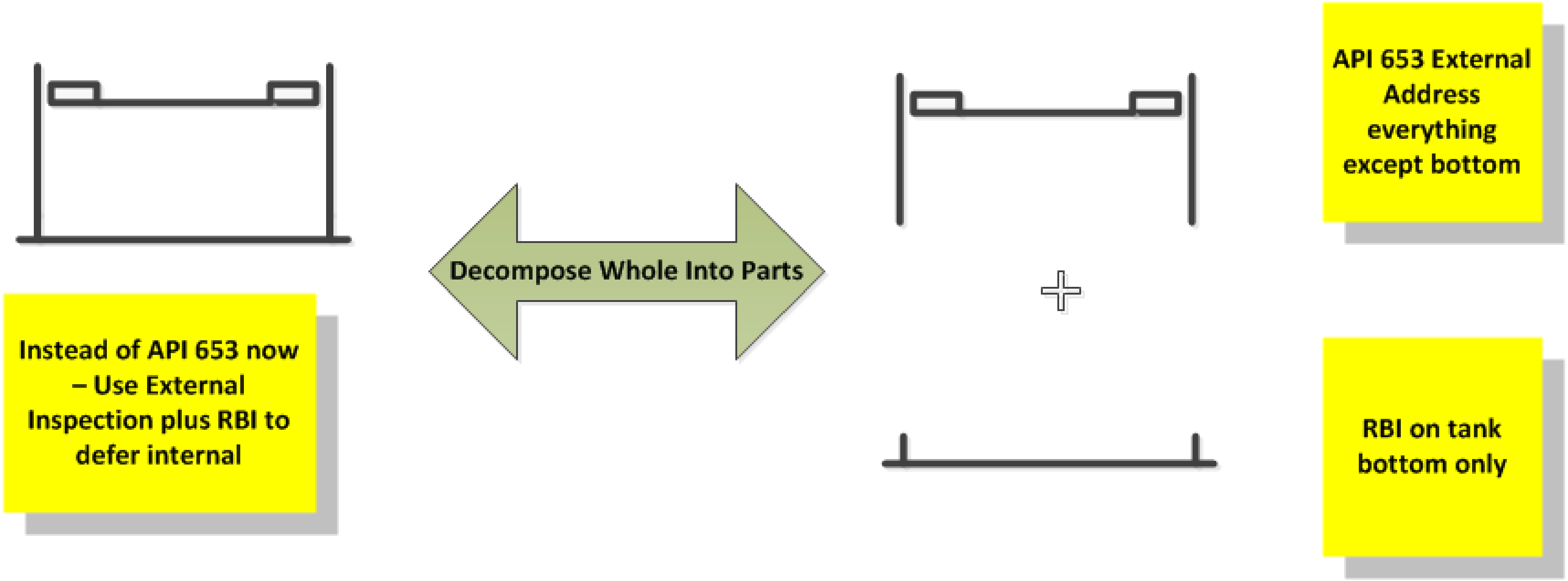
Senior management: typical info requests

1. What are our biggest exposures?
   - Where are we generally OK (about the same as the rest of the industry)?
   - Where are we essentially risk-free?
2. Is there anything we need to address right away?
3. What should we be doing longer-term?
4. *Next – more detail about inputs, the process, and the outputs*

At the end of the day, the RBITIP program needs to be able to answer these questions efficiently and credibly!

