ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Performance indicators
Reliability

Main points

- When using reliability as a performance indicator
  - prioritization of interventions with respect to net benefit is rarely possible
  - for an item, there are multiple ways to estimate the reliability
  - for a sub-item – don't forget that the LOS it provides depends on how it is integrated into the item as a whole and the reliability of the other sub-items in the item.

- Expectation of you (after this class, reading the script, the handouts, and doing the assignments):
  - to be able to estimate the reliability of interconnected sub-items
  - to be able to determine which objects within an interconnected sub-item should be repaired to maximize reliability

Introduction

Items and sub-items / Systems and elements / Networks and objects

Super-Items $\xrightarrow{\text{consist of}}$ **Items** $\xrightarrow{\text{consist of}}$ **Sub-items**

Performance and performance indicators

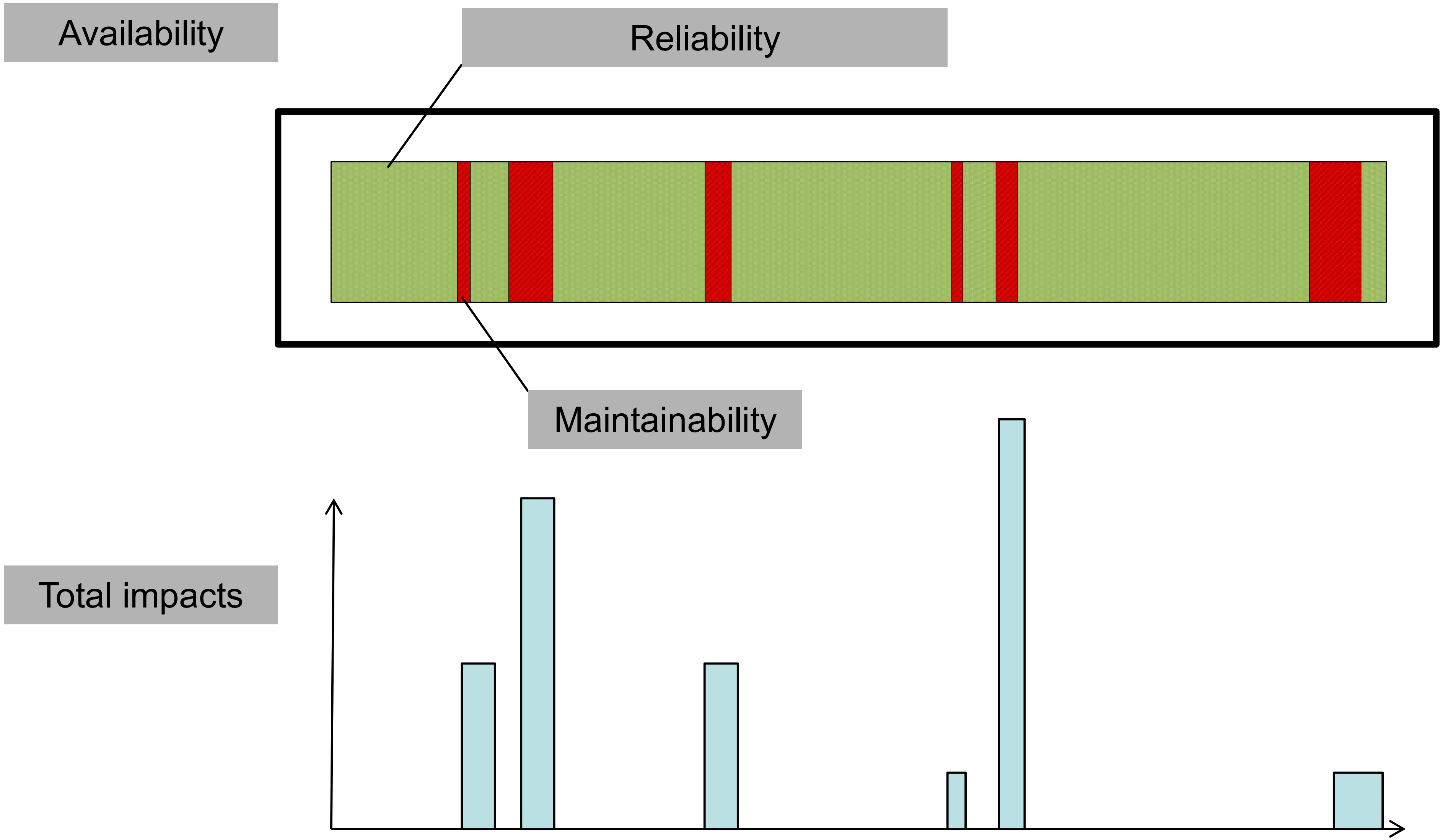
- **Total impacts**
  - the total impacts related to the performance of the item

- **Reliability**
  - the ability of an item to provide an adequate level of service

- **Availability**
  - the proportion of time an item provides an adequate level of service

- **Maintainability**
  - the ease with which an item can be maintained

How are they connected?



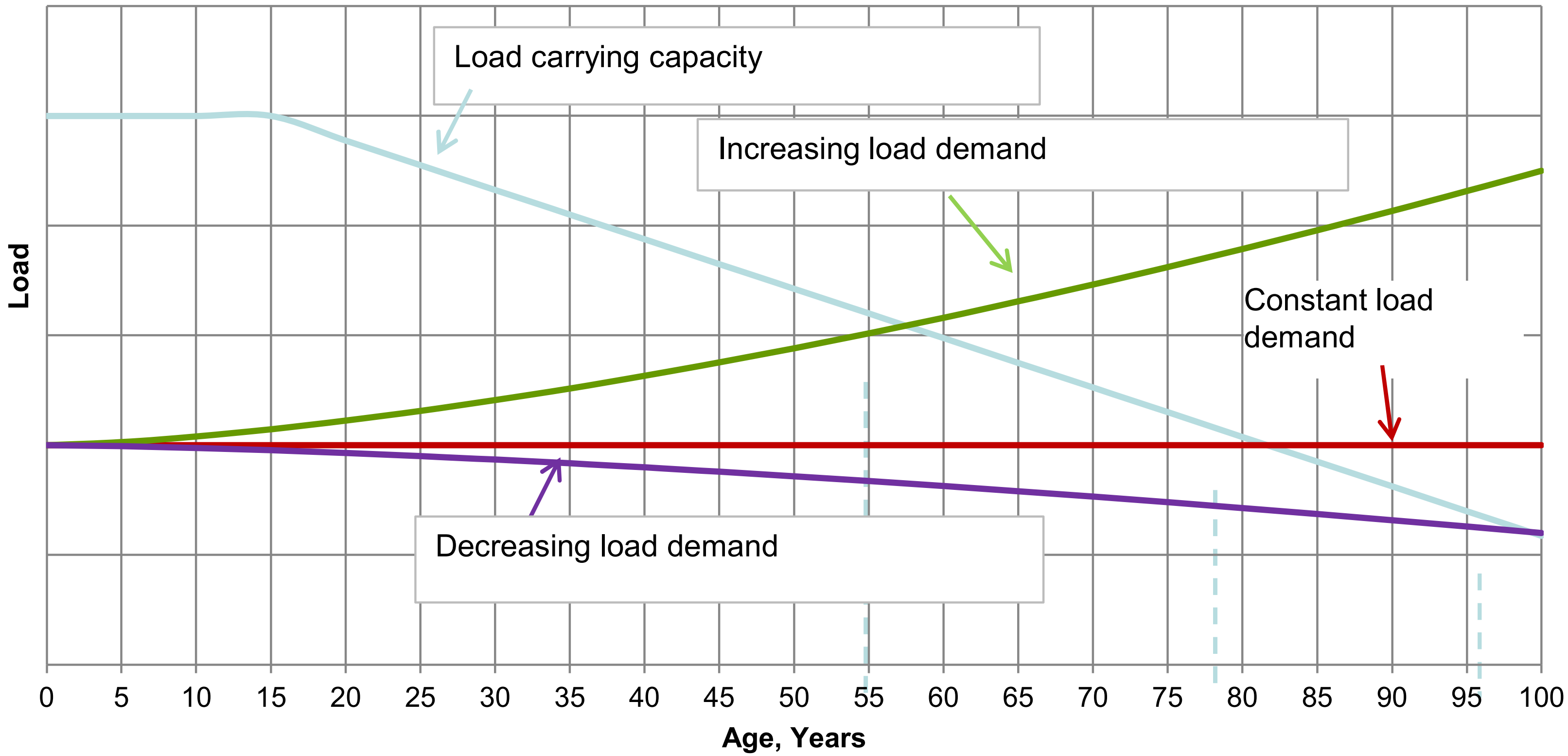
Common questions related to reliability

- How do you determine the reliability of an item?
- How do you determine the probability of failure of an item?
- How do you determine the amount of time until the first time an item reaches a state in which it provides an inadequate LOS?
- How do you determine the amount of time until the first failure of an item?
- How do you determine the service life of an item?

