NE529
RISK ASSESSMENT
Fault & Event Trees
5

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Learning objectives

Chapter 14, 16 in the book

Skipping decision trees in chapter 12 for later

Quantifying risk using fault and event trees

Identifying where these tools fall short

See case studies in OER

Learning nodes

Defense in depth

Getting failure rate data

Failure over lifecycle

Pyroprocessing failures

Data perception

Monte Carlo analysis

Human error

Delphi technique

Event tree analysis
Fire
Pump
Gas fracking
LOCA
Limitations

Fault tree analysis
TAM airline
Building the fault tree
Doorbell
Lighting the room
Car crash
Counterexample
Limitations

How likely is it to happen?

Fault and event trees require frequency analysis for initiating events

We need to establish frequencies for a PRA

Data data data data data

Data doesn't magically appear, however

We've been talking about the pyroprocessing system

Troubles with scaling up from the laboratory experiments

Expert judgment only goes so far to where you're just making it up

Then any analysis is effectively meaningless

Defense in depth

Multiple barriers reduce risk

A well designed system has multiple barriers that are implemented to stop or reduce consequences of events

The probability that an accidental event will lead to unwanted consequences will therefore depend on whether these barriers are functioning

Event and fault trees can then also be used as a design tool

Design, procedural weaknesses can be identified

Fault & event trees are needed together for PRA

Explicitly shows all the different relationships necessary to result in the top event

Thorough understanding is obtained of the logic and basic causes leading to the top event

Systematic analysis of the logic and basic causes leading to the top event

Provides a framework for thorough qualitative and quantitative evaluation of the top event

Input for Farmer's chart

Getting failure rate data

Failure rate data is probably the most important

We need to know when equipment is going to fail for basically everything

As well as the probability distributions

We can also just buy equipment and test it

Manufacturer might have the data

Though most entities outside of academics don't really have the time

There is a 30 year test bed for clay and radioactive waste in France at the repository site

Because the repository is completely new and unprecedented

We need to model behavior for at least 1000 years

Some data can be obtained from the manufacturer

Historical data (e.g., MCNP error messages)

Government and military handbooks

Reliability Information Analysis Center

U. S. Energy Information Administration

Failure over lifecycle

We've shown the bathtub curve

Airplanes – Like a tylenol with wings!

Failure Knowledge Database

Table 8.2 from the book

Failure rate example

Sorting data can present a picture of what is going on

First, they sorted by failure

I then sorted by temperature and hours of operation

Obervations?

Failure rate $- \lambda = \frac{20}{130300} = 1.53 \times 10^{-4}$ per hour

Mean Time Before Failure (MTBF) $- \theta = \frac{1}{\lambda} = 6515$ hours

Assumes all systems fail in the same way

Above 100

$\lambda = 2.14 \times 10^{-4} \, /h$
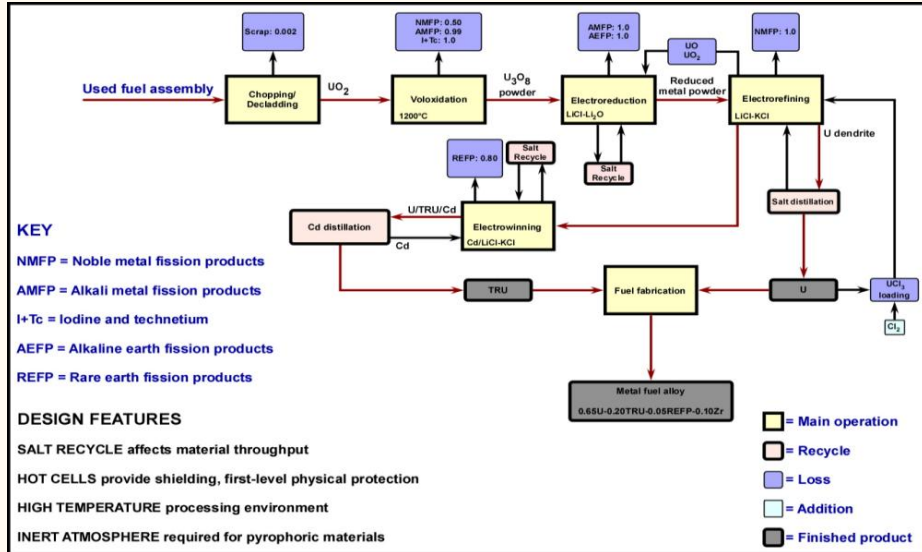
$\theta = 4675 \, h$