RBI on Individual Tanks

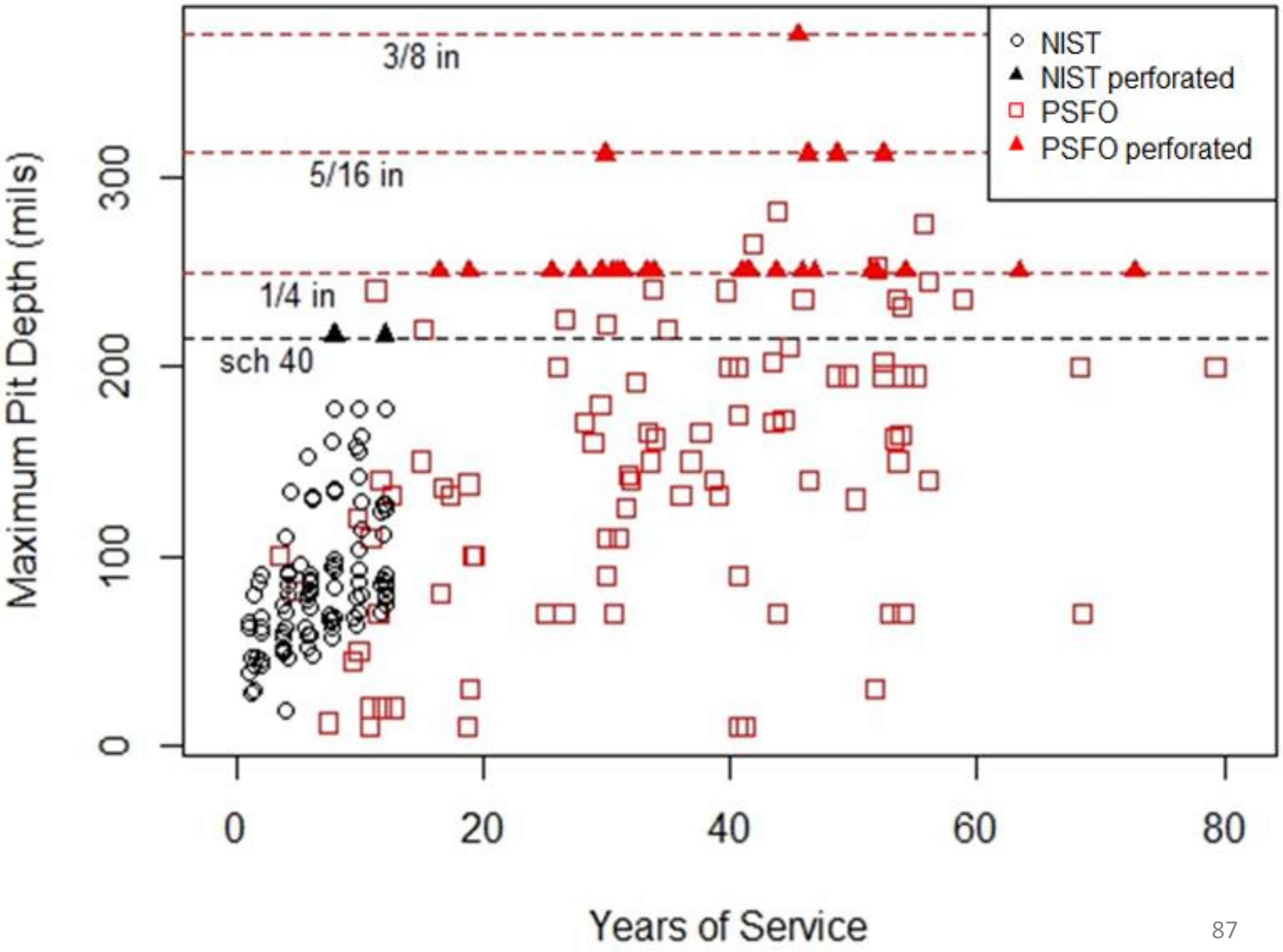
Divide and conquer



Tank RBI is best implemented by segregating what can be addressed by external inspection and what can be done related to the bottom separately.

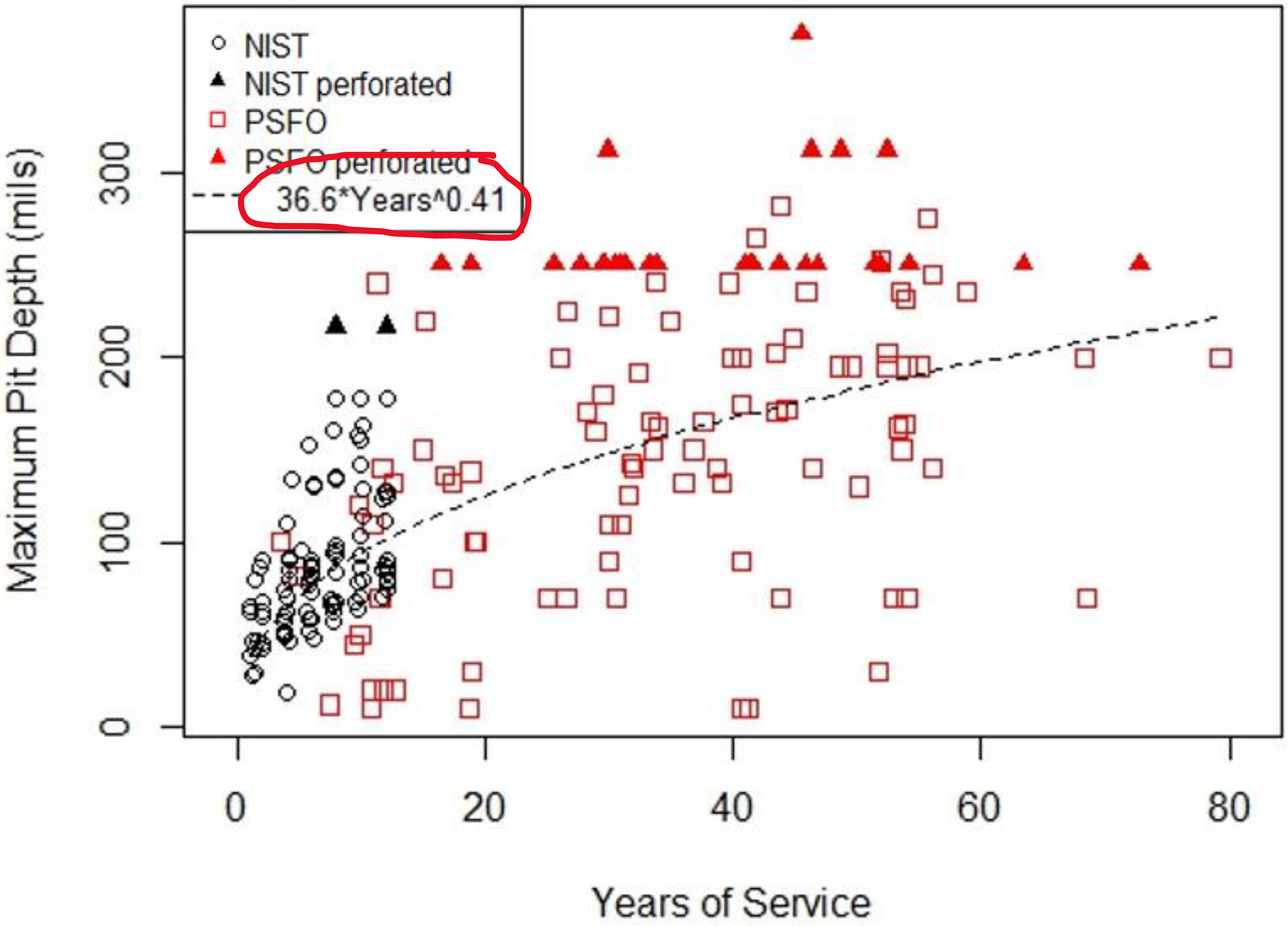
Combined NIST and PSFO Data

Thickness of tank bottom plates and of schedule 40 pipe walls are shown. Perforated-pit depths are lower bounds on potential penetration. Such “censored” observations require special handling in statistical analyses [6].