Introduction

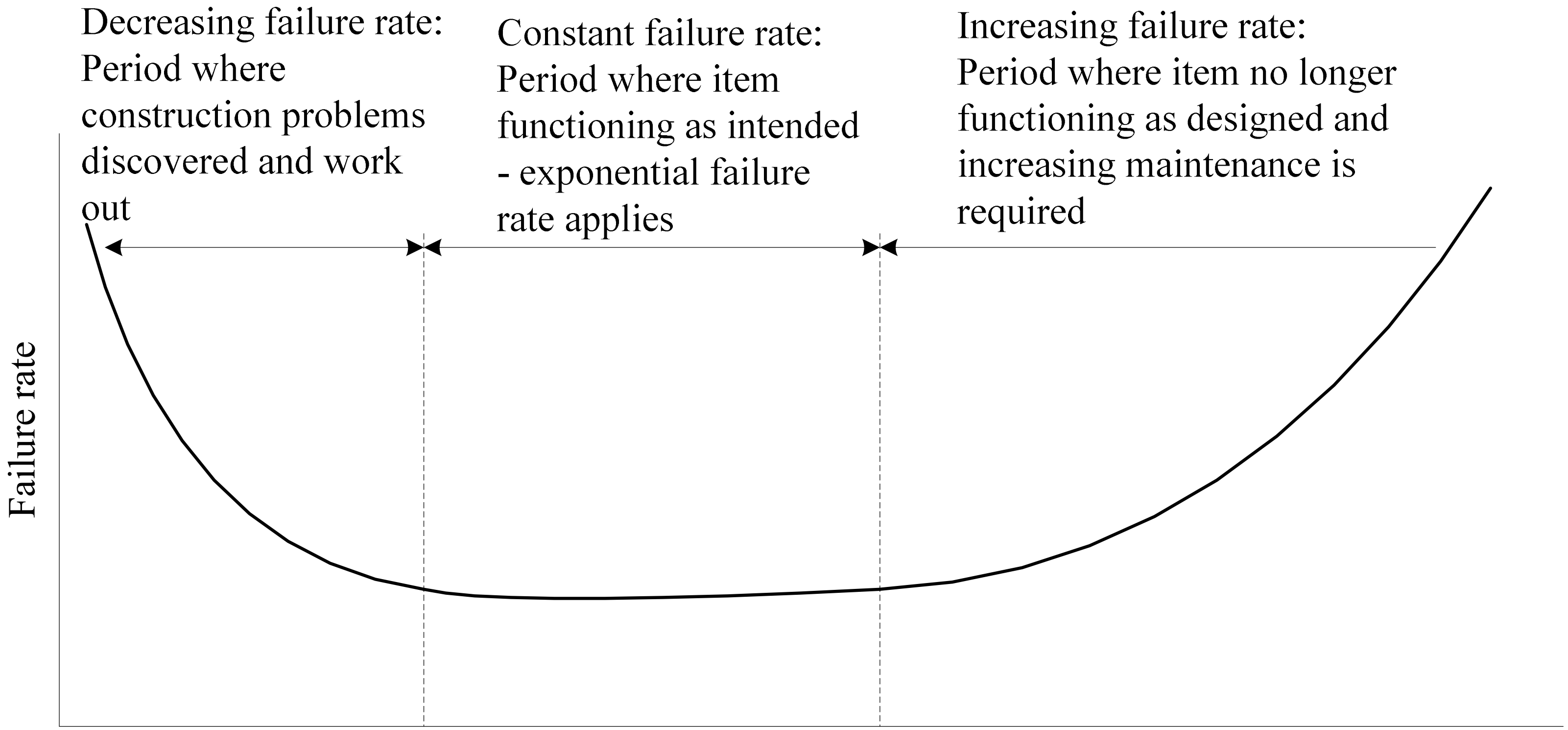
Reliability and service life

End of construction CS1 → Service life → inadequate LOS provided CSx



Variation of service life with varying demand

Failure rates are not always constant

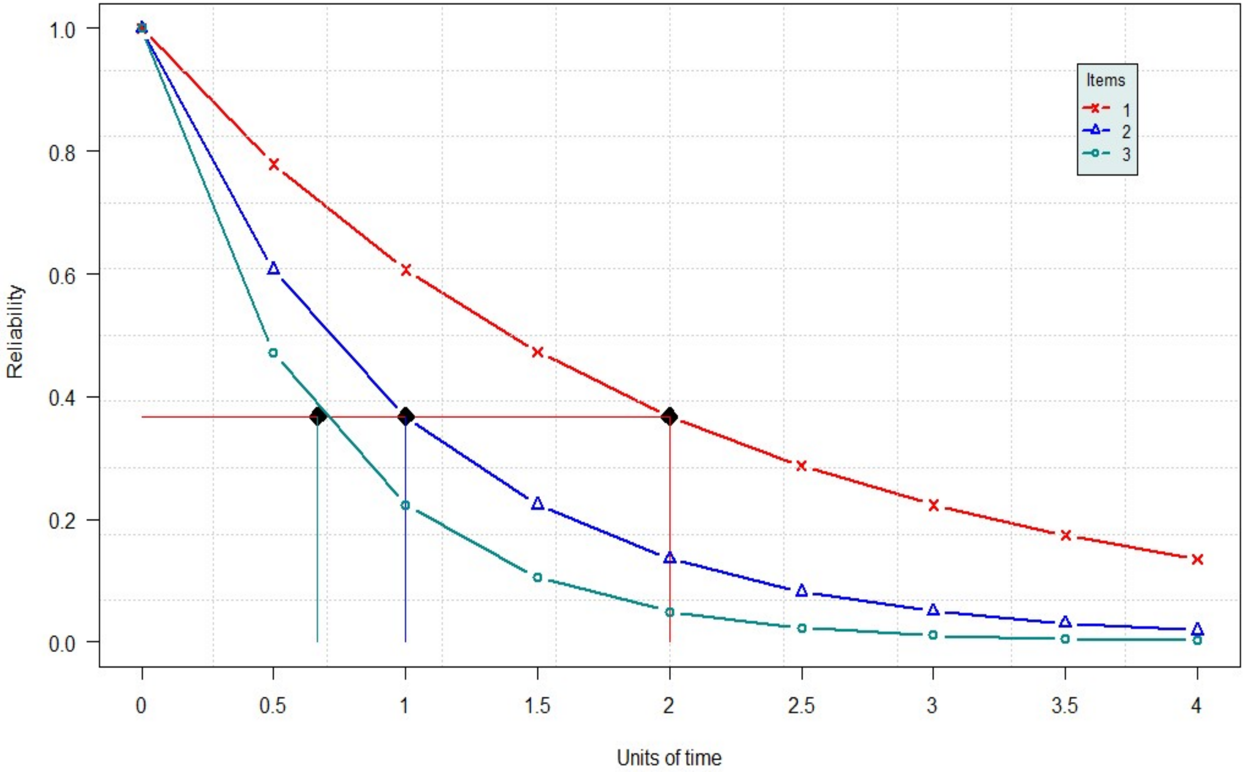


Bathtub curve based on time-dependent failure rate

Reliability of an item with a time invariant failure rate

- The reliability of item *i,* which has an exponentially distributed lifetime, is:

$$R(t) = R(\frac{1}{\theta}) = \exp(-\theta \cdot \frac{1}{\theta}) = \exp(-1) = 0.3678794 \approx 0.37$$