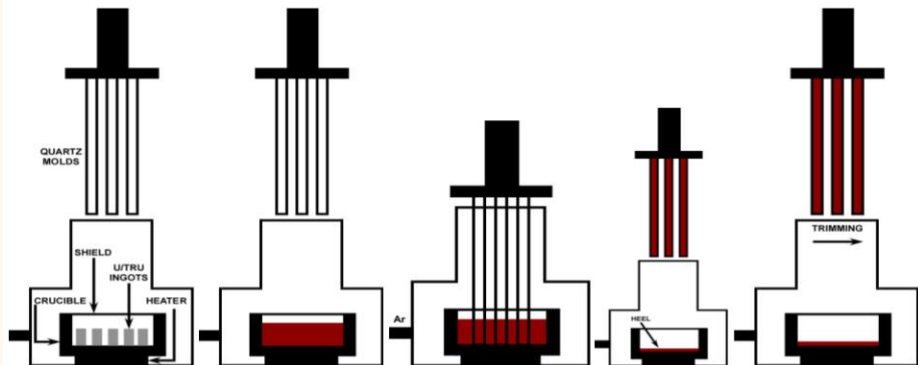**Below 100**
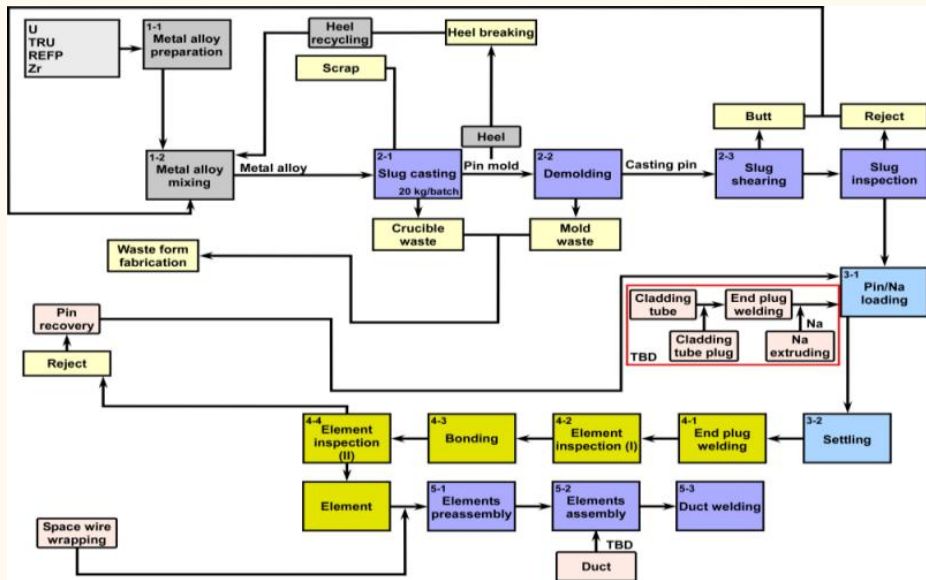
$\lambda = 1.08 \times 10^{-4} \, /h$

$\theta = 9275 \, h$

Pyroprocessing failures

Multiple failures, much more complexity

Getting material into the crucible

Heater fails to sufficiently melt all the metal

Vacuum cannot be induced

Molds get stuck or break

Cannot remove heel

If one component fails the equipment fails

Systems do not fail in the same way

Data perception

It is important to consider how to frame failure data or what the data actually is

Space shuttle program used as an example 8.1.9

At the time, failure rate was 1 in 25

2 catastrophic failures in 132 flights currently however

Each shuttle operated for different number of missions with varying operating time (table 8.5)

