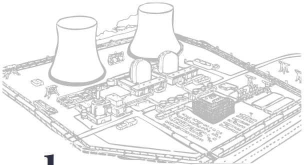


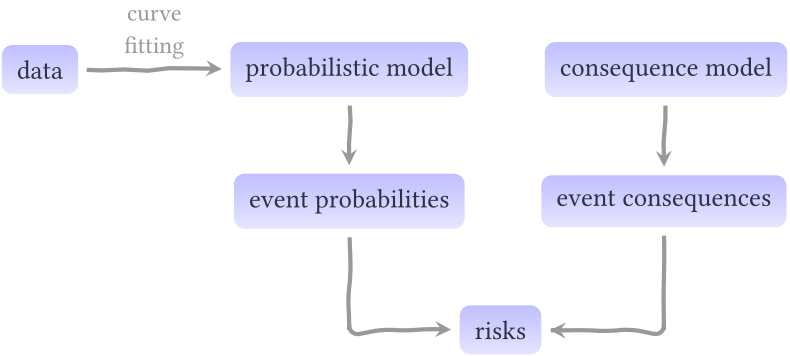
Operational Experience Feedback and reliability data

Eric Marsden

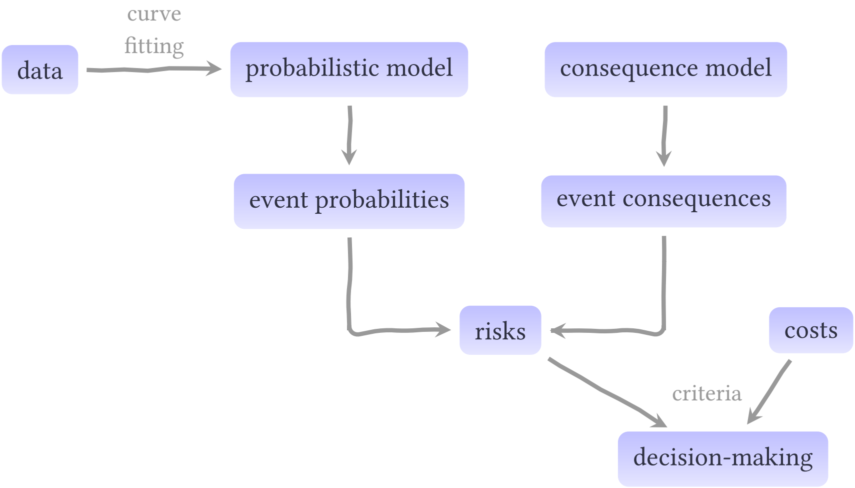
<eric.marsden@risk-engineering.org>

> *Good judgment comes from experience. Experience comes from bad judgment.*
>
> *– Nasrudin*

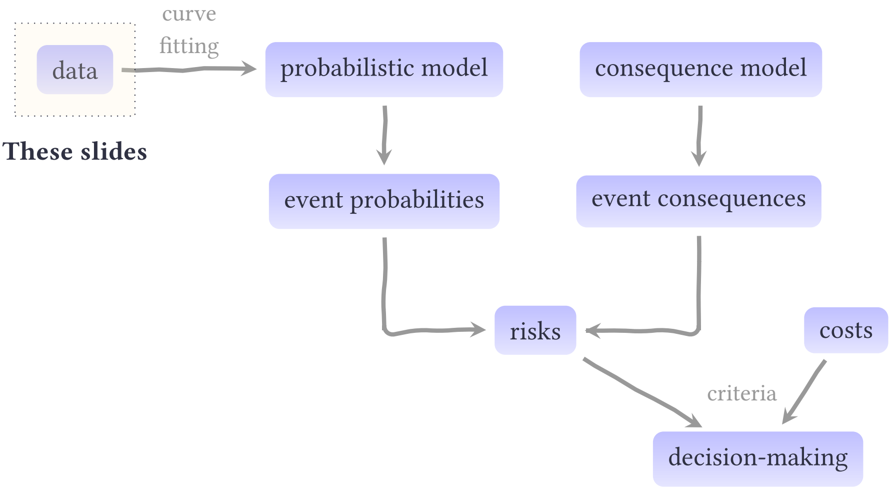
Where does this fit into risk engineering?



Where does this fit into risk engineering?