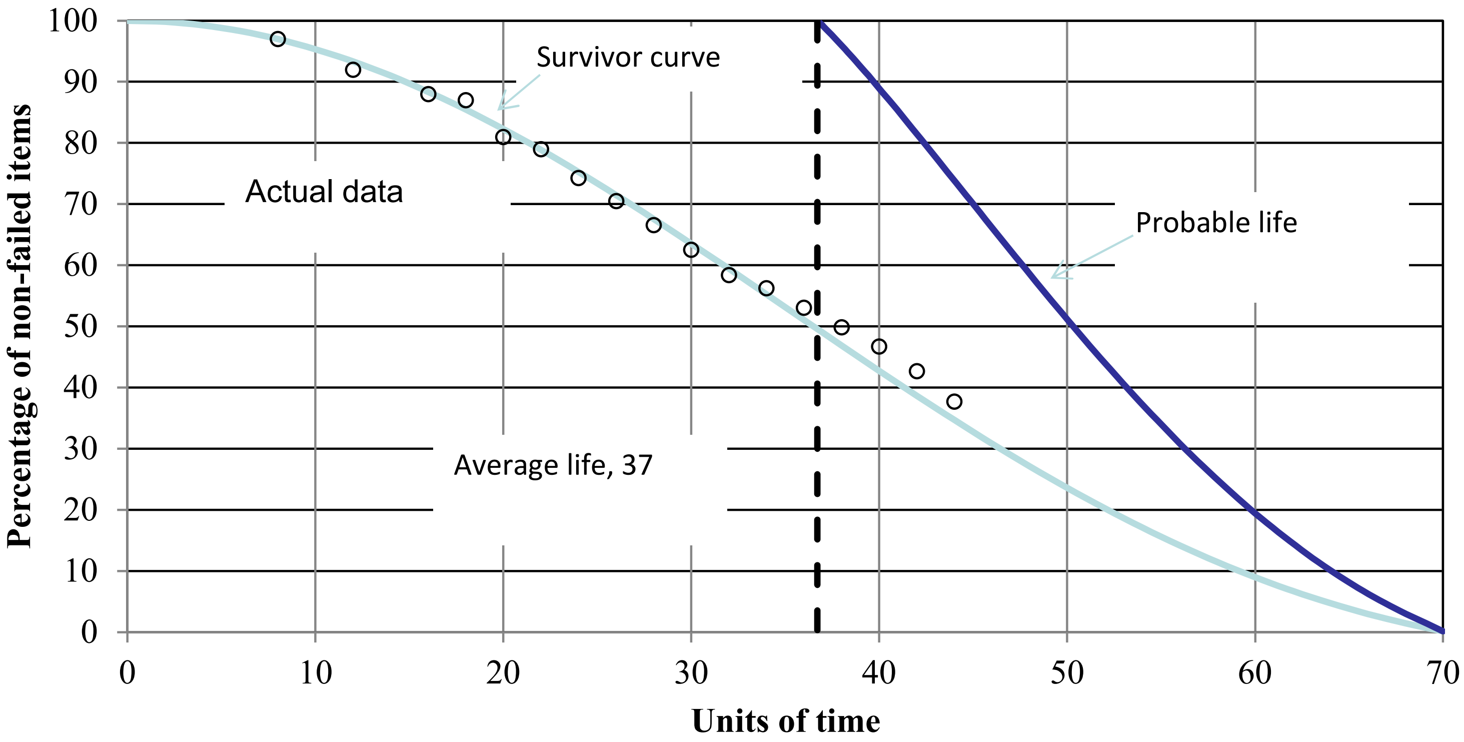


Failure rates
Item 1 – 0.5
Item 2 – 1
Item 3 – 1.5

Mean life times
Item 1 – 2
Item 2 – 1
Item 3 – 0.667

Reliability

Remaining amount of time an item will provide an adequate LOS



Life expectancy of non-failed items at *t* = remaining area at *t* tus / % of non-failed items at *t*

Probable life of non-failed items at *t* = life expectancy of non-failed items at *t* + *t*

Remaining amount of time an item will provide an adequate LOS

Units of time (A)	Number of failed items (B)	Cum. number of failed items B(t)+C(t-1) (C)	Number of non-failed items Sum(B)-C (D)	% of non-failed items D/sum(B)* 100 (E)	A*B (F)	Total remaining amount of service *Integration* (G)	Life expectancy of non-failed items G/E (H)	Probable life of non-failed items A+H (J)
0	0							
2	2							
5	6							
10	11							
15	24							
20	22							
25	17							
30	11							
35	5							
40	2							
Sum(B)	100			Avg. life				

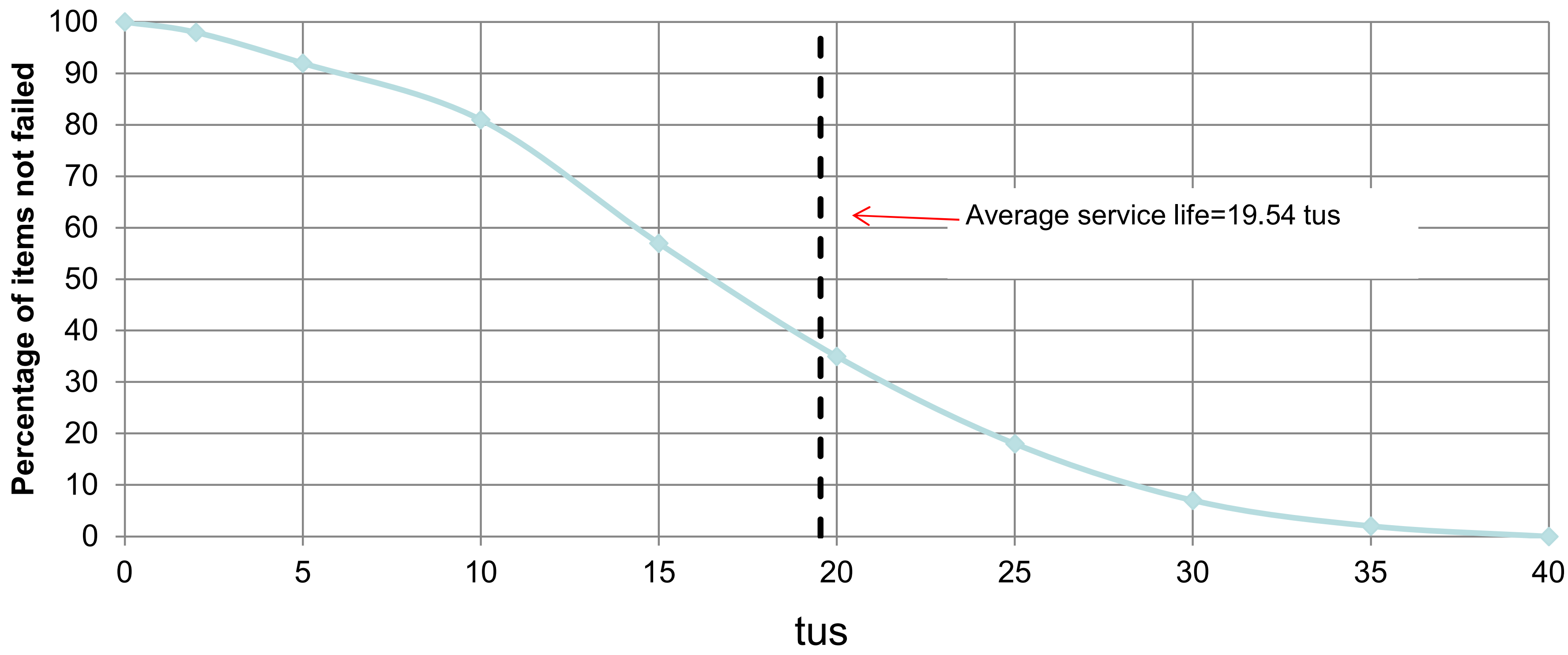
Remaining amount of time an item will provide an adequate LOS

Units of time (A)	Number of failed items (B)	Cum. number of failed items B(t)+C(t-1) (C)	Number of non-failed items Sum(B)-C (D)	% of non-failed items D/sum(B)* 100 (E)	A*B (F)	Total remaining amount of service *Integration* (G)	Life expectancy of non-failed items G/E (H)	Probable life of non-failed items A+H (J)
0	0	0	100	100	0			
2	2	2	98	98	4			
5	6	8	92	92	30			
10	11	19	81	81	110			
15	24	43	57	57	360			
20	22	65	35	35	440			
25	17	82	18	18	425			
30	11	93	7	7	330			
35	5	98	2	2	175			
40	2	100	0	0	80			
Sum(B)	100			Avg. life	1954/100 = 19.54			

Reliability

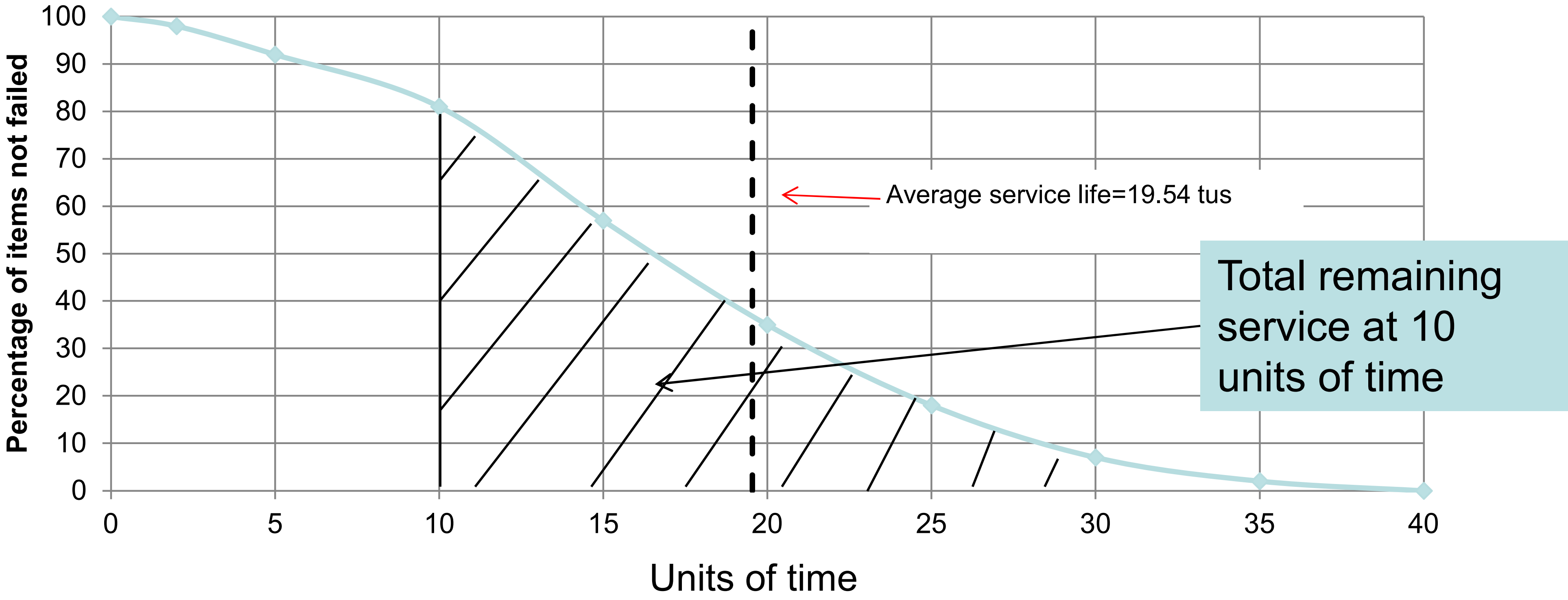
Remaining amount of time an item will provide an adequate LOS

