Fault Tree Inference for One-Shot Devices using Bayes and Empirical Bayes Methods, driven by Expert Judgement

Tim Bedford, John Quigley, Lesley Walls
Strathclyde University
COST ESR Training School

Motivating Problem

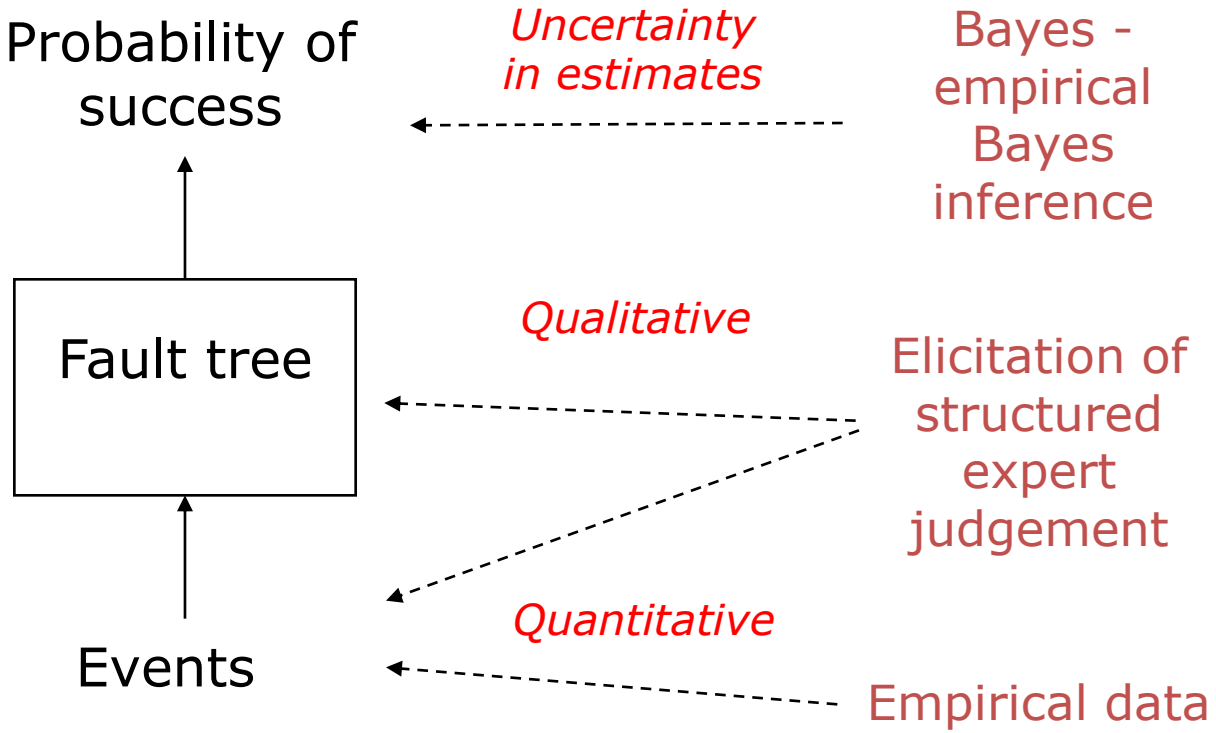
One-shot system in advanced state of design