Where does this fit into risk engineering?



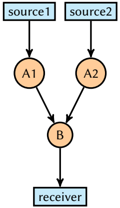
Use of reliability data

- **Managing maintenance**:
  - forecasting cost of maintenance during system design
  - preventive maintenance: stock management
- **Component design**:
  - better knowledge of the reliability and the failure modes of your products
- **Risk analysis**:
  - analyze and predict the occurrence of major accidents
  - supply quantitative information used in safety cases & QRA

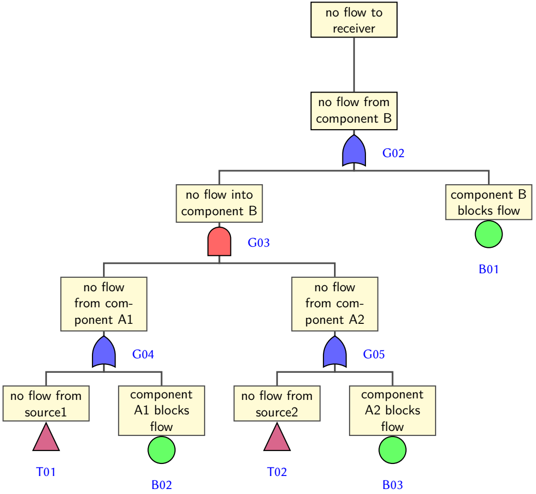
Use for safety cases

- ▷ Framework: use of **probabilistic methods** in **safety cases** or QRAs
- ▷ The top event whose probability we wish to estimate is rare
  - little statistical information on frequency is available
- ▷ One possible approach to quantifying probability:
  - decompose the rare event into a chain of events that have an observable frequency
  - determine, for each initiating event, the accident sequences that may lead to the top event
  - quantify the frequency of the initiating event
  - quantify the availability of the preventive and protective barriers

