I&AB in RiskSpectrum

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1 November 2017

RISK SPECTRUM

A member of the Lloyd's Register group.

Main Message

Extension of mission time requires better treatment of repair

- We do not want to reduce the information in the PSA model
- We want a dynamic method that operates on full scale PSAs
- I&AB is such a method
- Implemented in RiskSpectrum software

Mission Times

- Different types of problems may require extended times to safe state
  - Fuel pool cooling analysis
  - External events
- To reach safe state – may require longer mission times

Repairs

Why should we consider repairs?

- A scenario:

  LOOP, DG1 fails after 2h, DG2 fails after 24 hours

- + probability that DG1 does not get repaired in 22 hours

Repairs

Why should we consider repairs?

- A scenario:

  LOOP, DG1 fails after 2h, DG2 fails after 24 hours

- **+ probability that DG1 does not get repaired in 22 hours**

Potentially relevant

Repairs

Why should we consider repairs?

- A scenario:

  LOOP, DG1 fails after 2h, DG2 fails after **192** hours

- **+ probability that DG1 does not get repaired in 190 hours**
- + probability that DG1 is repaired and fails again
- + probability that DG1 is repaired, fails and is not repaired
- + …

Significant

The Initiator & All Barriers (I&AB) Method - Basis

Modelling

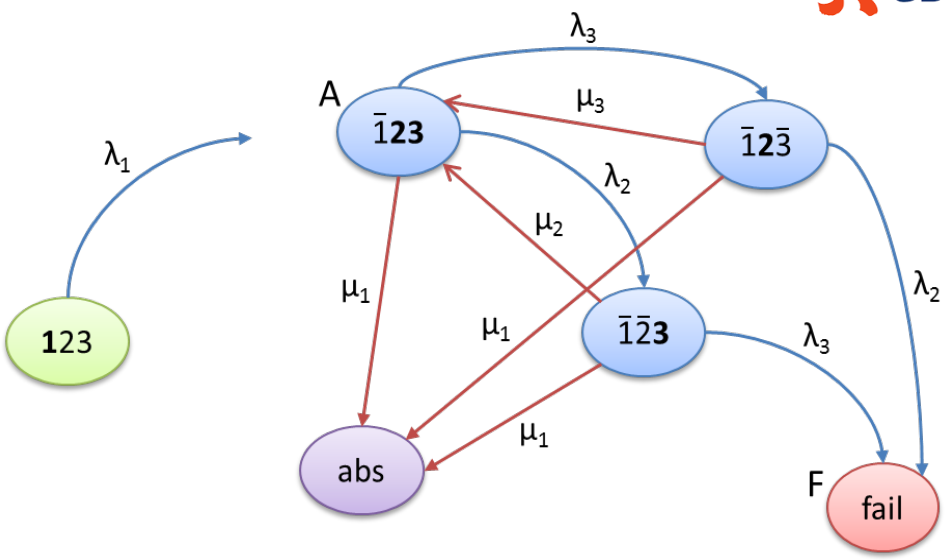
- A standard Event tree/Fault tree model with initiators
- Repairs:
  - Possible for each basic event
  - Repair of the initiating event ends the sequence. (*safe end state*)
  - Repair times: exponentially distributed
  - Each event can have its own repair rate specified.
- *Grace delays*
- *Deterministic times*