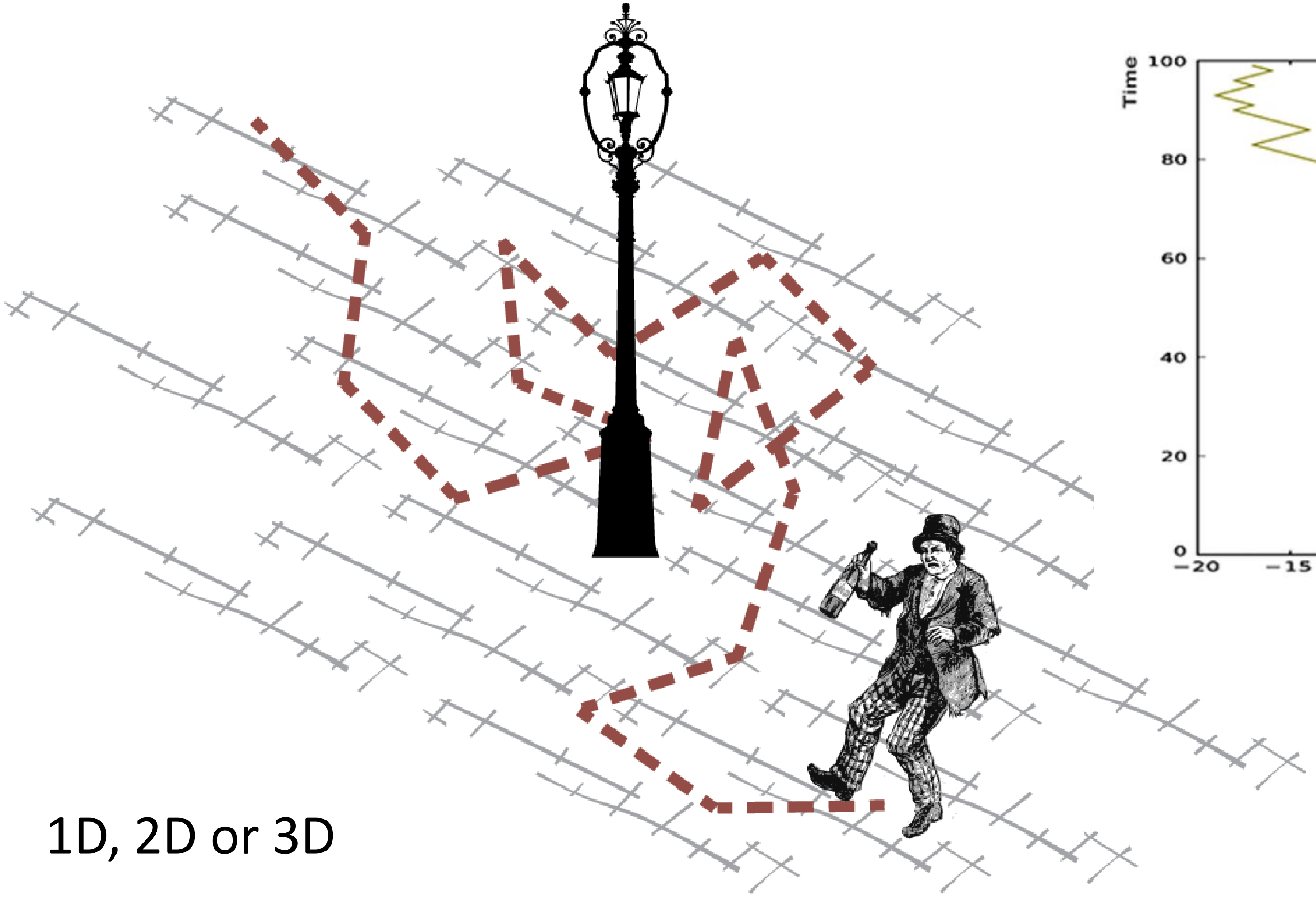
Power Law

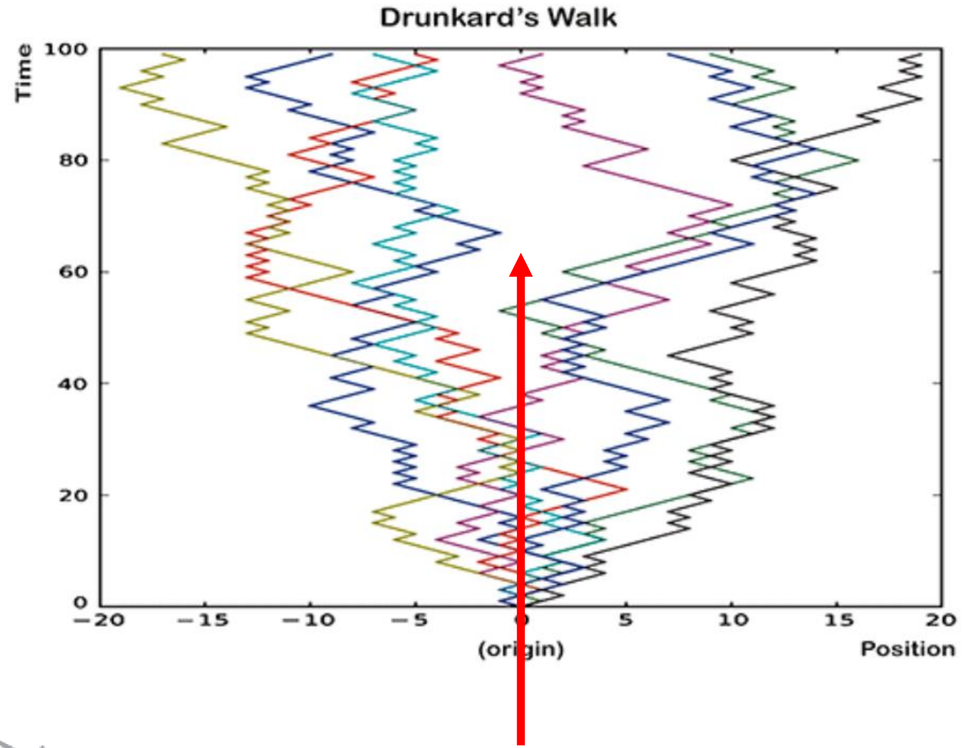
- Oxygen diffusion is increasingly limited by accumulating corrosion product.
- So on average, pit depth increases at a decreasing rate, typically as a fractional power of time.
- $Depth = A \cdot time^b$
- Tank-to-tank variation is large.



Forecasting Component Failure

- Actuarial methods are fine when there is a massive amount of data on component lifetimes.
- When data are sparse and expensive we need a good statistical model of component lifetimes.
- The gamma diffusion process is a productive way to model diffusion limited corrosion– but other models can be used such as the standard linear model





Mean value
of all possible
paths is zero

1D, 2D or 3D

Gamma Process Pit-depth Depth Model

Mean depth at year t (mils):

$$\mu(t) = t_{ref} \cdot A\left(t/t_{ref}\right)^b$$

Reference time: t_{ref} *(years)*

Corrosion rate at t_{ref} *(mils/yr):*

$$A = \mu\left(t_{ref}\right)/t_{ref}$$

Power parameter: b (unitless)