- Average service life = $\frac{\sum N \times f}{\sum f} = \frac{1954}{100}$ = 19.54 tus



Remaining amount of time an item will provide an adequate LOS

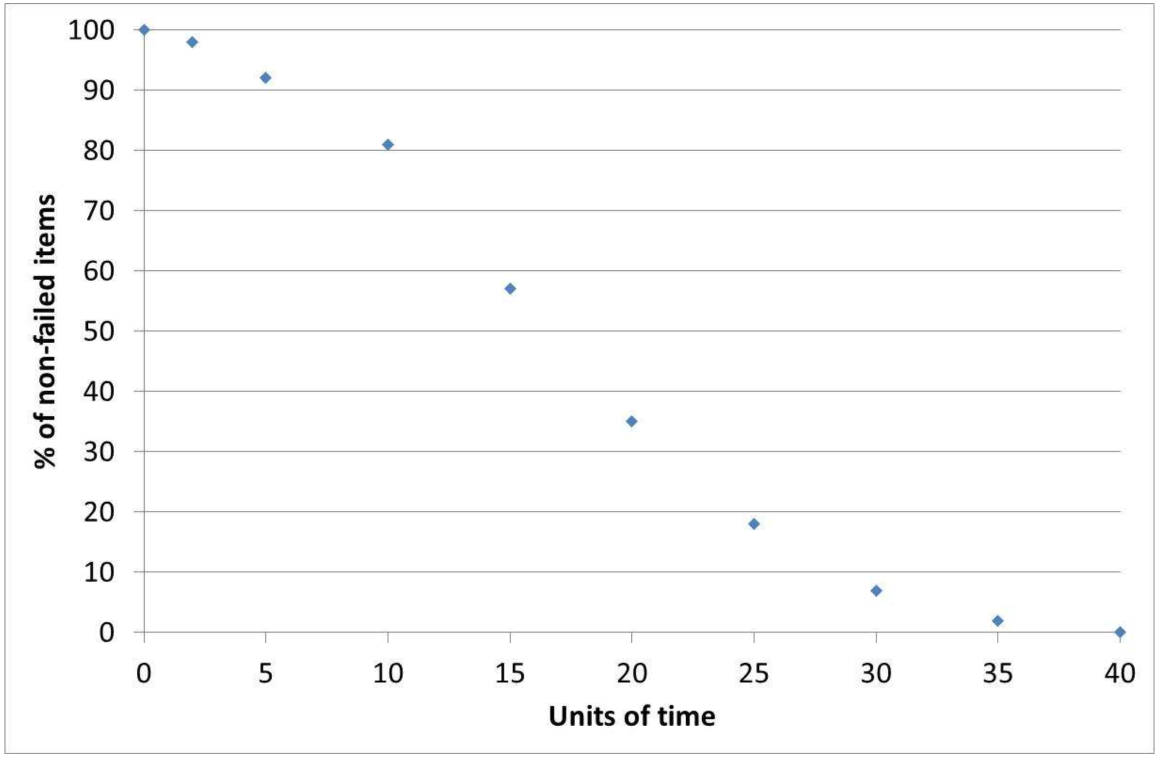
- Total remaining amount of time an item will provide an adequate LOS at *t* =
  - the area under the curve (*assumed as a triangle*) to the right of the time ordinate
  - 0.5 * (T - *t*) * (% items not failed at time *t*)
  - 0.5 * (40-0) * 100 = 2’000



Reliability

Remaining amount of time an item will provide an adequate LOS

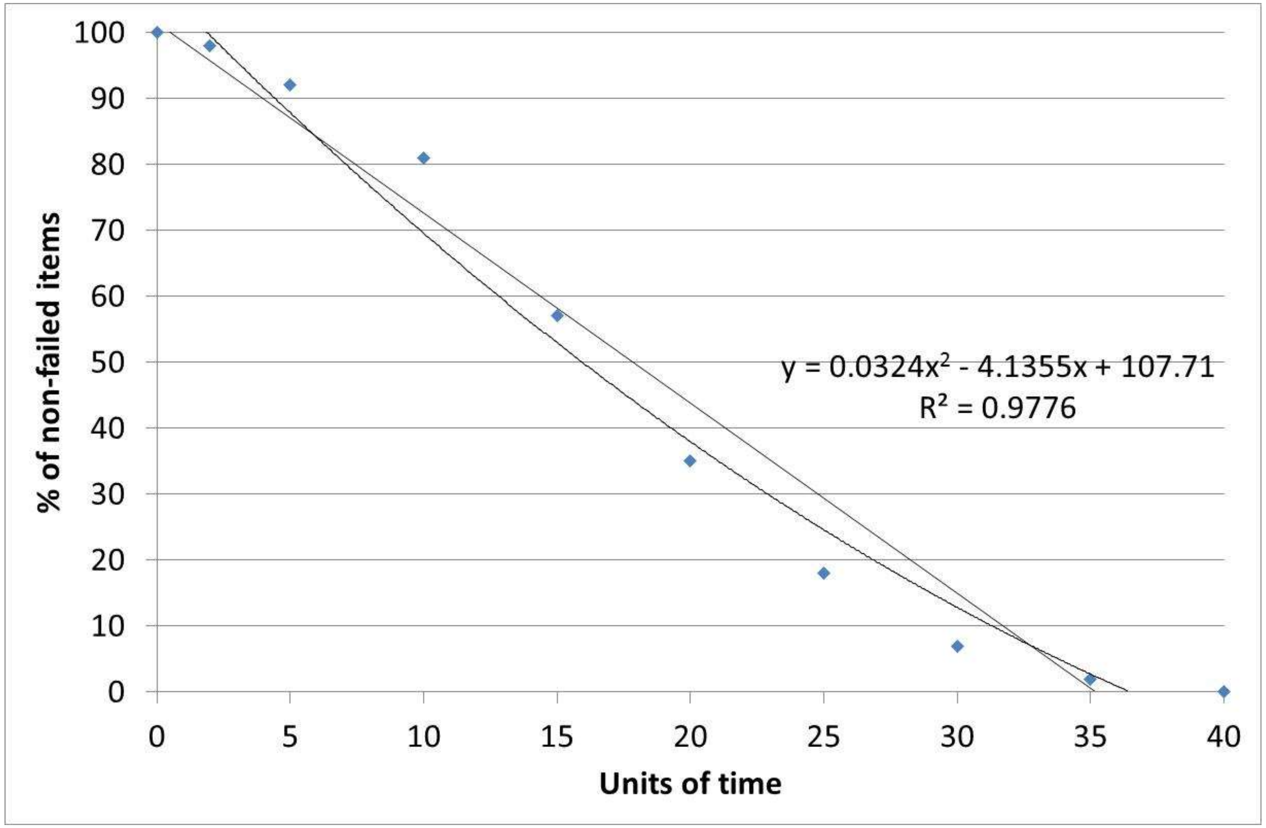
- Area calculation by integration
  - Enter values in Excel
  - Draw a scatter plot for % of non-failed items (E) against time (A) using the following Excel option



Reliability

Remaining amount of time an item will provide an adequate LOS

- Area calculation by integration
  - Enter values in Excel
  - Draw a scatter plot for % of non-failed items (E) against time (A) using the following Excel option
  - Determine best fit regression curve (polynomial of order 2)



Reliability

Remaining amount of time an item will provide an adequate LOS

- Area at any t can be calculated by integrating the regression equation between two age limits

$$t_1 = \int_{t=t_1}^{t=T} y \cdot dt \qquad y = 0.0324 \cdot t^2 - 4.1355 \cdot t + 107.71$$

$$\left[0.0324 \cdot \frac{t^3}{3} - 4.1355 \cdot \frac{t^2}{2} + 107.71 \cdot t\right]_t^T \Rightarrow \left[0.0324 \cdot \frac{2^3}{3} - 4.1355 \cdot \frac{2^2}{2} + 107.71 \cdot 2\right]_2^{40}$$

1484 % - units of time

Reliability

Remaining amount of time an item will provide an adequate LOS

Units of time (A)	Number of failed items (B)	Cum. number of failed items B(t)+C(t-1) (C)	Number of non-failed items Sum(B)-C (D)	% of non-failed items D/sum(B)* 100 (E)	A*B (F)	Total remaining amount of service *Integration* (G)	Life expectancy of non-failed items G/E (H)	Probable life of non-failed items A+H (J)
0	0	0	100	100	0	1691		
2	2	2	98	98	4	1484		
5	6	8	92	92	30	1203		
10	11	19	81	81	110	810		
15	24	43	57	57	360	504		
20	22	65	35	35	440	278		
25	17	82	18	18	425	122		
30	11	93	7	7	330	29		
35	5	98	2	2	175	-9		
40	2	100	0	0	80	0		
Sum(B)	100			Avg. life	1954/100 = 19.54			