The I&AB Method

Mathematics

- Initiating event: **1**
- Two barriers: **2**, **3**

- At least one barrier needed to avoid a failure

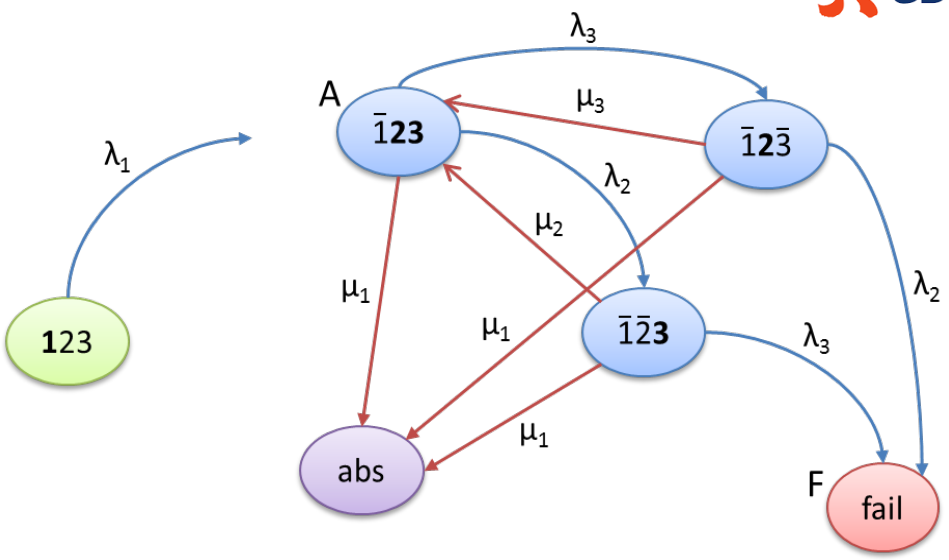


The I&AB Method

Mathematics

- Initiating event: **1**
  - Failure rate: [?]$_1$
  - Repair rate: [?]$_1$

- Repair ends the sequence
  - State ‘abs’
  - Safe end state

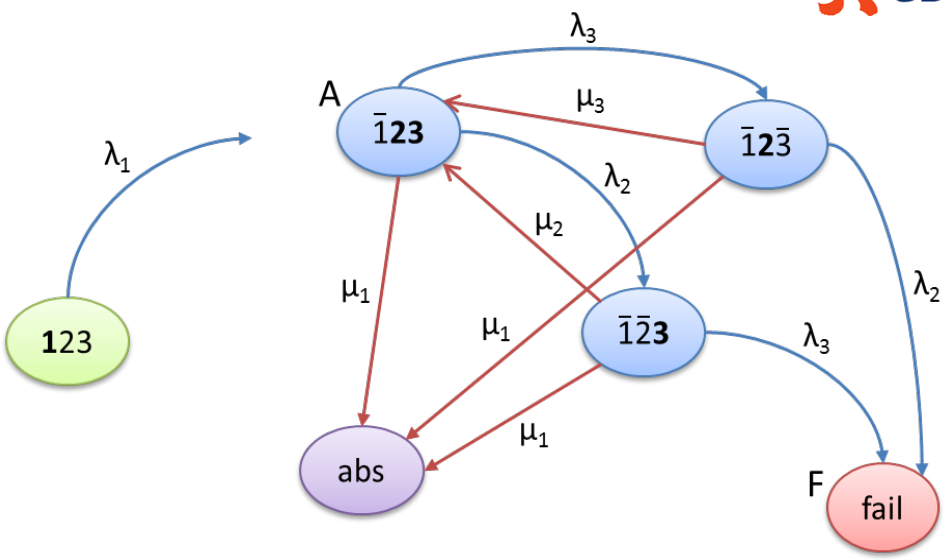


The I&AB Method

Mathematics

- Two barriers: **2**, **3**
  - Start: the initiating event
  - Failure rates: λ_2, λ_3
  - Repair rates: μ_2, μ_3

- Repeated failures and repairs possible



The I&AB Method

Mathematics

- An analytical solution: efficient implementation

$$E_c(N(t)) = \prod_{i=1}^{l} \gamma_{c,i} \times \int_0^t \exp(-\mu_{c,ie} x) f(x) dx \quad (11)$$

where

$$f(x) = \exp\left(-x \sum_{j=1}^{l} \mu_{c,j}\right) \sum_{i=1}^{m} W_{c,i}(x) \prod_{\substack{j=1 \\ j \neq i}}^{m} Q_{c,j}(x).$$

- M. Bouissou, O. Hernu: Boolean approximation for calculating the reliability of a very large repairable system with dependencies among components, ESREL 2016
- M. Bouissou: Extensions of the I&AB method for the reliability assessment of the spent fuel pool of EPR, ESREL 2018

Modelling in RiskSpectrum

Modest modelling effort

- Adding repair rates:
  - Mandatory for initiating events (frequency events)
  - Optional for other events
  - Each event can have a repair rate

- Failure in function – events with a failure rate; dynamic
- Failure on demand – probability; fail directly after the initiator

Comparison Between Analysis Methods

Comparison for electrical Supply of a Data Centre

Solver	CPU [s]	Top value	Absolute cutoff	Qualitative results
Figseq: Search and quantification of sequences in Markov chain.	12	**9.23E-4**	1E-9	1542 first sequences
YAMS: Monte Carlo simulation	180	7.98E-4 +-4E-5		9 sequences among the first ones
Fault tree generation + I&AB	3	**9.55E-4**	0	68860 cutsets (exhaustive)
Fault tree generation + Static PSA	3	2.67E-3	0	68860 cutsets (exhaustive)

Result is close to the fully dynamic methods in a fraction of the calculation time

Experiments

Evaluated on full-scale PSA studies

- Different repair times for initiating events: 24 – 192 h
- Repairs: failures in function only, MTTR: 20 h
- Failures on demand: non-repairable

- Comparison: static analysis with mission times 24 – 192 h
- *Note: mission time – an upper bound, MTTR – a mean*

24 Hours

Standard (static) PSA is good

Model	Analysis case	24h		
		I&AB	Static	Decrease in the top frequency
M 1	AC 2	1.57E-07	1.60E-07	1,88 %
	AC 3	6.16E-09	6.81E-09	9,54 %
	AC 4	1.37E-08	1.52E-08	9,87 %
	AC 5	7.25E-09	7.64E-09	5,10 %
	AC 6	1.61E-10	1.77E-10	9,04 %
M 2	AC 1	1.10E-05	1.17E-05	5,98 %
	AC 2	7.79E-07	1.08E-06	27,9 %
	AC 3	2.04E-06	2.05E-06	0,48 %
M 3	AC 1	3.15E-07	3.16E-07	0,32 %
	AC 2	3.82E-08	3.87E-08	1,29 %
	AC 3	1.91E-07	1.94E-07	1,55 %
	AC 4	4.33E-06	4.37E-06	0,92 %

192 Hours

Large decreases for longer accident times

Model	Analysis case	192h		
		I&AB	Static	Decrease in the top frequency
M 1	AC 2	2.28E-07	2.40E-07	5,00 %
	AC 3	3.12E-08	5.62E-08	44,48 %
	AC 4	7.71E-08	1.59E-07	51,51 %
	AC 5	5.02E-08	9.52E-08	47,27 %
	AC 6	6.75E-10	1.98E-09	65,91 %
M 2	AC 1	1.69E-05	3.96E-05	57,32 %
	AC 2	2.36E-06	1.22E-05	80,66 %
	AC 3	1.48E-05	1.76E-05	15,91 %
M 3	AC 1	7.16E-07	2.05E-06	65,07 %
	AC 2	1.92E-07	9.58E-07	79,96 %
	AC 3	8.48E-07	1.65E-06	48,61 %
	AC 4	6.79E-06	1.03E-05	34,08 %

Conclusions

Static

- Generally no repairs
- No timing of failures
- Conservative
- Fast
- Good for short mission times

Dynamic: I&AB

- Repairs
- Reduces conservatism
  - Significant for long mission times
- Fast: Efficient also for large-scale PSA
- Available in RiskSpectrum

Thank you

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