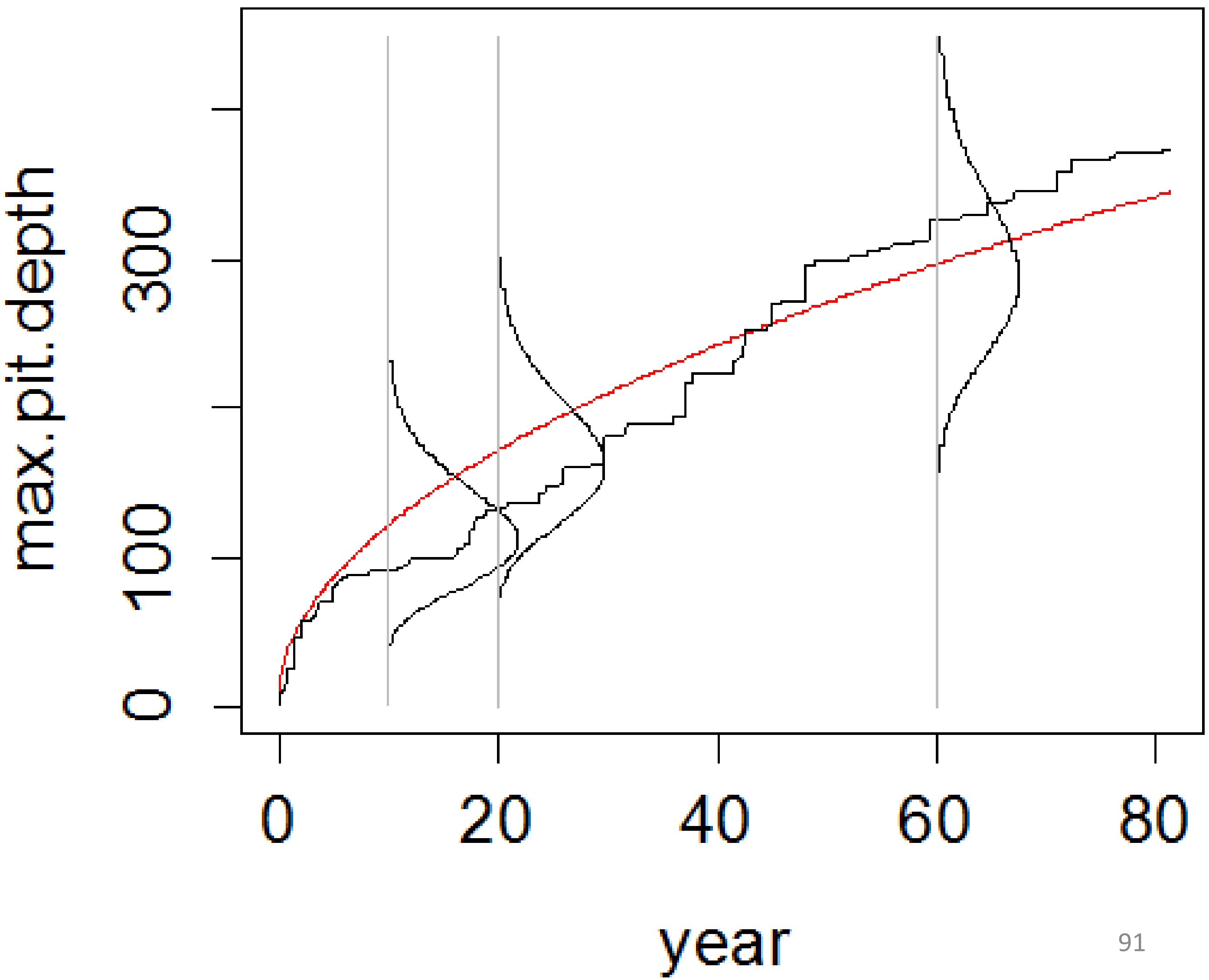
Noise intensity: s *(mils/yr)*

Standard deviation: $\sqrt{\mu(t) \cdot s}$

Distribution: gamma with

$$shape = \mu(t)/s$$

$$scale = s$$



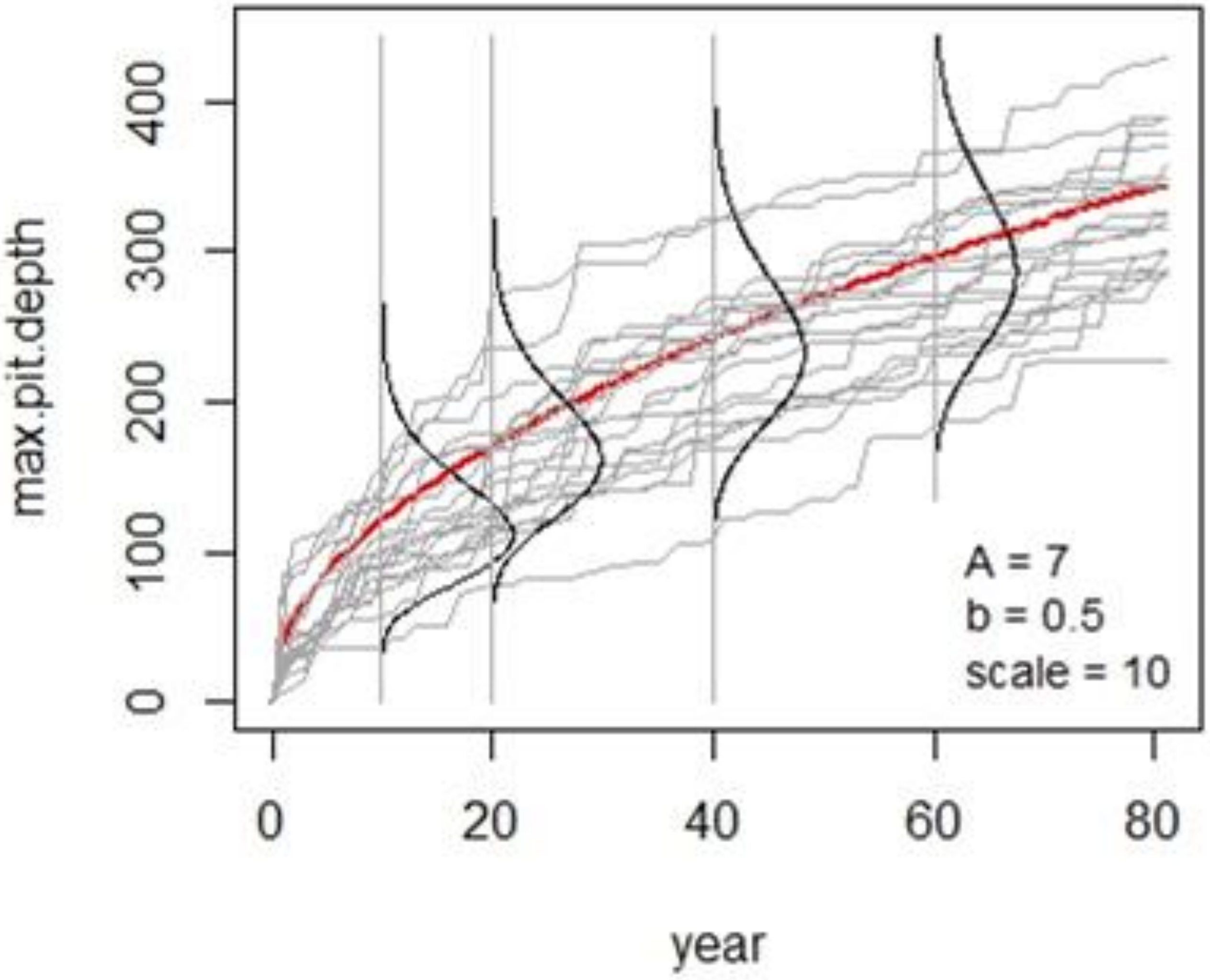
Simulating Fine-Grained Corrosion Histories