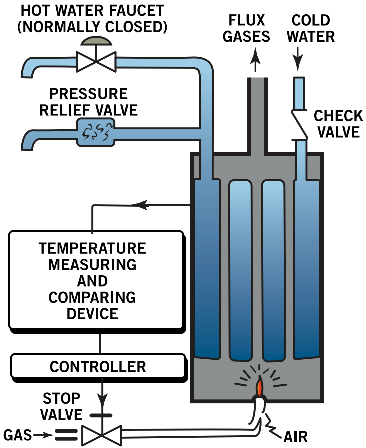
Fault tree

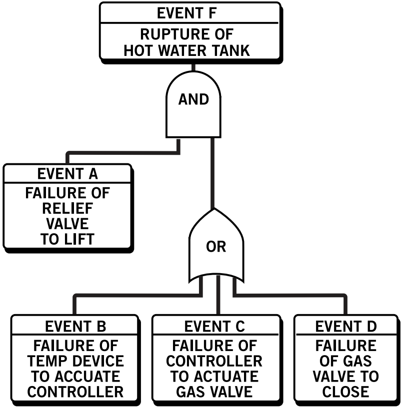


system flow diagram



Fault tree



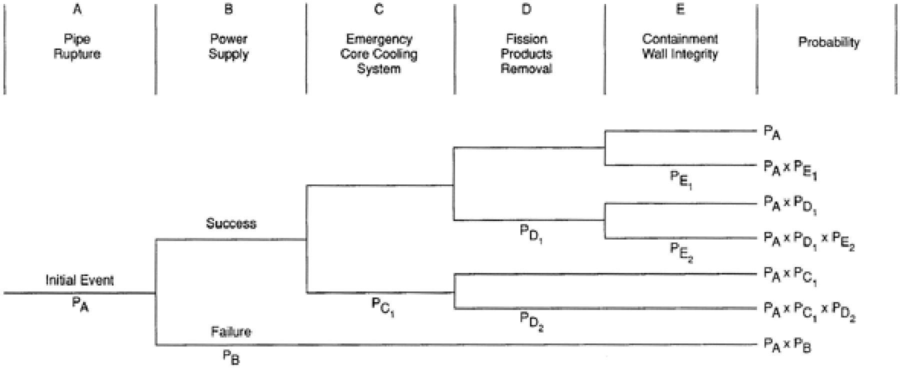


BOOLEAN EXPRESSION

$$F = A\,(B + C + D)$$

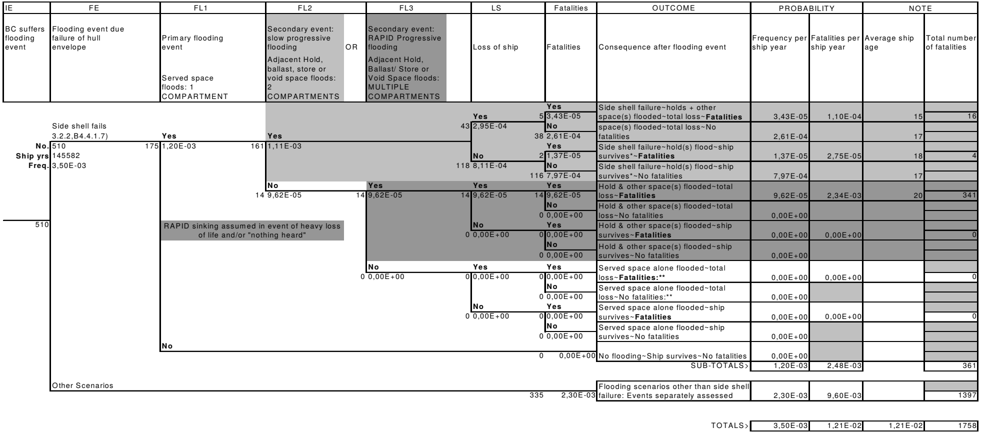
Source: adapted from C. Eckberg, WS-133B Fault Tree Analysis Program Plan, Boeing Co., 1963, by T. Wellock, public domain

Event tree

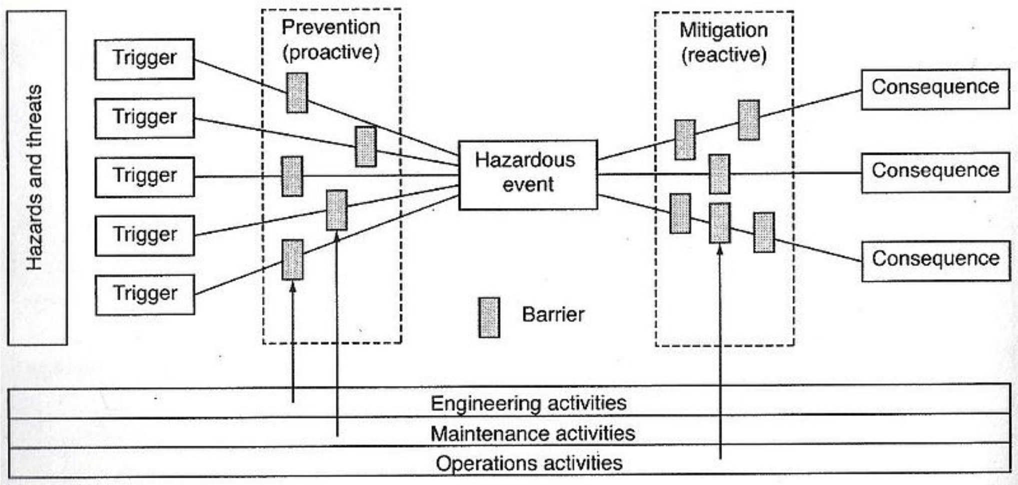


Source: `oecd-nea.org/brief/brief-08.html`

Event tree: hull failure example



Bow tie diagram



Data sources

- Databases based on accidents on units identical to yours
  - good level of representativity
  - requires a large number of similar equipment observed over a long time period
- Tests of equipment in similar conditions to expected operation
  - very expensive; difficult to "accelerate time"
  - difficult to reproduce all details of operational conditions (temperature stress, vibration, corrosion, impact of maintenance…)
- Reliability data collected in the same industry
  - doesn't account for the specifics of your equipment, your maintenance policy
- "Generalist" data sources
  - don't account for the differences between industrial sectors
- Academic/technical literature
- Expert judgment
  - subjective, but allows the specificity of your plant/equipment to be taken into account

RISK ENGINEERING

Reliability of reliability data

IEC 61511:2016, clause 11.9.3 states

> *The reliability data used when quantifying the effect of random failures shall be credible, traceable, documented, justified and shall be based on field feedback from similar devices used in a similar operating environment.*

IEC 61511 standard *Functional safety - Safety instrumented systems for the process industry sector* provides good engineering practices for the application of safety instrumented systems in the process sector. It's a sector-specific standard based on the generic framework proposed in the IEC 61508 *Functional safety of electrical/electronic/programmable electronic safety-related systems* standard.

