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Ministry of Defence

Independent Thinking:

Uncertainty and Risk from Single Points of Failure

- Abstract: The design intent is that safety-critical and safety-related systems should be engineered without single points of failure. This is often achieved through the use of multiple systems that perform the same function (eg, a main system and a backup, multiple copies running in parallel, etc). Achieving, and demonstrating, independence between such systems can be a difficult and subtle problem. This presentation uses several simple examples to illustrate potential difficulties before presenting key challenges for the research and practitioner communities.

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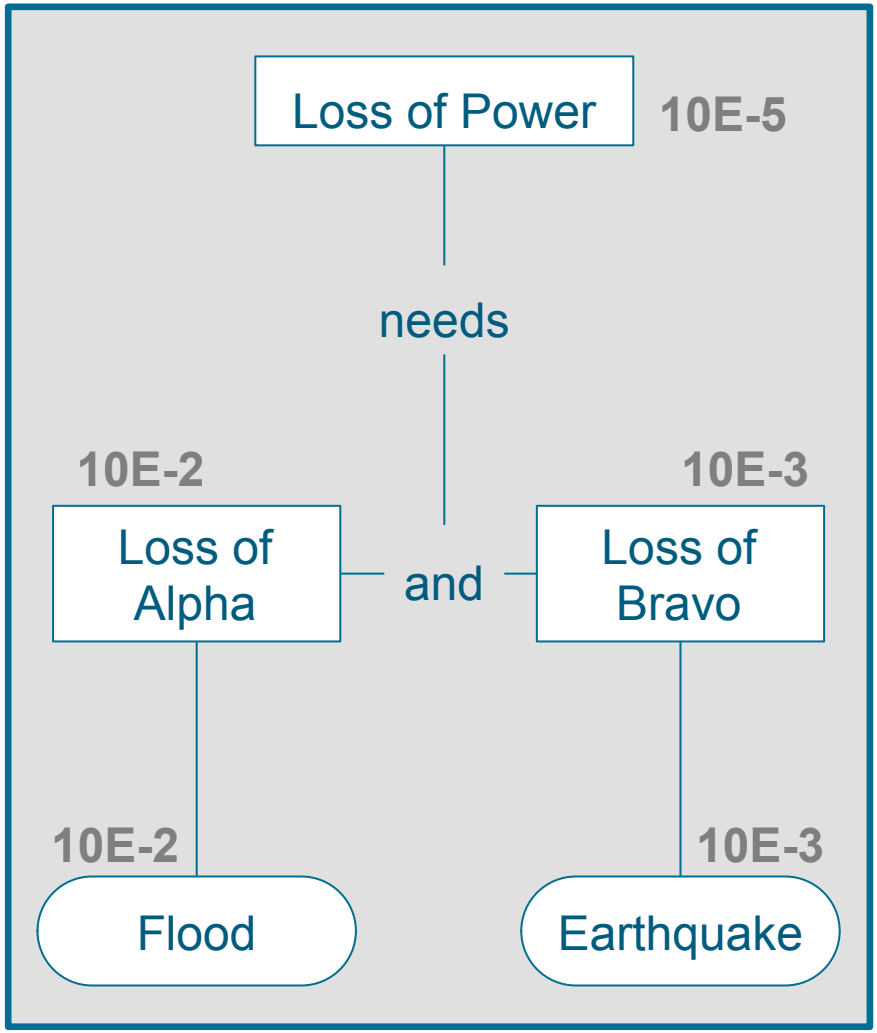
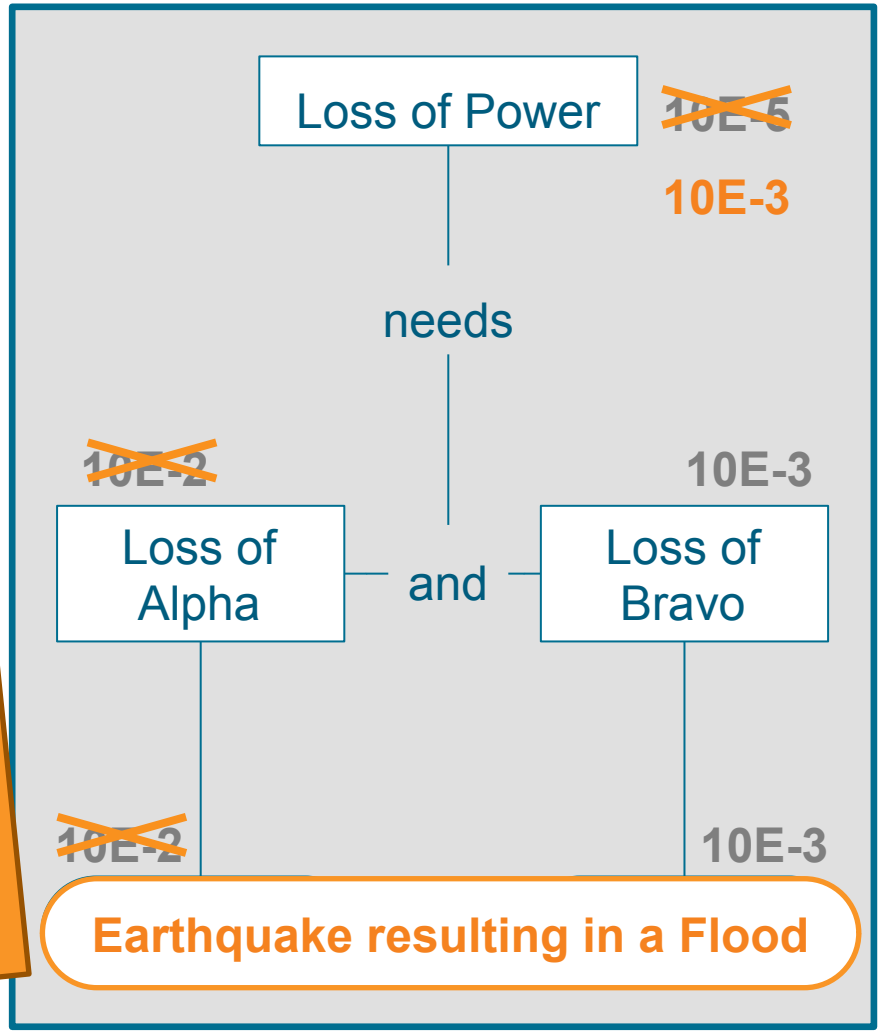
An Example