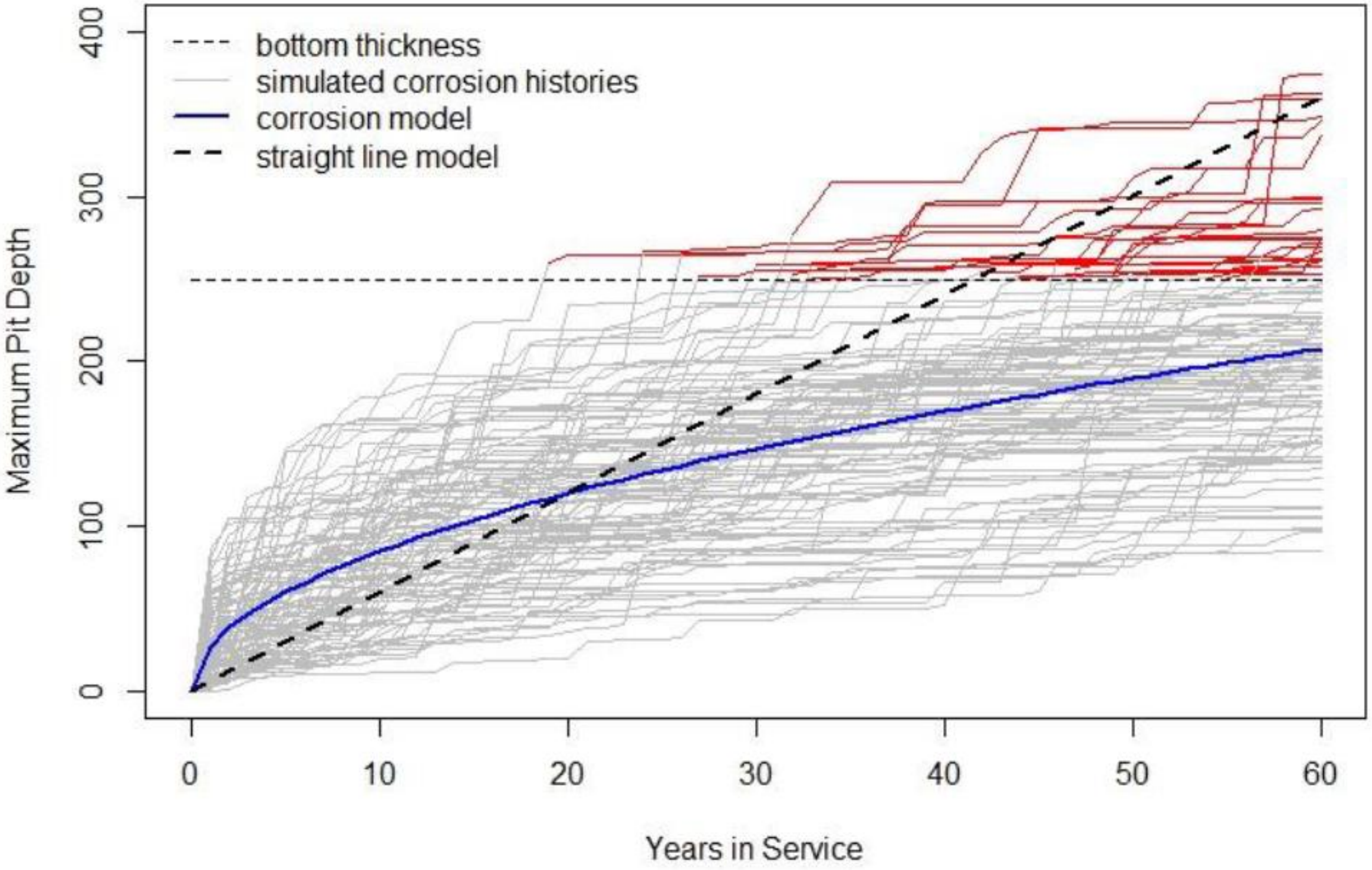
In this example,

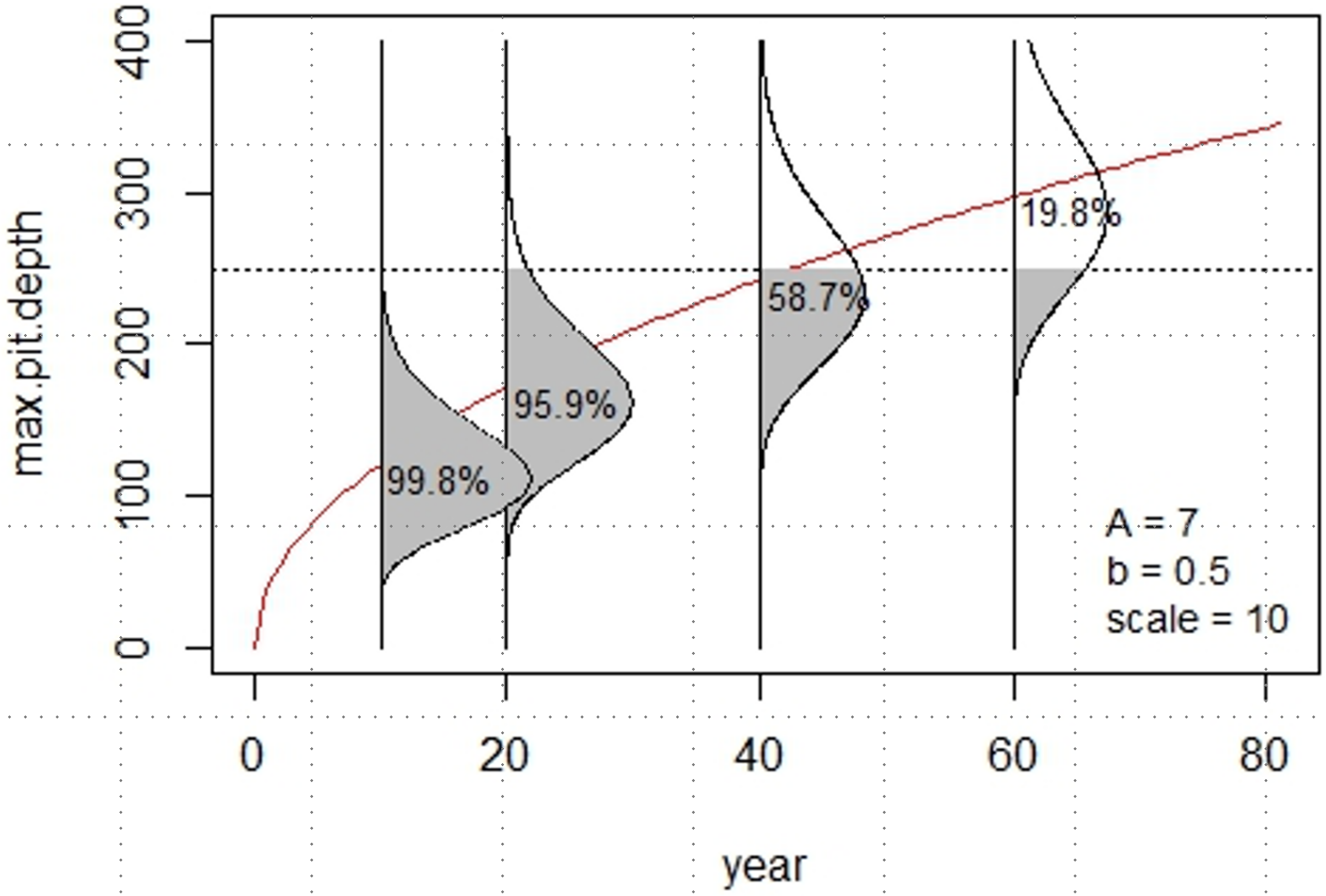
$$t_{ref} = 20\ yrs,$$

so mean pit depth at 20 yrs is,

$$A \cdot 20 = 140\ mils$$




bottom thickness
simulated corrosion histories
corrosion model
straight line model
Maximum Pit Depth
0
100
200
300
400
0
10
20
30
40
50
60
Years in Service