Remaining amount of time an item will provide an adequate LOS

Units of time (A)	Number of failed items (B)	Cum. number of failed items B(t)+C(t-1) (C)	Number of non-failed items Sum(B)-C (D)	% of non-failed items D/sum(B)* 100 (E)	A*B (F)	Total remaining amount of service *Integration* (G)	Life expectancy of non-failed items G/E (H)	Probable life of non-failed items A+H (J)
0	0	0	100	100	0	1691	16.91	
2	2	2	98	98	4	1484	15.14	
5	6	8	92	92	30	1203	13.08	
10	11	19	81	81	110	810	10.00	
15	24	43	57	57	360	504	8.85	
20	22	65	35	35	440	278	7.93	
25	17	82	18	18	425	122	6.78	
30	11	93	7	7	330	29	4.18	
35	5	98	2	2	175	-9	-4.35	
40	2	100	0	0	80	0	0.00	
Sum(B)	100			Avg. life	1954/100 = 19.54			

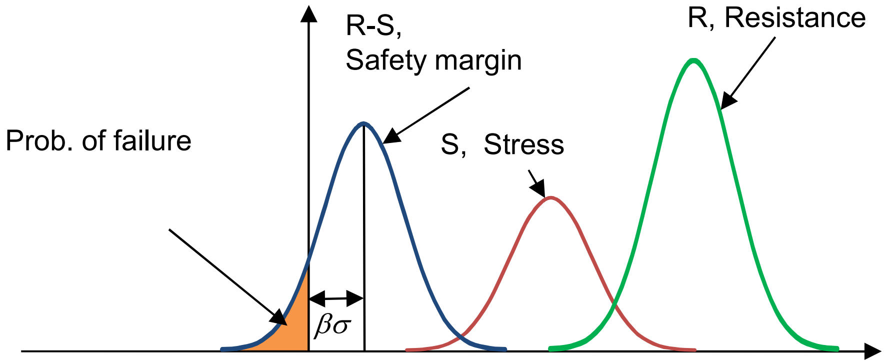
Remaining amount of time an item will provide an adequate LOS

Units of time (A)	Number of failed items (B)	Cum. number of failed items B(t)+C(t-1) (C)	Number of non-failed items Sum(B)-C (D)	% of non-failed items D/sum(B)* 100 (E)	A*B (F)	Total remaining amount of service *Integration* (G)	Life expectancy of non-failed items G/E (H)	Probable life of non-failed items A+H (J)
0	0	0	100	100	0	1691	16.91	16.91
2	2	2	98	98	4	1484	15.14	17.14
5	6	8	92	92	30	1203	13.08	18.08
10	11	19	81	81	110	810	10.00	20.00
15	24	43	57	57	360	504	8.85	23.85
20	22	65	35	35	440	278	7.93	27.93
25	17	82	18	18	425	122	6.78	31.78
30	11	93	7	7	330	29	4.18	34.18
35	5	98	2	2	175	-9	-4.35	30.65
40	2	100	0	0	80	0	0.00	40.00
Sum(B)	100			Avg. life	1954/100 = 19.54			

Estimation

- Based on data

- Based on models and uncertainty of parameters



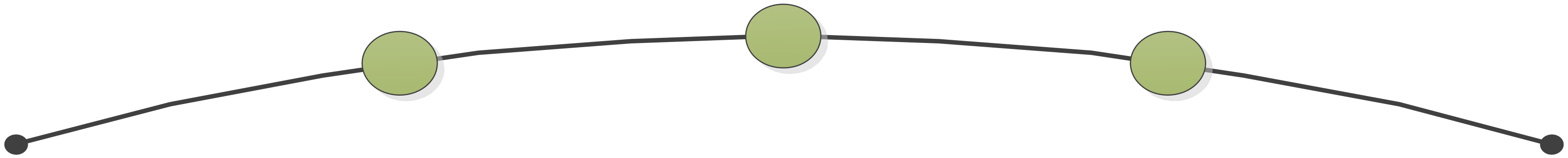
- Based on reliability sub-items

Assumptions

- Assume:
  - sub-items are either operational or non-operational, i.e. two states
- The state of sub-item *i* will be described by a binary variable x_i:
  - $x_i = 1$ if sub-item operational,
  - $x_i = 0$ if sub-item non-operational
- Assume:
  - item is either operational or non-operational, i.e. two states
- The dependence of an item's state on the states of its sub-items is determined by means of a structure function $\phi(\mathbf{x})$,
  - where $x = (x_1, x_2, \ldots x_n)$
  - $\phi(\mathbf{x}) = 1$ if item operational, and
  - $\phi(\mathbf{x}) = 0$ if item non-operational.

Sub-items in series

- An item with sub-items connected in series is operational if and only if all of its sub-items are operational

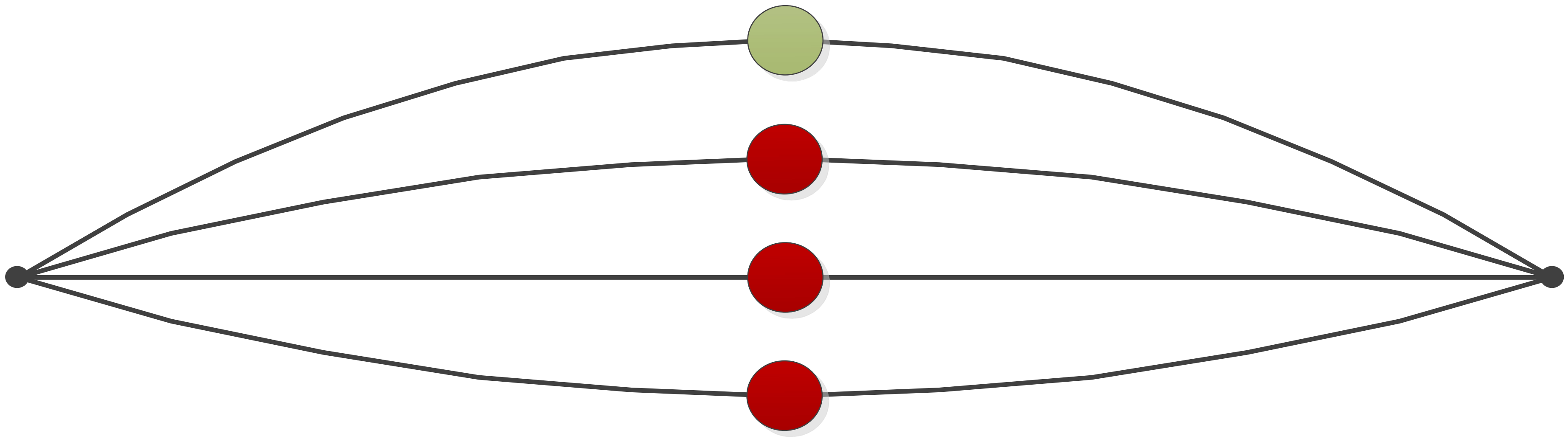


$$\phi\left(\vec{x}\right) = \prod_{i=1}^{n} x_i = \min_{1 \le i \le n} x_i \quad \Rightarrow \quad \vec{R}(t) = \prod_{i=1}^{n} R_i(t)$$

Reliability: Item comprised of sub-items

Sub-items in parallel

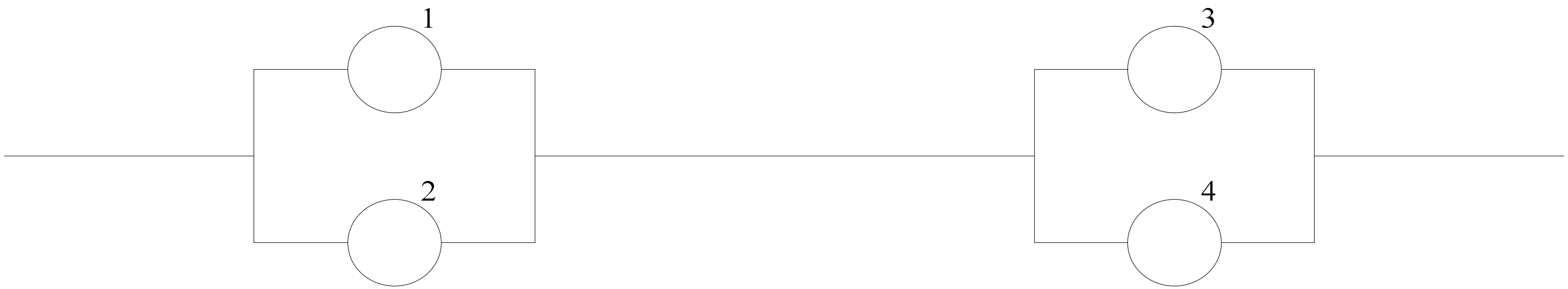
- An item with sub-items connected in parallel is operational if and only if at least one sub-item is operational



$$\phi\left(\vec{x}\right) = 1 - \prod_{i=1}^{n}\left(1 - x_i\right) = \max_{1\le i\le n} x_i \quad \Rightarrow \quad \vec{R}(t) = 1 - \prod_{i=1}^{n}\left(1 - R_i(t)\right)$$