Total of 30946 operating hours = 4.5 operating years

1 failure in 15000 operating hours for 5 different shuttles

There is not any normalization in terms of failures per operating year

Monte Carlo analysis

Monte Carlo simulation is very famous, but not fancy

Generates values of a random variable based probability distributions

Applied to wide variety of complex problems involving random behavior

$$R(T) = e^{-(\frac{T}{\eta})^{\beta}} \tag{1}$$

$U \equiv R(T)$ – U is a random number

$$T = -\eta(\ln U)^{\frac{1}{\beta}} \tag{2}$$

When $\beta = 1$ we have the exponential distribution

Weibull pdf
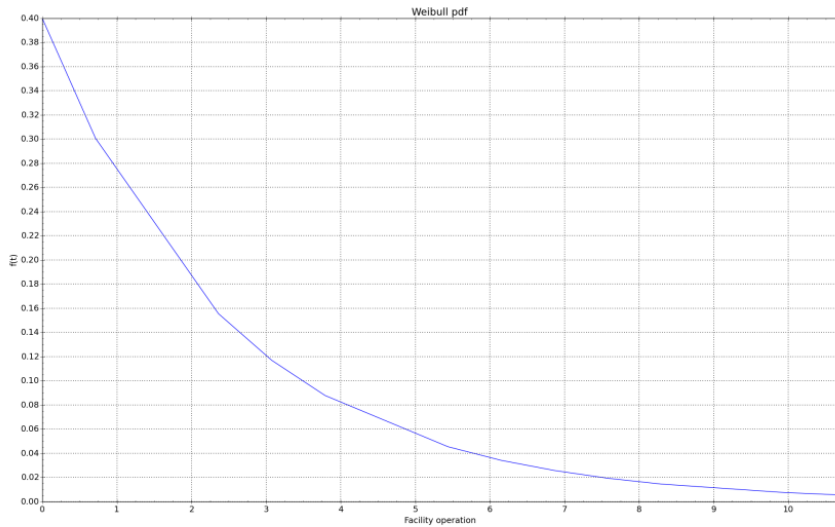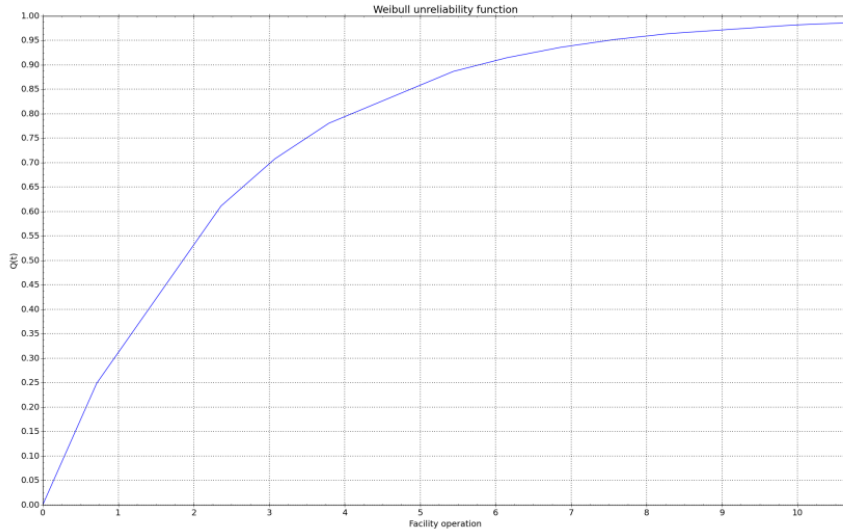
Weibull unreliability function

$$Q(t) = 1 - R(t) \tag{3}$$

$$Q(t) = 1 - e^{-(\frac{t}{\eta})^{\beta}} \tag{4}$$

Assume $\beta = 1$ for general failures

$\lambda = 0.4$ per day

Monte Carlo simulates area under the curve at t = T

A 'hit' is an equipment failure

```
campaign:  1
operation time:  0.7144
failure probability:  0.2486
failure test:  0.1808
failure

campaign:  2
operation time:  3.0762
failure probability:  0.2486
failure test:  0.6888
no failure
```
New equipment is installed, so there is new distribution

Early times the likelihood of failure is low

Later times it is higher because equipment is older

Failure testing repository

Human error

Human error probability is difficult to quantify

Because people generally behave stupidly even sober

Or, different responses are elicited by people in the same environment

What would be examples of human errors that could be quantified?

Astronaut behavior in normal conditions and critical conditions

Psychological stress

Performance shaping factors account for human response to stressors

hot/cold

noise level

light level (my office is dark)

vibration

ergonomics

experience and training

management

time

stress

equipment design/human machine interface

Delphi technique

Initially developed in the 1950s by Helmer and Dalkey at Rand Corp

Controlled opinion feedback

. . . to solicit expert opinion to the selection, from the point of view of a Soviet strategic planner, of an optimal U.S. industrial target system and to the estimation of the number of A-bombs required to reduce the munitions output by a prescribed amount.