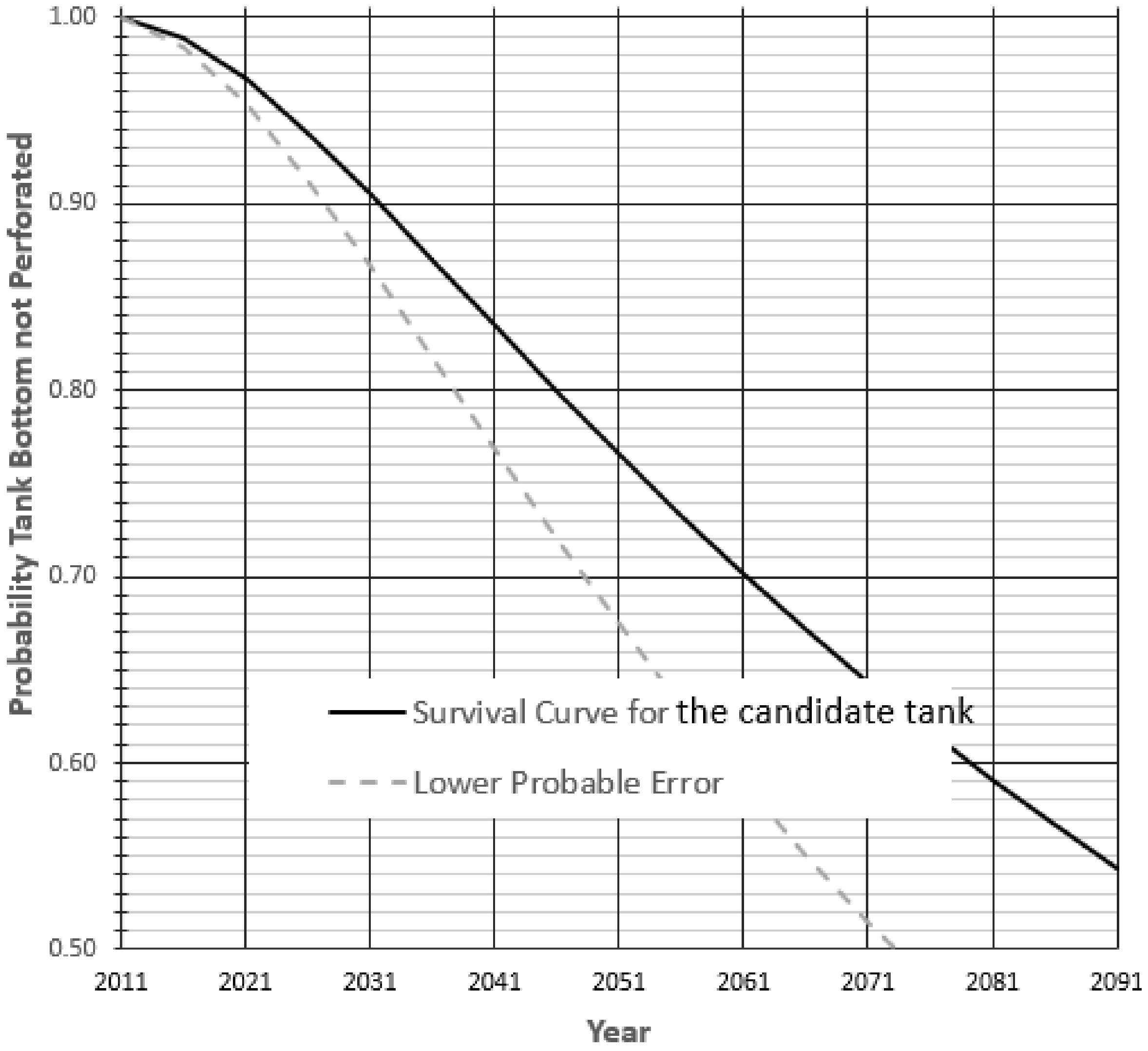


year	Surviving %
0	100
10	99.8
20	95.9
40	58.7
60	19.8

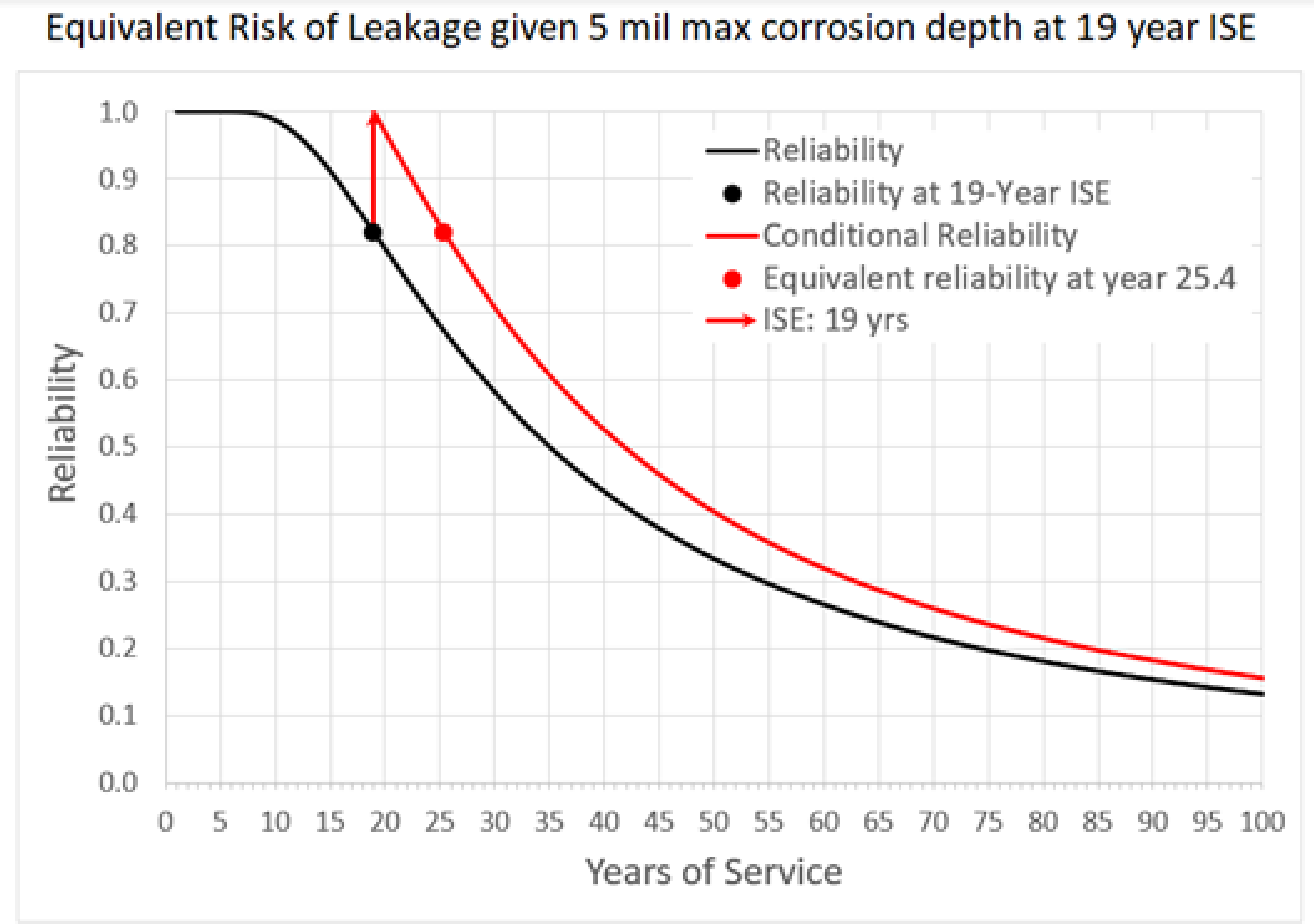
Estimated Survival Function

There's 75% confidence that the true survival curve is above the dotted line. So the chance of surviving 20 years could be less than 90%.

We need more and better data on factors that influence corrosion to reduce that uncertainty.



Equivalent Survival Time



Conclusions

Risk Based Inspection hurdles

- Framing critical
- RBI can be examined for validity by criteria on slide 34
- Precision in terminology (i.e. risk=probability, risk=combined consequence and probability)
- May require expert assistance to review
- Like statistics RBI can lie – caveat emptor
- But like statistics there can be super value not achievable by any other means

Any Questions?

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