Reliability: Item comprised of sub-items

Parallel sub-items connected in series



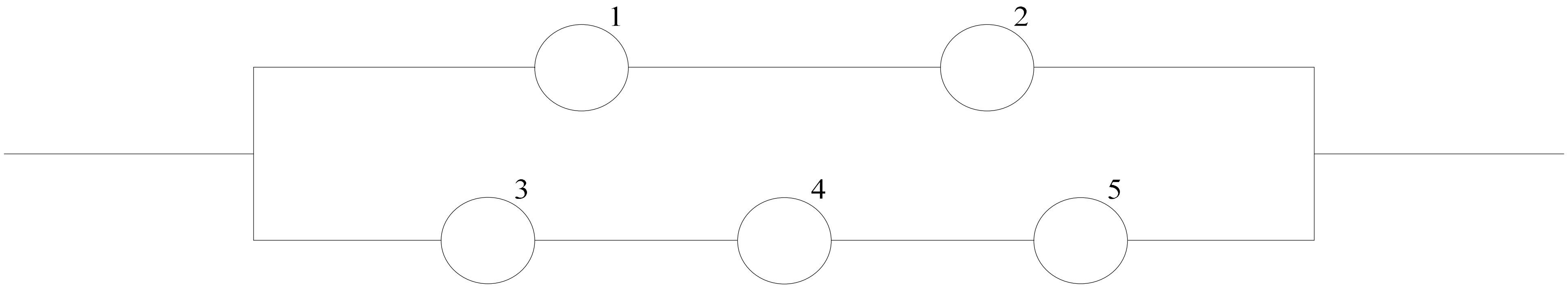
$$\phi\left(\vec{x}\right) = \left[1-\left(1-x_1\right)\cdot\left(1-x_2\right)\right]\cdot\left[1-\left(1-x_3\right)\cdot\left(1-x_4\right)\right]$$

$$\Downarrow$$

$$R = \left[1-(1-R_1)\cdot(1-R_2)\right]\cdot\left[1-(1-R_3)\cdot(1-R_4)\right]$$

Reliability: Item comprised of sub-items

Series sub-items connected in parallel



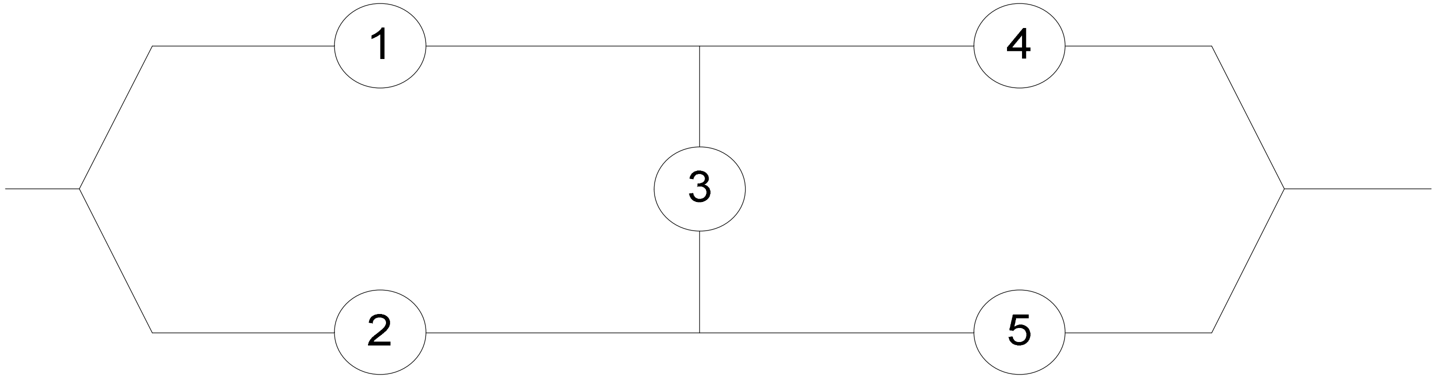
$$\phi\left(\vec{x}\right) = 1 - \left(1 - x_1 \cdot x_2\right) \cdot \left(1 - x_3 \cdot x_4 \cdot x_5\right)$$

$$\Downarrow$$

$$R = 1 - (1 - R_1 \cdot R_2) \cdot (1 - R_3 \cdot R_4 \cdot R_5)$$

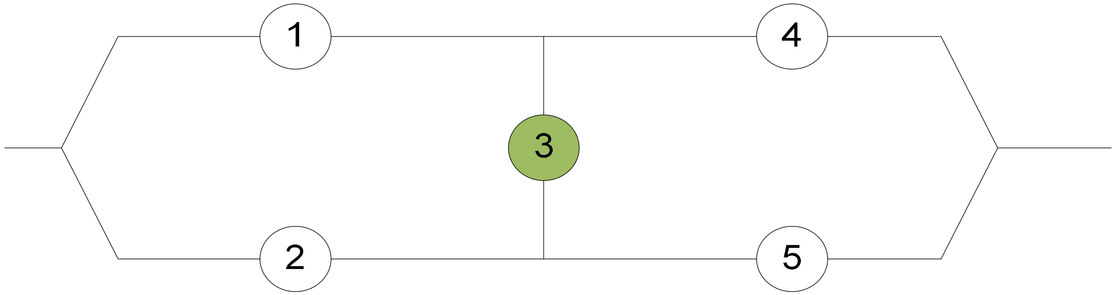
Reliability: Item comprised of sub-items

Complex configurations – pivotal decomposition

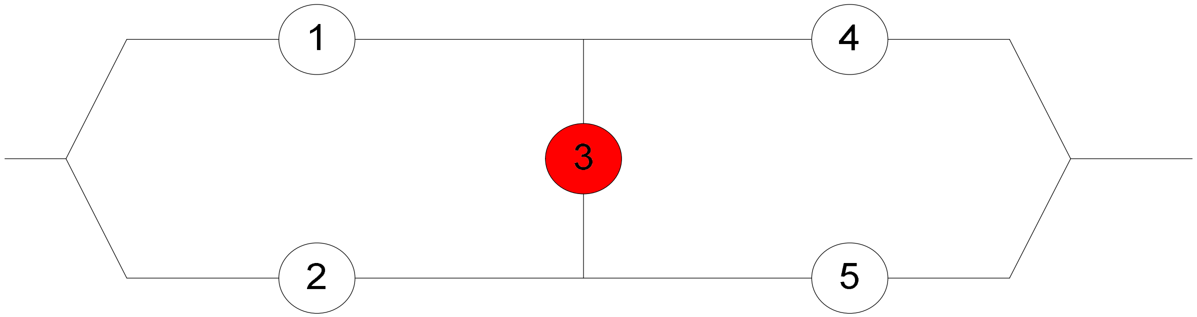


Reliability: Item comprised of sub-items

Complex configurations – pivotal decomposition



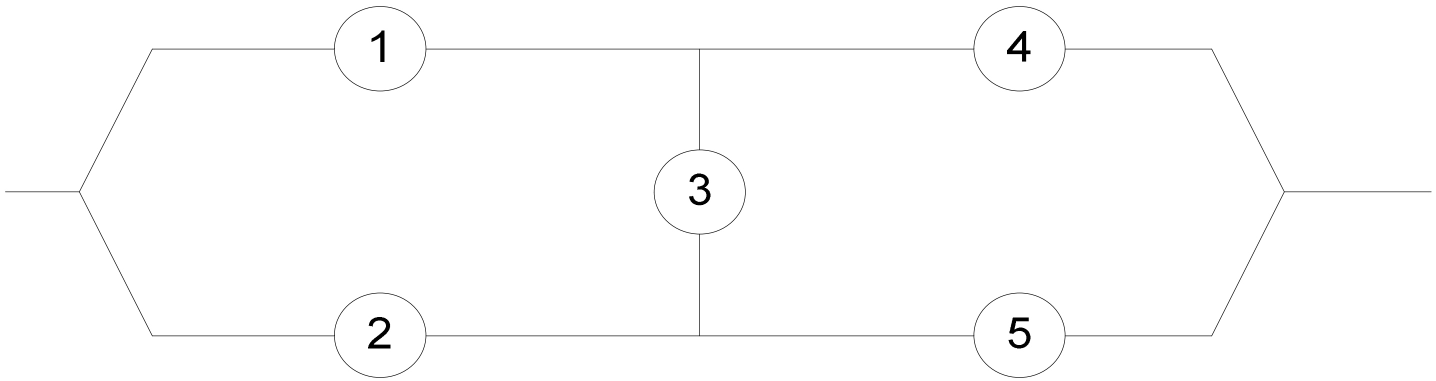
$$R\left(1_3, \vec{x}\right) = \left[1 - \left(1 - R_1\right)\left(1 - R_2\right)\right] \cdot \left[1 - \left(1 - R_4\right)\left(1 - R_5\right)\right]$$



$$R\left(0_3, \vec{x}\right) = \left[1 - \left(1 - R_1 \cdot R_4\right)\right] \cdot \left[1 - \left(1 - R_2 \cdot R_5\right)\right]$$