- Two separate power systems (Alpha and Bravo)
- One has (perfect) protection against earthquakes and no protection against floods
- Reverse applies to the other
- For (semi-)plausible flood and earthquake frequencies then the risk of losing power is 10E-5 per operating year

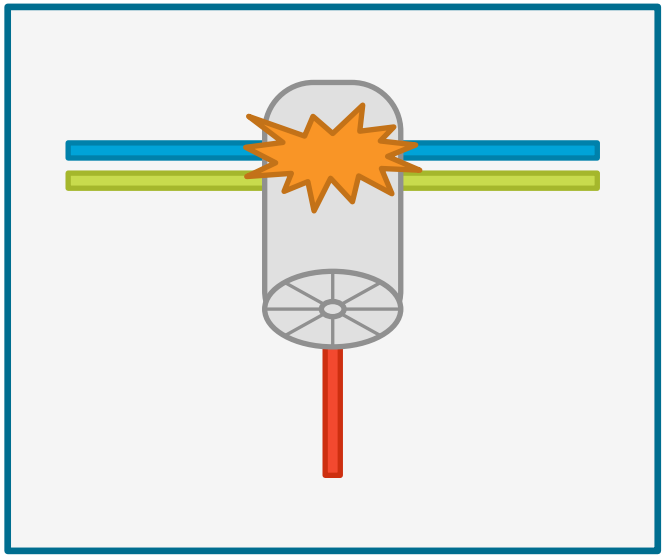


An Example

- But this calculation assumes that floods and earthquakes occur independently
- If our installation is near the coast this may not be true
- Removing the independence assumption has a very large effect on system-level risks