Problems with existing systems to be removed through re-design

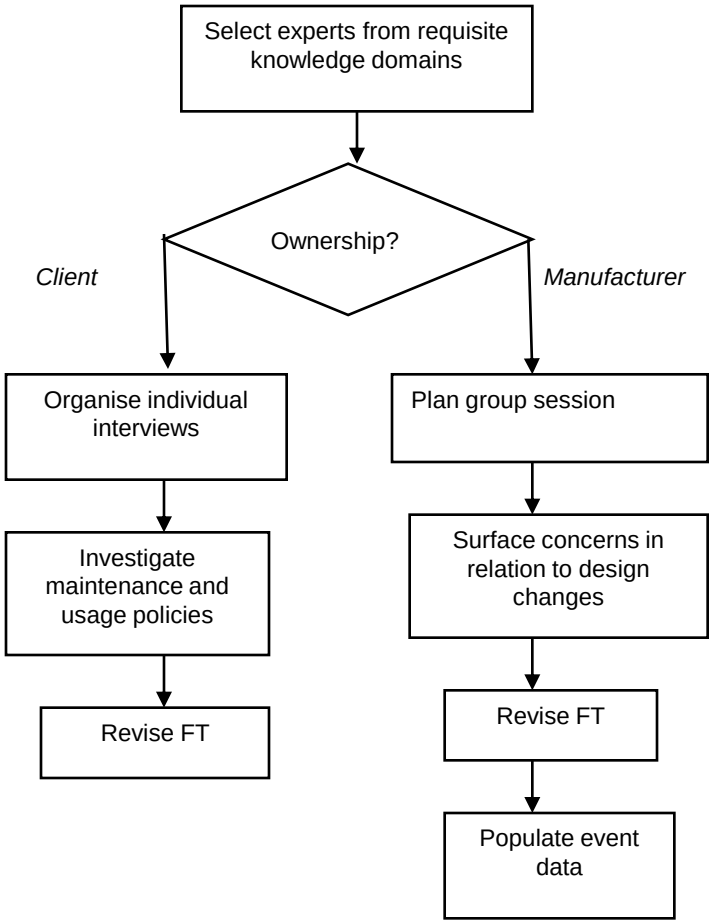
- Other substantial design changes imply subsystem elements are not simple developments of existing design
- Probability of achieving successful operation when the decision to use the system has been taken and the signal has been transmitted to the system

Indicative systems level model rather than hard forecasting model with full details of subsystems