Reliability: Item comprised of sub-items

Complex configurations – pivotal decomposition



$$R = R_3 \cdot R\left(1_3, \vec{x}\right) + \left(1 - R_3\right) \cdot R\left(0_3; \vec{x}\right)$$

$$= R_1 \cdot R_3 \cdot R_4 + R_1 \cdot R_3 \cdot R_5 + R_2 \cdot R_3 \cdot R_4 + R_2 \cdot R_3 \cdot R_5 + R_1 \cdot R_2 \cdot R_4 \cdot R_5$$

$$- R_1 \cdot R_2 \cdot R_3 \cdot R_4 - R_1 \cdot R_3 \cdot R_4 \cdot R_5 - R_1 \cdot R_2 \cdot R_3 \cdot R_5 - R_2 \cdot R_3 \cdot R_4 \cdot R_5$$

Minimal paths and minimal cuts

- Any monotone item can be represented in two equivalent ways:
  - as parallel sub-items connected in series each being a minimal cut set, or
  - as series sub-items connected in parallel each being a minimal path set

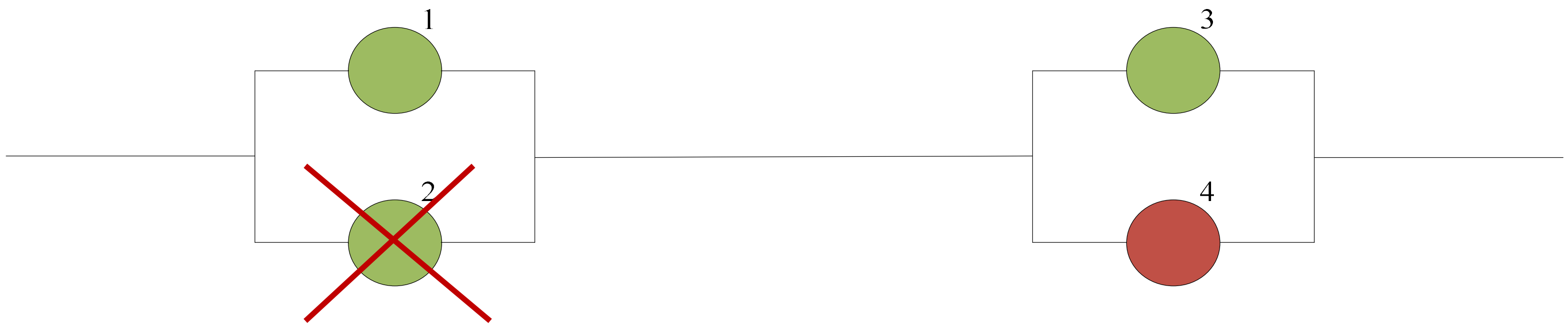
- Let $P_1, P_2, \ldots, P_s$ = the minimal path sets of the item. Then

$$R\left(\vec{x}\right) = 1 - \prod_{j=1}^{s}\left(1 - \prod_{i \in P_j} R_i\right)$$

- Let $C_1, C_2, \ldots C_k$ = the minimal cut sets of the item. Then

$$R\left(\vec{x}\right) = \prod_{j=1}^{k}\left(1 - \prod_{i \in C_j}\left(1 - R_i\right)\right)$$

Minimal paths and minimal cuts – Example



Reliability: Item comprised of sub-items

Minimal paths and minimal cuts – Example

- The structure function for these parallel sub-items connected in series can be based

  - on minimal cuts {1,2} and {3,4},

$$R(\vec{x}) = \left[1-(1-R_1)\cdot(1-R_2)\right]\cdot\left[1-(1-R_3)\cdot(1-R_4)\right]$$

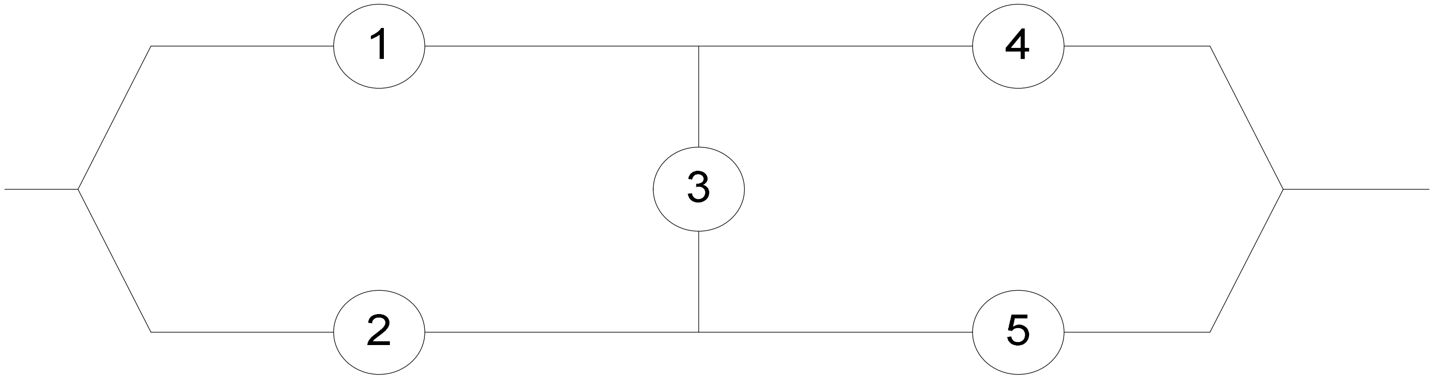
  - on minimal paths: {1,3}, {1,4}, {2,3}, {2,4}.

$$R(\vec{x}) = \left[1-(1-R_1\cdot R_3)\cdot(1-R_1\cdot R_4)\cdot(1-R_2\cdot R_3)\cdot(1-R_2\cdot R_4)\right]$$

Pivotal decomposition vs. minimal paths

Challenge:

Show that the minimal path method will give the same answer as pivotal decompositon



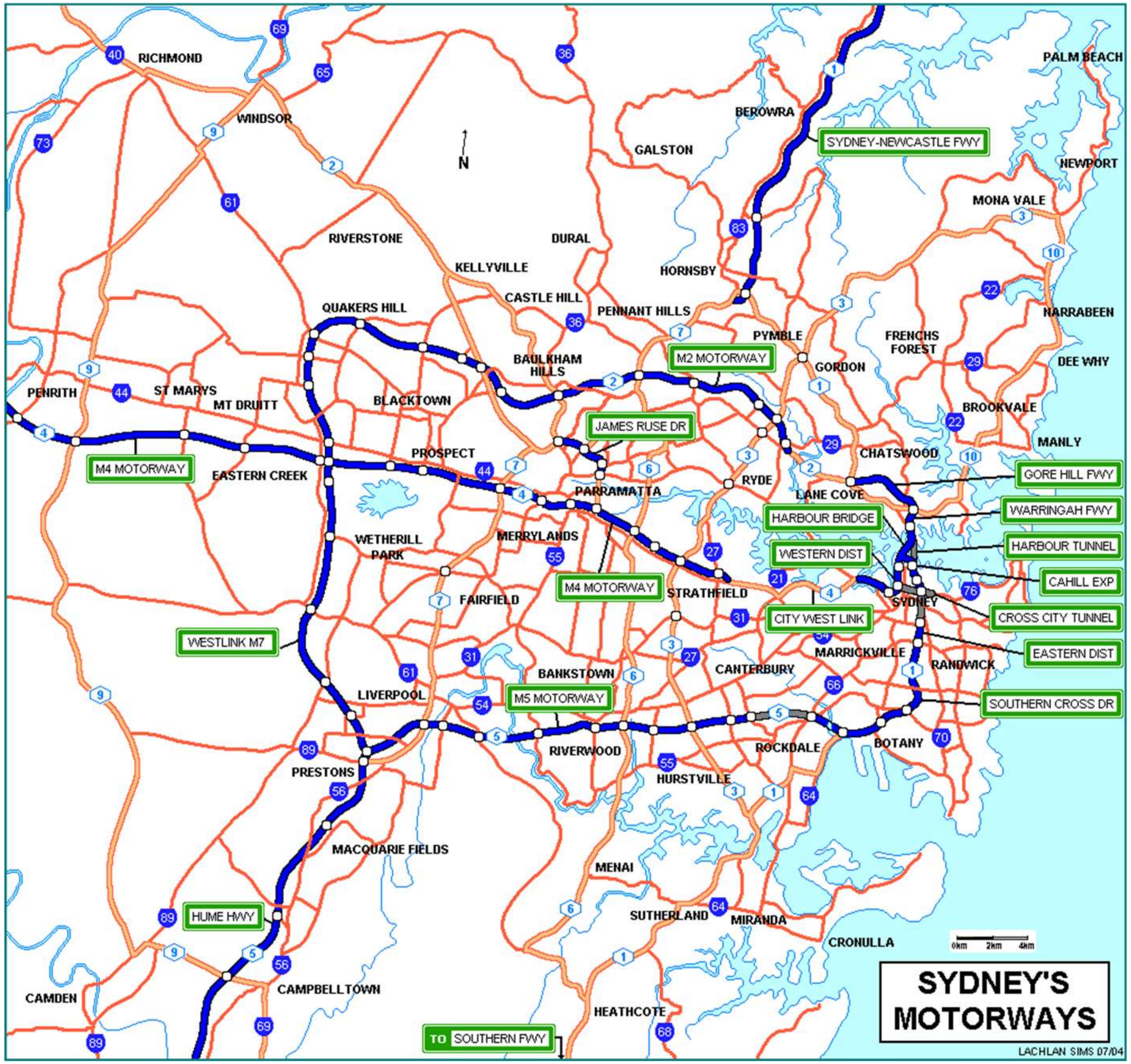
$$R\left(\vec{X}\right) = 1 - \left(1 - R_1 \cdot R_3 \cdot R_5\right) \cdot \left(1 - R_2 \cdot R_3 \cdot R_4\right) \cdot \left(1 - R_2 \cdot R_5\right) \cdot \left(1 - R_1 \cdot R_4\right)$$

Time!