Delphi can be used to validate research outcomes

Impact analysis of changes to the international business environment

Identify national park selection criteria

Develop a taxonomy of organizational mechanisms

Develop rules for a ceramic casting process

Examine and explain how recruitment message specificity influences job seeker attraction to organizations

Well suited to rigorously capture qualitative data or when knowledge is incomplete

Assemble a panel of experts

Mission
Build consensus with a panel
Aircraft maintenance tasks - missing structural anomalies on an inspection (8.1.12)
For composite structural material

Select panel and eliminate bias
Airline inspectors (regulations)
Structural experts from manufacturer(s)
Repair/mechanics experts

Calibrate the panel on the topic
Historical data on detecting cracks in the structure (not the same but close)
Inspection, procedures, etc.
In book example, estimated probabilities are presented

Present the parameters of the task to evaluate

Qualitatively assess the problem

Discuss any direct historical experience from inspectors, mechanics

What kind of structural anomalies would be present?

Perform the initial round of discussions on the error probability

Detecting anomalies 2" or less

Establish nominal probabilities for each class of crack

Discuss the results and iterate

Repeat until consensus reached for each class

Develop performance shaping factors

What factors would lower the probability of the task?

Lack of training; experience

Environmental conditions; lighting, etc.

Time to inspect

Establish the conditions where the task can be achieved satisfactorily

For use in human reliability analysis

Event tree analysis

An event tree is a graphical representation of a series of possible events in an accident sequence

Each event is either a fail or success with associated frequency

Assumes events occur in sequence to a final state

Event sequences follow from some initial event of interest, usually a component failure

Downstream events follow from original event and subsequent events of other components

Initiating event $\rightarrow$ event 1 $\rightarrow$ event N $\rightarrow$ Final State

We covered ways to assess frequency - now we ask 'What are the consequences?'

We start with the initiating events and work to what eventually happens

Event trees are used to describe the major events in the accident sequence

Each event can then be further analyzed using a fault tree

Event trees are accident sequence development tools

We talked about WASH1400 that basically invented for nuclear power plants

NRC handbook

Figure 12.3 in the book

Event trees are essential to PRA

Visualize event chains following an accidental event

Visualize barriers and sequence of activation

Good basis for evaluating the need for new/improved procedures and safety functions

Draws on prior PRAs, etc., to determine initiating events

So it's a natural progression into PRA I,II,III

Examples

Fire

Initiating event	Event 1	Event 2	Final states
Fire	Fire suppression	Alarm alert to fire department	
	Success		Minimal damage
Start			
		Success	Moderate damage
	Fail		
		Fail	Severe damage

Calculate probabilities and losses

Pumps

Pump valve maintenance	Detected by engineer	Temporary flange installed, parallel pump	Gas alarm	Explosion	SEQ #	End State
					1	Safe
					2	Unsafe, gas released
		P3A			3	Small spill, injury
P1			P4	P5A	4	Small spill, fire, injury
					5	Safe
	P2				6	Unsafe, gas released
		P3B			7	Small spill, injury
			P4	P5B	8	Large Spill, fire, injury

Fracking

High pressure gas in formation	Annular Cement & shoe track	Hydrostatic pressure	Inner pipe	Leak detected by system	Leak detected by rig crew	Mud gas separator	Vapour cloud	Ignition source	Blowout preventer	Sequence #	End State
										11a	Safe
										12a	Safe
										13a	Safe
										14a	Safe (Gas leaked but vented to safe location)
						P6				15b	Unsafe (Gas leaked and vented onto rig)
							P7			16b	Unsafe (Gas leaked, vented onto rig and entered engine room)
								P8		17c	Small fire
									P9	18c	Fire and major accident
P0										19a	Safe (Gas leaked but vented to safe location)
	P1					P6				20b	Unsafe (Gas leaked and vented onto rig)
		P2					P7			21b	Unsafe (Gas leaked, vented onto rig and entered engine room)
			P3					P8		22c	Small fire
				P4					P9	23c	Fire and major accident
					P5					24b	Unsafe (Gas leaked and vented onto rig)
							P7			25b	Unsafe (Gas leaked, vented onto rig and entered engine room)
								P8		26c	Small fire
									P9	27c	Fire and major accident

Description of the events

0: High pressure gas in rock formation;
1: Annular cement and shoe track barriers fail to isolate gas;
2: Hydrostatic pressure does not hold and entered the well;
3: Failure of inner pipe;
4: Gas leak is not detected by the system;
5: Gas leak is not detected by rig crew;
6: Mud gas separator fails to control the release;
7: HVAC fails to shut down, transfers more gas-rich mixture, and vapour cloud forms;
8: Ignition source, e.g., over-speed engine;
9: Blowout preventer fails to be activated.