Modelling Strategy

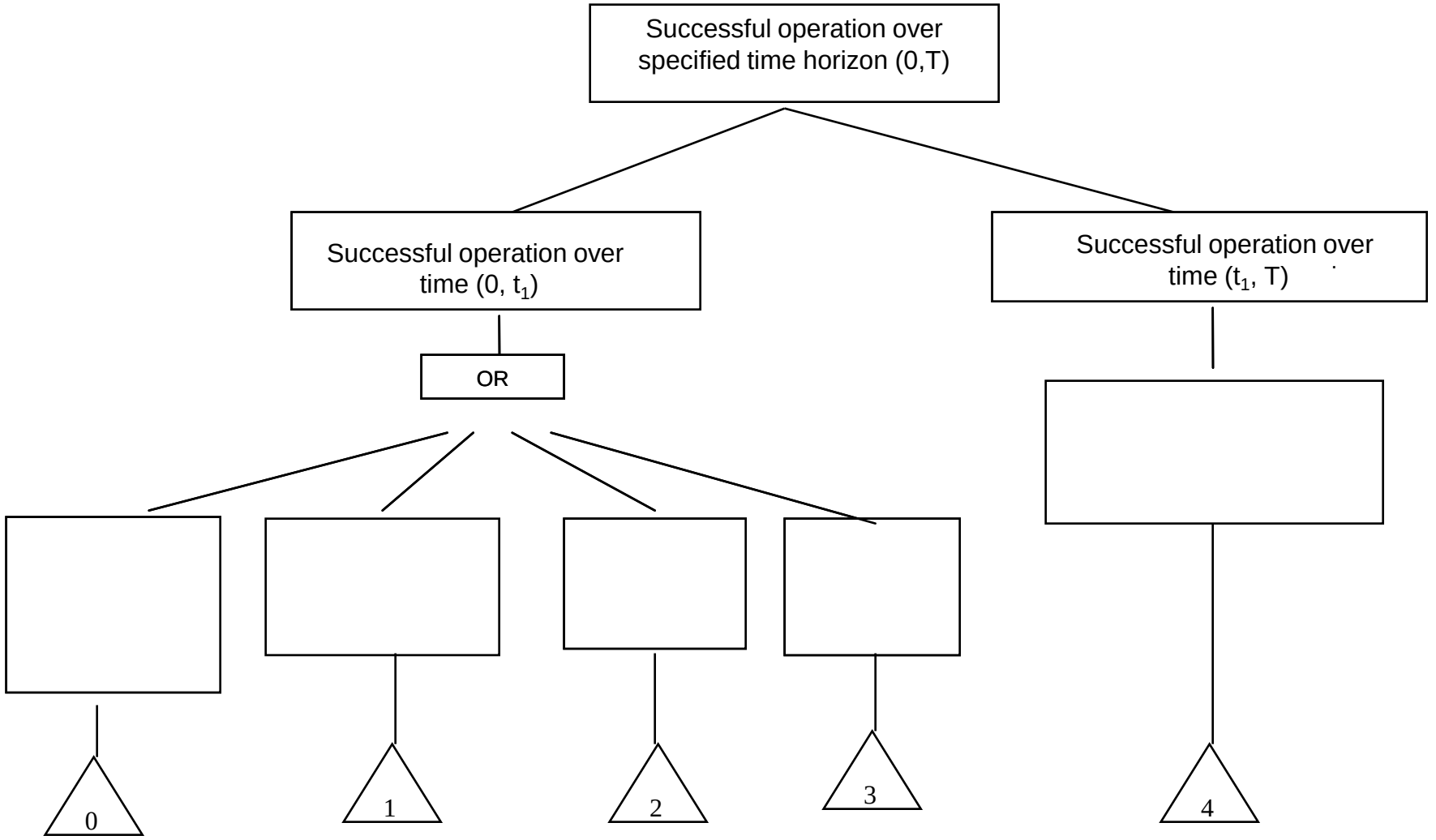


Structuring the Fault Tree



- Stakeholder data ‘speaks for itself’
- Agree top event then drill down
- Initial version scoped at group session
- Much cycling between modellers and stakeholders to finalise
- Seven versions before mature, yet, shallow, fault tree with 31 basic events

Fault Tree Extract



Eliciting Structured Expert Data

WHO?

↓

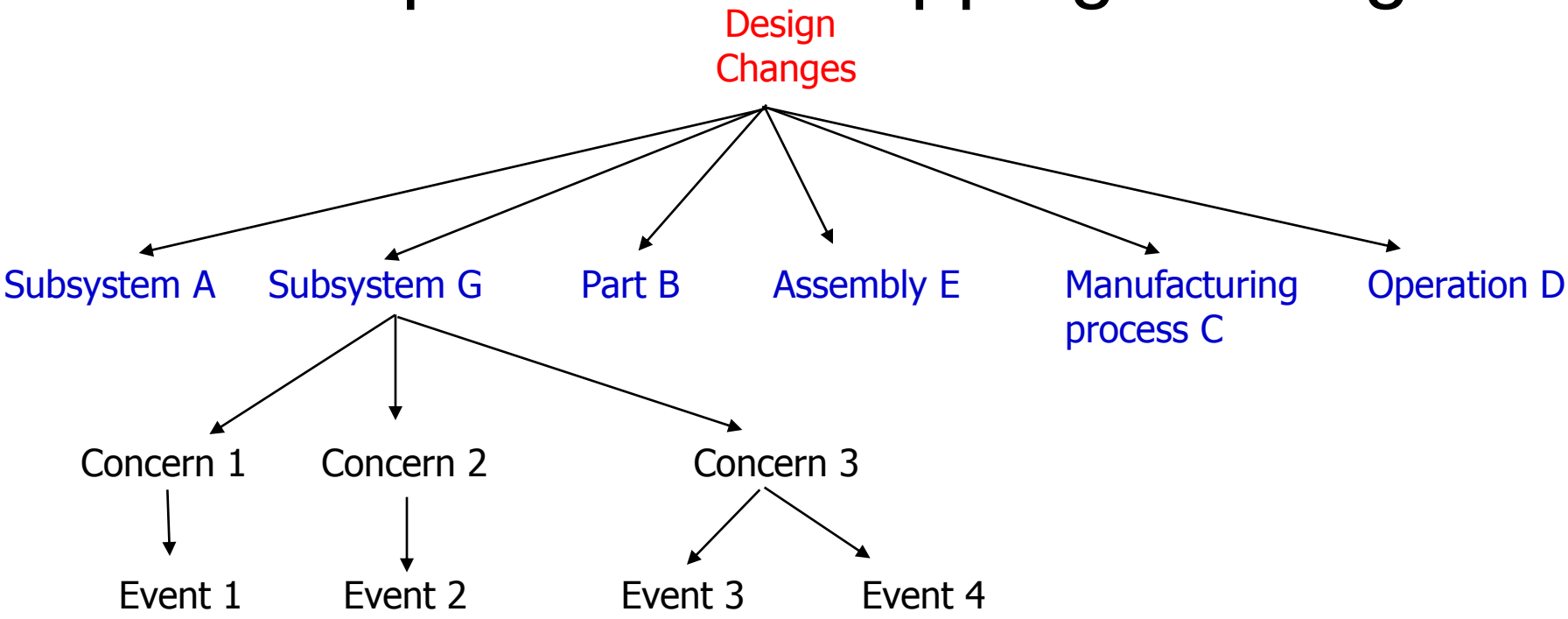
WHAT?