Another Example

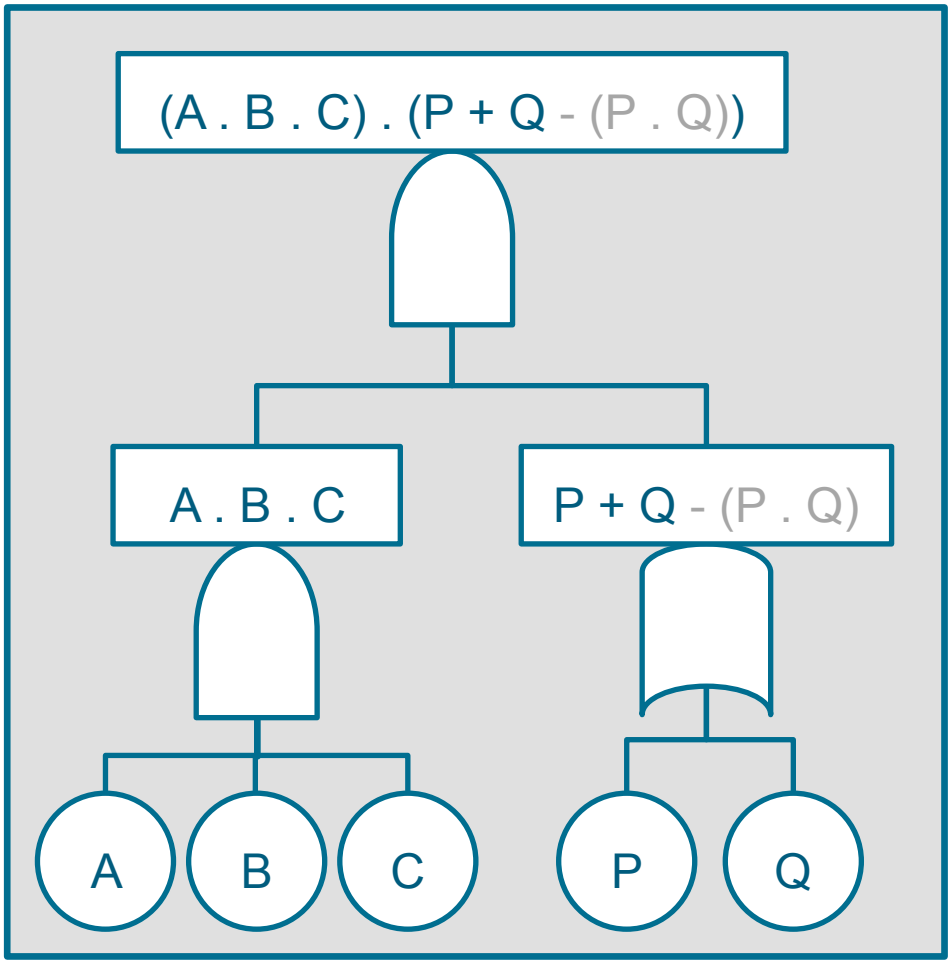


- Suppose an aircraft has three independent hydraulic systems
- But all three route close to an engine (and none are equipped with hydraulic fuses)
- In this case an uncontained engine failure could lead to catastrophic loss of all three hydraulic systems
- Again, the assumption of independence is violated

Common Cause Analysis (CCA)

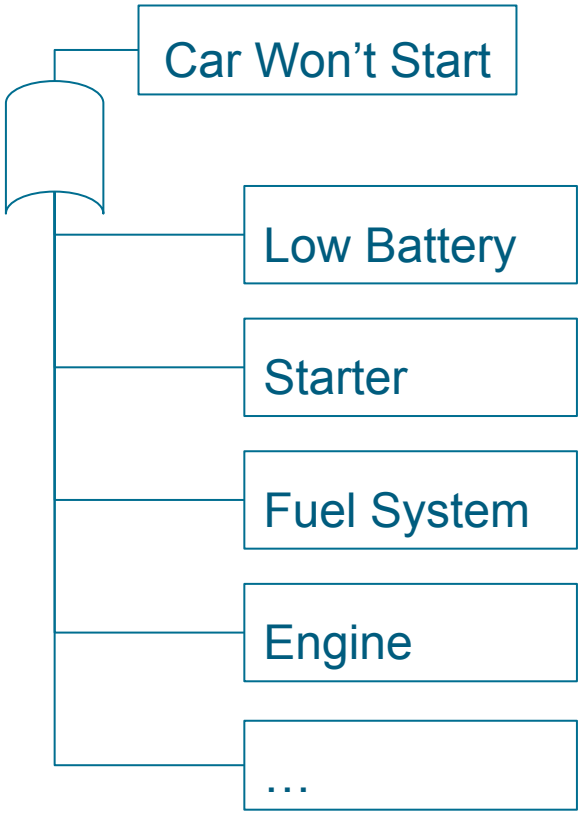
- Common Cause Analysis seeks to identify cases where assumptions about independence may be violated
- ***Particular Risk Analysis*** considers items outside the system that affect multiple zones at the same time (eg, bird strike, tyre burst)
- ***Zonal Safety Analysis*** works through on a zone-by-zone basis (eg, installation, potential interference between systems)
- ***Common Mode Analysis*** verifies that items combined with AND gates in a Fault Tree are independent