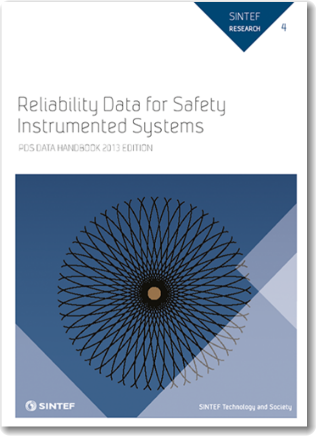
Reliability databases

- **OREDA**: collection of reliability data on offshore equipment, managed by petroleum companies
  - detailed information on failure rates, repair times, failure modes
- NPRDS (Nuclear Plant Reliability Data System): data on reliability of equipment used in civil nuclear power plants in the USA
- *Base Process Equipment Reliability Database* (PERD) of the Center for Chemical Process Safety (CCPS), AIChE
- Hydrocarbon Release Database (HCRD) compiled by UK HSE
- ESReDA *Handbook on Quality of Reliability Data* published by DNV
- The *Red Book* published by TNO, Dutch R&D organization

Reliability databases

Reliability Data for Safety Instrumented Systems

Handbook with reliability data estimates for components of control and safety systems, based on the work of the PDS Forum.
Data dossiers for input devices (sensors, detectors, etc.), control logic (electronics) and final elements (valves, etc.) are presented, including data for subsea and drilling related equipment.



Example: applications of OREDA data

Main uses of OREDA reliability data are in the following areas:

Discipline	*Typical Applications*
Design / Engineering	**Production availability and reliability management:** • Production availability estimates (e.g. system performance simulation) • Design optimisation (e.g. evaluate justification for redundancy) • Reliability engineering (e.g. FMECA, equipment selection) **Safety and risk:** • Estimate probabilities of critical events • Estimate survival time and system unavailability for safety-critical items • Analysis (SIL) of instrumented safety systems (ref.: IEC 61508/ 61511)
Operation/ Maintenance	**Asset management:** • Benchmarking/ KPI parameters • Production assurance and decision-support **Reliability monitoring and maintenance optimisation**: • Optimise maintenance intervals and spare part storage • Integrated operations • Analyse reliability characteristics (e.g. lifetime distribution, failure mechanisms) • Reveal weak designs that need modification or redesign (feedback to manufacturer)
Typical analyses where data are used	Quantitative risk assessment, reliability centred maintenance, reliability based inspection, life cycle cost, production availability, safety integrity level (SIL), spare parts storage, manning resources, FMEA-analysis, benchmarking/ KPI assessment, root cause analysis, (ref.: ISO 20 815)

Source: OREDA brochure, at oreda.com

Example: the OREDA taxonomy

The following types of equipment are covered in the OREDA database:

Rotating machinery	**Mechanical equipment**	**Control & Safety**	**Subsea equipment**
Combustion engines	Cranes	Control Logic Units	Control systems
Compressors	Heat exchangers	Fire & Gas detectors	Dry tree riser
Electric generators	Heaters and Boilers	HVAC	El. power distribution
Electric motors	Loading arms	Input devices	Flowlines
Gas turbines	Swivels	Nozzles	Manifolds
Pumps	Turrets	Power transformers	Pipelines
Steam turbines	Vessels	UPS	Production risers
Turboexpanders	Winches	Valves	Running tools
		Frequency converters	Subsea pumps
		Switchgear	Subsea vessels
			Templates
			Wellhead & X-mas trees

Source: OREDA brochure, at `oreda.com`

Example: an OREDA datasheet

Taxonomy no		Item		
2.2.2.13		Electric Equipment Electric motors Pump Oily water treatment		
Population	**Installations**	**Aggregated time in service (10^6 hours)**		**No of demands**
		Calendar time *	**Operational time †**	
9	1	0.3039	0.2406	