↓

HOW?

- Formal elicitation proforma used structure interviews and capture reasons for expert selection
- Evaluation of process coverage as designed and implemented
- Important for Reliability Case delivered to client

Interview phase 1 – Mapping Heritage



Interview phase 2 – Event data

- Fault tree event reference
  - Ownership : manufacturer or client
  - Observable : basic event prior to deployment?
  - On-board maintenance: Could fault be corrected?
  - Degradation: Chance of failure change through time?
  - Relation to existing system: record of heritage system with justification
  - Relevant test : identify where feasible to update
  - Other: catch-all comments and reasoning

Event Characteristics

- Empirical events (23)
- Relevant sample size to capture exposure (e.g. number of units or parts)
- Number of observed events
- 20 on-demand, 3 occurrence rate converted to P(fail in given time horizon)

- Judgemental events (6)
- Fractile method
- Expected number of realisations if 100 systems are in use; surprised if less than Y events; disappointed if more than Z events.

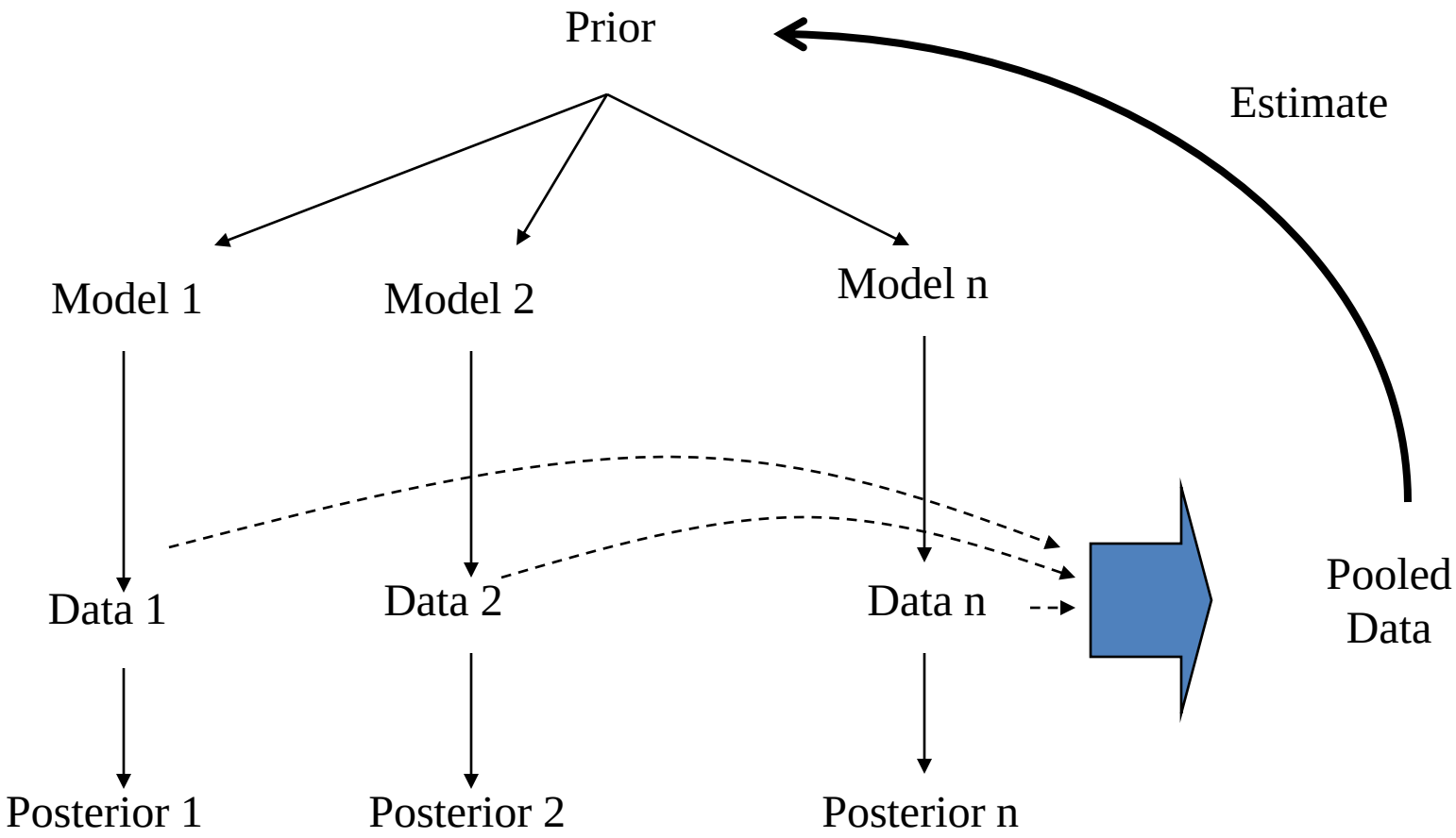
- Generic reliability database (1)
- Human error from HEART database