Fault Trees



- Built from undeveloped base events
- Combined via logical operators (primarily AND, OR gates)
- Probabilities (almost always expressed without uncertainty) propagate upwards
- Support quantitative and qualitative analysis

Fault Trees



- What's missing from this example?
- How would you allocate probabilities to the nodes?
- How big will the final tree be?

- Despite their limitations, fault trees are a practical and widely-used way of understanding how individual components affect overall system safety

Models

Some models are **“deep”**

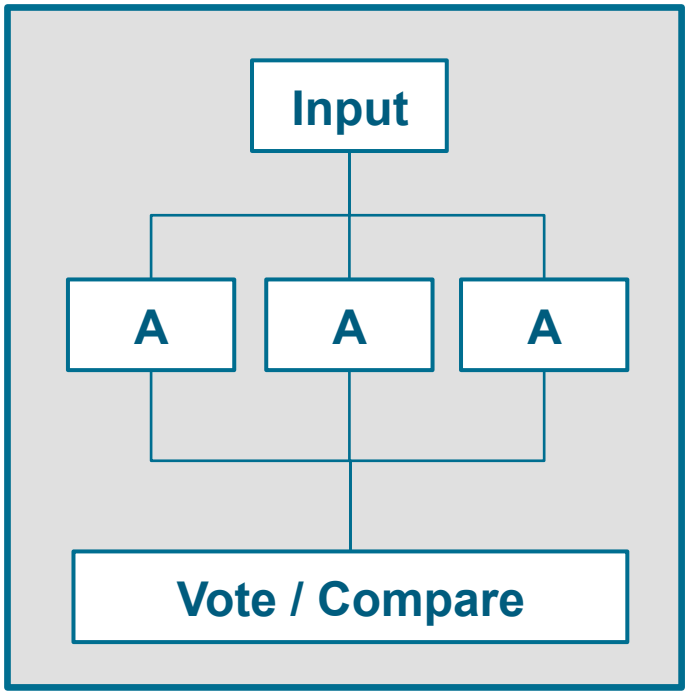
- They have complicated internal structures
- They take a long time to run
- Sensitivity / uncertainty analyses are often based on emulators
- Building an emulator often involves pre-selecting “key” inputs and outputs

Some models are **“shallow”**

- Internal structures are built from a small number of simple components
- They can be very quick to run
- But they are large scale, often featuring many thousands of equivalent-level inputs

Common Software

- The nature of software means it is particularly susceptible to common mode failure
- Providing identical software with identical inputs (almost always) gives identical results
- This can undermine assumptions associated with the provision of independent (computer) hardware



Software - Adding Independence

Software

- Can try to introduce independence by using different (independent) development teams
- But all will be working from the same requirements
- And this approach significantly increases costs

Data

- Can add diversity into the input data
- Occasionally, this is naturally available (eg, multiple sensors)
- Theoretically, artificial diversity can also be added
- But it is difficult to justify any given level of diversity

Hardware

- Can compile the same source code for different targets
- This offers some protection against errors in compiler (and processor) implementation
- But these are not the main sources of software errors

Software Independence

- There is ***no way of achieving (total) independence*** between common software
  - As a minimum, they share common requirements
- There is ***no (easy) way of accurately measuring software independence***
  - Since this is conceptually equivalent to the problem of fully testing the software
- The level of independence could be "***almost none***"
  - Close to that which arises from Single Event Upsets and hardware faults
- Or it could be "***quite large***"
  - Independent development teams, using different languages, targeting different hardware
- Or "***anywhere in between***"

Challenges

1. **Quantifying software reliability**
   - Mostly a philosophical discussion - not for this conference!
2. **Effect of uncertainty in fault tree structure**
   - Uncertainty in overall structure
   - Uncertainty in independence assumptions - especially with regards to “undeveloped base events”
3. **Conducting meaningful sensitivity / uncertainty analysis on large-scale (1000s of components) “shallow” models**
   - Challenges computation, analysis and visualisation

Questions / Comments?

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