Failure mode	No of failures	Failure rate (per 10^6 hours). Lower	Mean	Upper	SD	n/τ	Active rep.hrs	Repair (manhours) Min	Mean	Max
Critical	**15***	**30.42**	**49.36**	**76.00**	**49.36**	**49.36**	**9.8**	**3.0**	**18.3**	**39.0**
	15†	**38.42**	**62.34**	**95.99**	**62.34**	**62.34**				
Breakdown	3*	2.70	9.87	25.52	9.87	9.87	11.2	8.0	19.7	27.0
	3†	3.41	12.47	32.23	12.47	12.47				
Fail to start on demand	3*	2.70	9.87	25.52	9.87	9.87	8.2	3.0	14.3	37.0
	3†	3.41	12.47	32.23	12.47	12.47				
Spurious stop	2*	1.17	6.58	20.72	6.58	6.58	4.0	5.0	5.5	6.0
	2†	1.48	8.31	26.16	8.31	8.31				
Structural deficiency	3*	2.70	9.87	25.52	9.87	9.87	10.8	4.0	21.7	39.0
	3†	3.41	12.47	32.23	12.47	12.47				
Vibration	4*	4.49	13.16	30.13	13.16	13.16	12.0	7.0	24.0	38.0
	4†	5.67	16.62	38.05	16.62	16.62				
Degraded	**10***	**17.85**	**32.91**	**55.81**	**32.91**	**32.91**	**6.4**	**3.0**	**11.9**	**32.0**
	10†	**22.55**	**41.56**	**70.49**	**41.56**	**41.56**				
Overheating	1*	0.16	3.29	15.62	3.29	3.29	3.0	6.0	6.0	6.0
	1†	0.21	4.16	19.72	4.16	4.16				
Structural deficiency	5*	6.48	16.45	34.60	16.45	16.45	7.4	3.0	13.4	32.0
	5†	8.19	20.78	43.70	20.78	20.78				
Vibration	4*	4.49	13.16	30.13	13.16	13.16	5.5	10.0	11.0	12.0
	4†	5.67	16.62	38.05	16.62	16.62				
Incipient	**3***	**2.70**	**9.87**	**25.52**	**9.87**	**9.87**	**2.0**	**2.0**	**2.0**	**2.0**
	3†	**3.41**	**12.47**	**32.23**	**12.47**	**12.47**				
Minor in-service problems	3*	2.70	9.87	25.52	9.87	9.87	2.0	2.0	2.0	2.0
	3†	3.41	12.47	32.23	12.47	12.47				
Unknown	**1***	**0.16**	**3.29**	**15.62**	**3.29**	**3.29**	**4.0**	**4.0**	**4.0**	**4.0**
	1†	**0.21**	**4.16**	**19.72**	**4.16**	**4.16**				
Unknown	1*	0.16	3.29	15.62	3.29	3.29	4.0	4.0	4.0	4.0
	1†	0.21	4.16	19.72	4.16	4.16				
All modes	**29***	**68.27**	**95.44**	**130.12**	**95.44**	**95.44**	**7.9**	**2.0**	**14.5**	**39.0**
	29†	**86.22**	**120.53**	**164.34**	**120.53**	**120.53**				
Comments										

Source: oreda.com

Example: datasheet for flange, DNV guidance

Process Equipment Leak Frequencies

Rev.:	1
Date:	26/9/2012
Source:	HCRD 10/92 – 03/10

Equipment Type: **Flange**

Frequency Data:

Equipment Size	Category	Total	Full Pressure	Zero Pressure
10 in	1 - 3 mm	8.880E-05	7.801E-05	1.884E-06
	3 - 10 mm	3.252E-05	2.731E-05	1.430E-06
	10 - 50 mm	1.176E-05	9.362E-06	1.225E-06
	50 - 150 mm	2.077E-06	1.560E-06	5.388E-07
	> 150 mm	7.110E-06	5.780E-06	1.779E-06
	Total	1.423E-04	1.220E-04	6.856E-06
14 in	1 - 3 mm	1.088E-04	9.559E-05	4.148E-06
	3 - 10 mm	3.984E-05	3.346E-05	3.148E-06
	10 - 50 mm	1.440E-05	1.147E-05	2.696E-06
	50 - 150 mm	2.544E-06	1.912E-06	1.186E-06
	> 150 mm	7.360E-06	5.956E-06	3.316E-06
	Total	1.729E-04	1.484E-04	1.449E-05
20 in	1 - 3 mm	1.379E-04	1.218E-04	1.454E-05
	3 - 10 mm	5.051E-05	4.263E-05	1.103E-05
	10 - 50 mm	1.826E-05	1.462E-05	9.450E-06
	50 - 150 mm	3.226E-06	2.436E-06	4.158E-06
	> 150 mm	7.724E-06	6.218E-06	1.037E-05
	Total	2.176E-04	1.877E-04	4.955E-05