LOCA

Figure G-1 Small-break loss-of-coolant accident (SLOCA) event tree

SMALL LOCA	CONDITIONAL LOOP GIVEN A LOCA	REACTOR TRIP	FEEDWATER	HIGH PRESSURE INJECTION	FEED AND BLEED	SECONDARY COOLING RECOVERED	RCS COOLDOWN	LOW PRESSURE INJECTION	RESIDUAL HEAT REMOVAL	LOW PRESSURE RECIRC	HIGH PRESSURE RECIRC	#	End State (Phase - CD)
IE-SLOCA	COND-LP-SL	RPS	FW	HPI	FTF-SYS-NLOSP FAB	FTF-SYS-NLOSP SSCR	SSC	LPI	FTF-SYS-NLOSP RHR	LPR	FTF-SYS-NLOSP HPR	FTF-SYS-NLOSP	
												1	OKAY
												2	OKAY
												3	MELTDOWN
												4	OKAY
												5	MELTDOWN
												6	OKAY
												7	MELTDOWN
												8	OKAY
												9	MELTDOWN
												10	MELTDOWN
												11	MELTDOWN
												12	OKAY
												13	OKAY
												14	MELTDOWN
												15	OKAY
												16	OKAY
												17	OKAY
												18	MELTDOWN
												19	OKAY
												20	MELTDOWN
												21	MELTDOWN
												22	MELTDOWN
												23	Event

Positive X%

Negative Y%

Limitations

But event trees have limitations

No standard for the graphical representation of the event tree

Only one initiating event can be studied in each analysis

Easy to overlook subtle system dependencies

Not well suited for handling common cause failures (only independent events)

Practical only when events can be ordered in time (chronology of events is stable)

Does not show acts of omission

Difficult to represent interactions among events

Difficult to consider effects of multiple initiating events

So we need other tools for comprehensive risk assessment

Fault tree analysis

Fault tree analysis is applied to identify areas to mitigate or prevent risk at all phases of system life cycle

Little things lead to catastrophic failures

Japan airlines

But before risk assessment was invented, most likely from common cause failures

Advancements in technologies increased complexity and necessitated detailed safety analysis

Developed by Bell Telephone Laboratories (1962) for Minuteman ICBM (can't find any information)

Though it seems that not formalized as part of risk assessment until WASH1400

Fault trees are a graphic to represent the interaction of failures and other events in a system

Top down, deductive failure analysis

Top event are hazards or failure modes (from event tree) – LOCA, emissions, explosions

Decompose the top event using boolean logic (AND, OR)

Bottom set of events are non-decomposable (basic events)

Identify failures as a malfunction in a component requiring repair (pump shaft)

Identify faults as malfunctions that self-repair once the governing condition is corrected (wet contacts for a switch; dry them)

Undeveloped events are neglected due to low probability or effect on system

FMEA can be used as input

What is the event?

Where does the event occur?

When does the event occur?

Immediate, necessary, and sufficient causes leading to the event

Connect via logic gates (down)

Get down to independent events

For which failure data is obtained (or distributions)

Work back up to compute top event probability

Basic failure event – description – credible? (table 14.5)

Assessing credibility = whether to include the event in the fault tree

Coolant system flushing procedure in the car (14.7.1)

Sprinkler system failure

System design tool

TAM airline

TAM Airlines Flight 3054 overran the runway and crashed into a warehouse (2007)

Use of fault trees for accident analysis with multiple failures (14.7.3)

Airplane are an instructive example because we know a lot about them

Warehouse next to gas station, which exploded

199 fatalities

Rain caused the runway to be wet

Plane overran the runway

Crossed the road(!)

20379 operating hours

Jammed braking device reported the day before (thrust reverser)

Landed and couldn't slow down

Veered left and overshot runway over the major road

Collided with warehouse

Safety issues with insufficient length of the runway (faster speed, more distance to stop)

Thrusters in climb position just before touchdown

Audio warning 2 seconds before touchdown for pilots to take manual control

One idle, one at climb position at touchdown; both needed to be in idle position

(cause of veering left)

So, what are some causes for this crash?