- Conditioning event (1)
- Probability that system is activated from other reliability modelling

Extract of Typical Data Structure

Event No.	*No. Units at Risk*	*No. Obs. Events*	*Lower Bound*	*Median*	*Upper Bound*	*Other Prob*
1.1	100	0				
1.2	50	0				
1.3			0.0001	0.001	0.005	
2.1	150	2				
2.2	20	1				
2.3			0.00001	0.0001	0.001	
3.1						0.02

Updating Process



Results

- Assume
- For basic events being tested, the chance of a basic failure being observed on test is equivalent to the chance of observing the basic failure in operation

- Event database revised
  - to ensure data used to update model is representative
  - to assess the retrospective efficacy of the test
-
- Findings
  - 0 occurrences with 20 opportunities for events estimated with subjective probabilities (engineers had expected 0.7 events)
  - 1 occurrence in 100 opportunities for events estimated with empirical Bayes (inference had estimated 5 events)
  - results from test within 5% significance level for EB estimates and subjective assessments
  - 4 additional events added to tree post test

Summary

- Model faired well regarding recorded basic events
- Additional events identified in test because aim to identify and design out expected and known events before test
- Reliance on empirical priors avoided stretching cognitive ability of engineers
- Grouping of basic events to form the pool provides potential for influencing the outcome of inference
- Need to examine pool for outliers and transformations of individual probabilities can be used to statistically homogenise the pool
- Opportunities to use expert judgement to assess pool membership in applications of empirical Bayes

Discussion

- Need for judgement
  - Model structuring (new, organisations usually outsource)
  - Quantification (SEJ to use engineering knowledge)
- Method for extracting and quantifying SEJ conditional upon reliability model and estimation process
  - Fault tree model and means of combining data to get reliability estimate informs structure of judgement required
  - Behavioural aggregation of judgements from different experts
- Process to show transparency of method to obtain buy-in and provide record
  - Sources of bias in judgements?
- Satisfy principles of SEJ?

Discussion

- Need for judgement
  - Model structuring (new, organisations usually outsource)
  - Quantification (SEJ to use engineering knowledge)
- Method for extracting and quantifying SEJ conditional upon reliability model and estimation process
  - Fault tree model and means of combining data to get reliability estimate informs structure of judgement required
  - Behavioural aggregation of judgements from different experts
- Process to show transparency of method to obtain buy-in and provide record
  - Sources of bias in judgements?
- Satisfy principles of SEJ?