Source: issuu.com/dnv.com/docs/failure_frequency_guidance_process_

RISK ENGINEERING

Example: complexity of data on "leak" event

Release Type			Total	GAS LEAK	OIL LEAK	CONDEN-SATE LEAK	2-PHASE LEAK	NON-PROCESS
Zero Pressure leak			6%	6%	7%	7%	2%	8%
Full pressure leak	Limited leak		48%	33%	75%	64%	67%	53%
	Full leaks	ESD isolated	43%	57%	16%	27%	30%	36%
		Late Isolated	3%	4%	2%	2%	1%	3%
Total			100%	100%	100%	100%	100%	100%

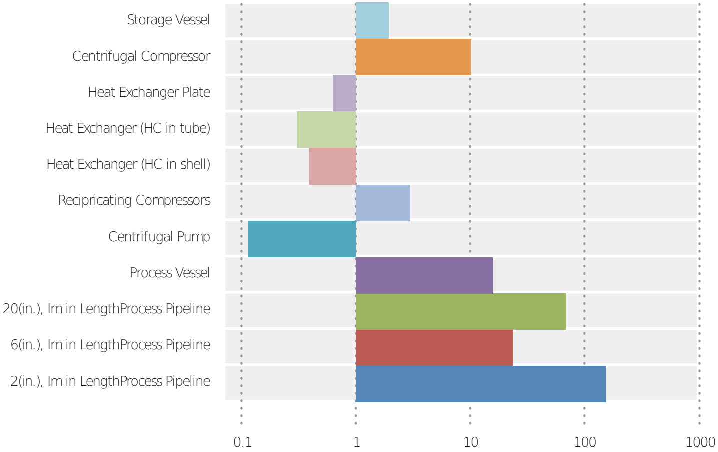
Leaks may be of very different natures:

- full pressure or partial pressure
- frequency dependent on pipe diameter
- impact dependent on success of emergency shutdown (ESD) valves

Source: issuu.com/dnv.com/docs/failure_frequency_guidance_process_

RISK ENGINEERING

Example: uncertainty on initiating event frequency



Comparison between DNV guidance and Belgium government data

Source: issuu.com/dnv.com/docs/failure_frequency_guidance_process_

Example: FIDES

- ▷ Reliability database for COTS electronic components
  - aeronautics and defence applications
  - detailed data on the impact of mechanical and thermal stress, on maintenance procedures; impact of design and quality assurance processes
  - data broken down by component supplier
  - also describes a reliability auditing method which allows the factors with most impact on reliability to be identified
- ▷ Aims to replace old standard MIL-HDBK-217F, which is overly pessimistic for COTS components
- ▷ Web: `fides-reliability.org`

COTS: Commercial Off-The Shelf

Difficulties

- Pulling together information from **heterogeneous sources**
- Integrating the influence of numerous factors on reliability
  - operating conditions: vibration, product characteristics, climate
  - inspection and maintenance policies
  - technological evolution
- Integrating **uncertainty** from different data sources
  - level of representivity increases with the number of observations
  - safety cases: the level of risk estimated generally comprises a factor of 10 of uncertainty

RISK ENGINEERING

Image credits

- Bow tie on slide 5: commons.wikimedia.org/wiki/File:Bow-tie_diagram.jpg, Free Art Licence
- Fault tree on slide 6: texample.net/tikz/examples/fault-tree, CC BY licence

Further reading

- IOGP report *Guide to finding and using reliability data for QRA*, available at `www.iogp.org`
- Booklet *Failure frequency guidance: process equipment leak frequency data for use in QRA* by DNV
- Risø technical report *Reliability Databases: State-of-the-Art and Perspectives*, available at `orbit.dtu.dk`

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