Como foi o acidente

Avenida Washington Luis

Rampa

Avenida Barão do Rego Barros

Rua Barão de Surui

2 O avião atravessa a av. Washington Luis, colide com o depósito de cargas da TAM e provoca incêndio no local

Via de Acesso Aeroporto de Congonhas

1 O Airbus A320 da TAM, vôo JJ 3054 não consegue realizar a manobra na pista e derrapa

Rua Otávio Tarquinio de Sousa

Aeroporto de Congonhas

Imagem: Google Earth

Wet runway (hydroplaning, loss of vehicle control)

Rain

Grooves cut in runway to drain and increase traction

Thrust reverser broken (known)

Airline policy allowed aircraft to be flown with broken thrust reverser

Short runway

Airport policy allowed larger planes to land on runway

Experienced pilots had not had training in this situation

Building the fault tree

How is the probability of crash calculated?
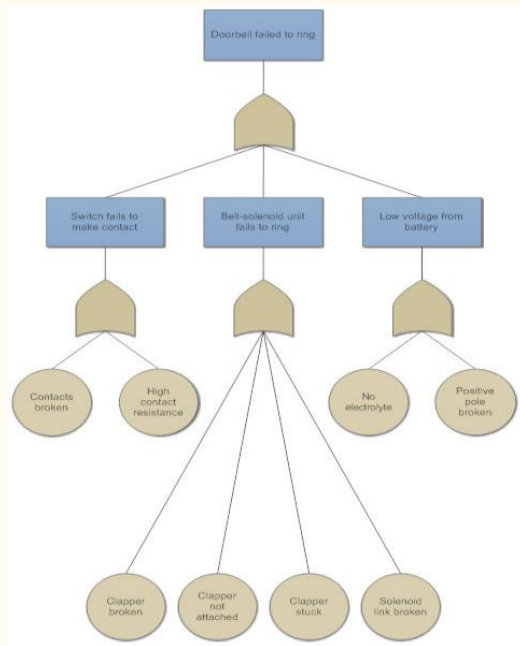
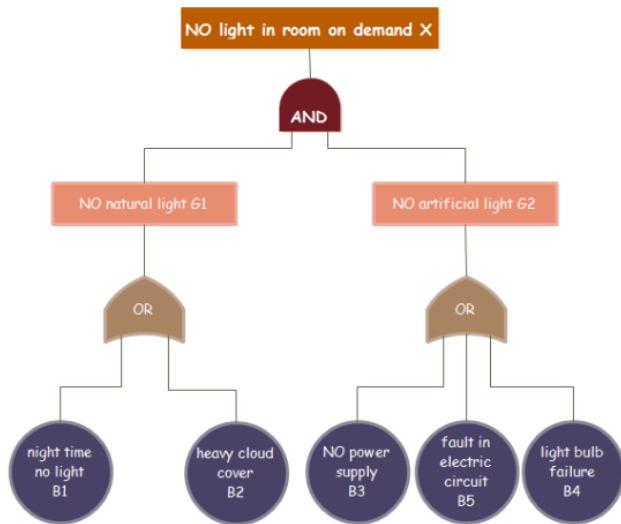Gates aren't limited to only two events
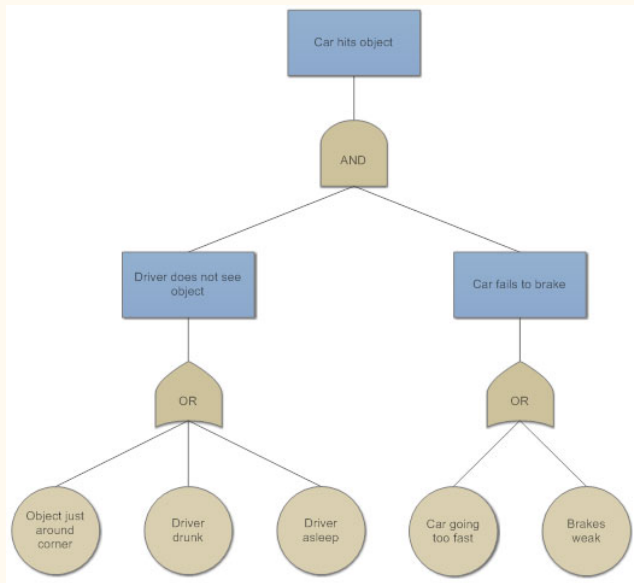
Can be more than one level of intermediate causes
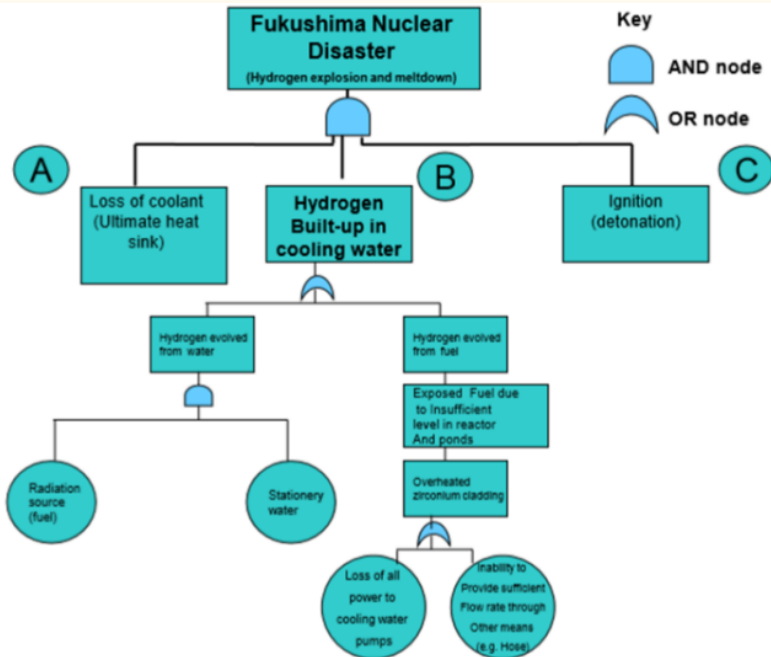
CRASH
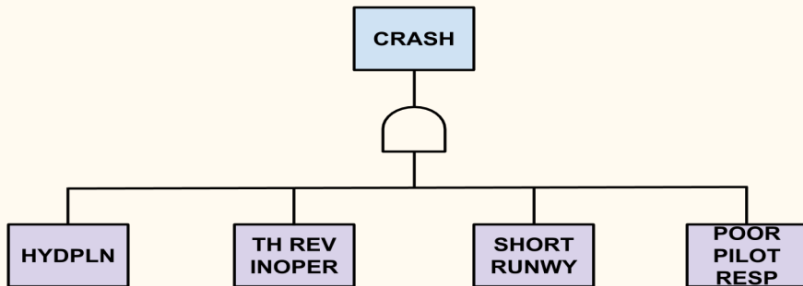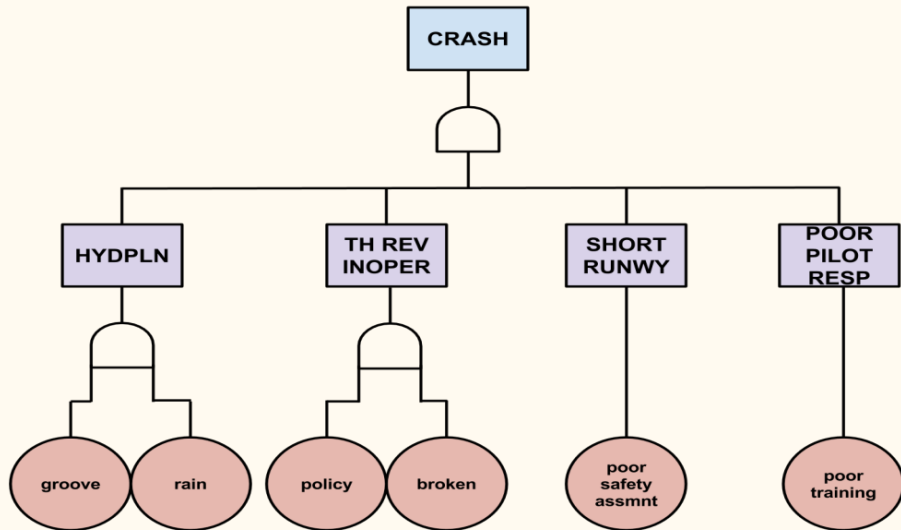
Doorbell

Lighting the room

Car crash

Counterexample

Limitations

Of course, there are limitations

Undesirable events must be foreseen

We don't know what we don't know

Each event analyzed singly

Significant contributors to fault/failure must be anticipated or predicted

Each initiator must be constrained to two conditional modes (AND/OR)

Initiators at beneath a common gate must be independent

Still requires detailed knowledge of the system