- What is the reliability of a road link with 4 objects that have mean life times of 60, 45, 105 and 32 *tus*?

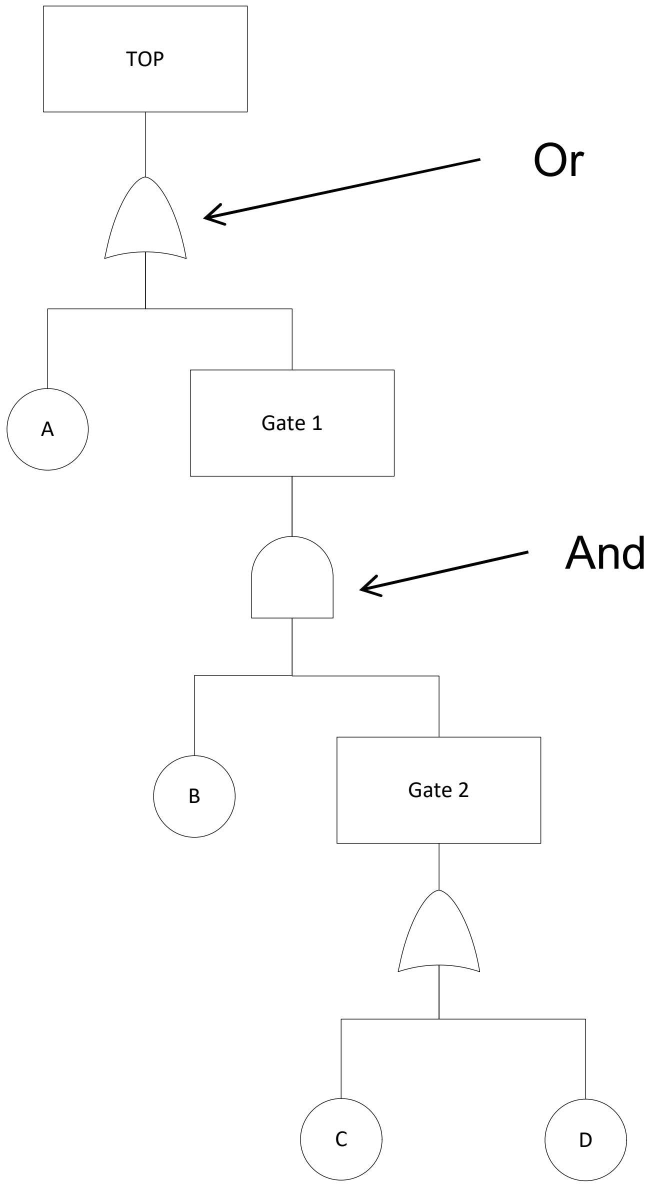
Reliability

Sub-item importance



Sub-item importance

Top event is failure



$q_a, q_c = 0.1$

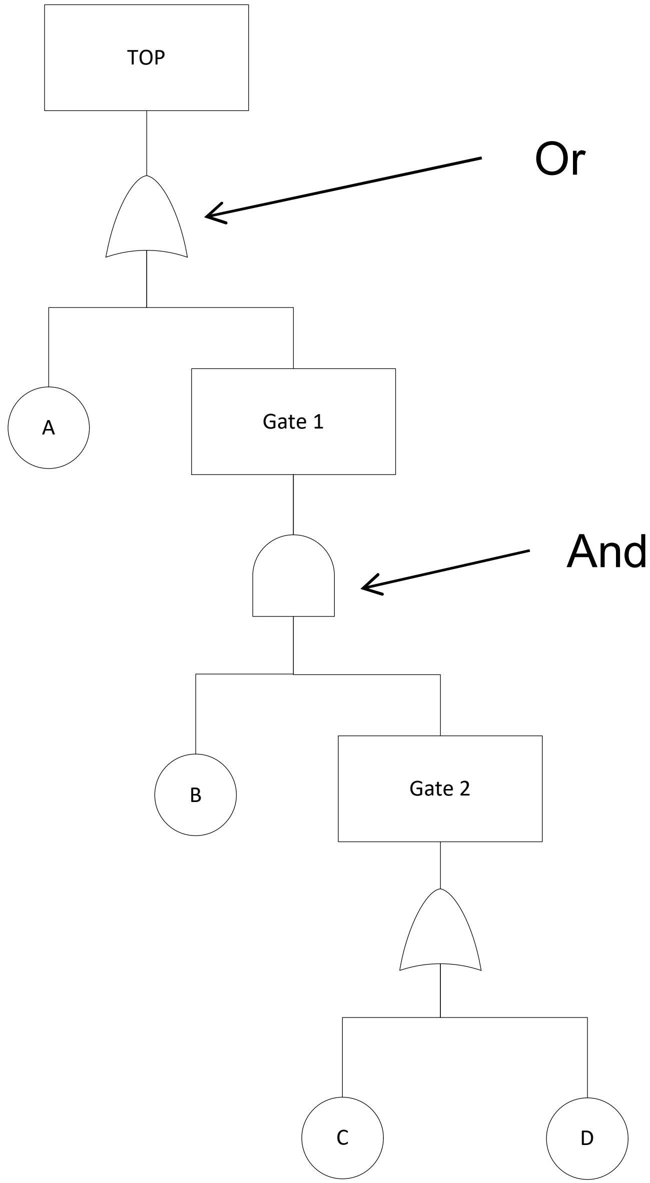
$q_b, q_d = 0.2$

Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub - item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub - items}$$

Importance of sub-item A

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	B	C	D	
1				
2				
3				
4				
5				
6				
7				
8				

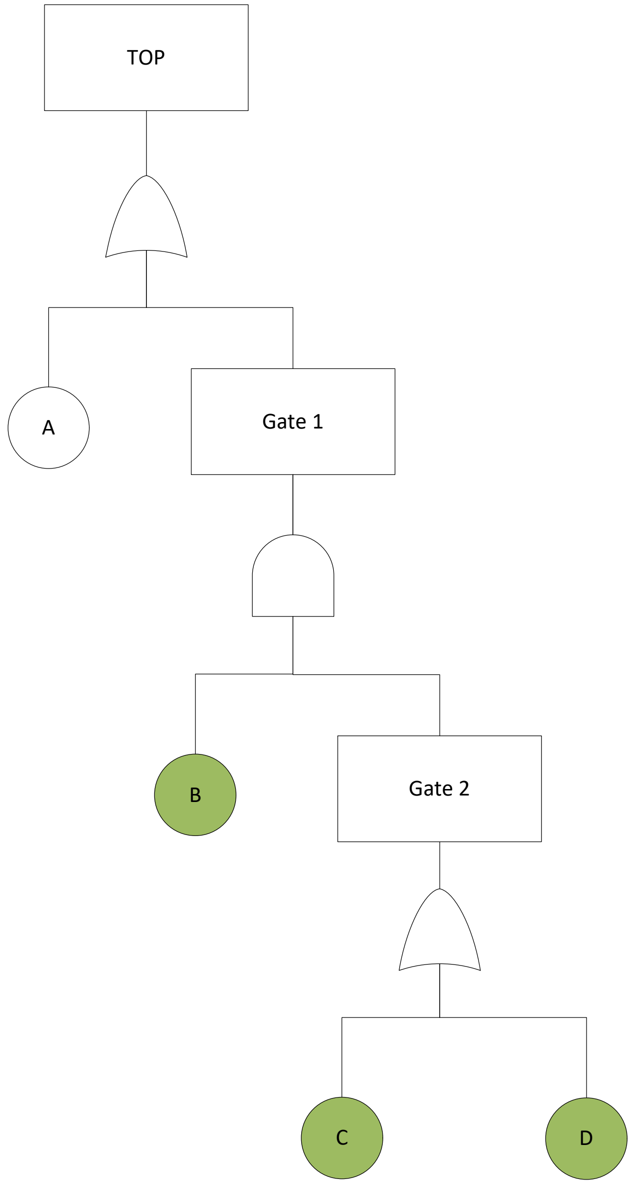


Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Importance of sub-item A

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	B	C	D	
1	W	W	W	Y
2				
3				
4				
5				
6				
7				
8				

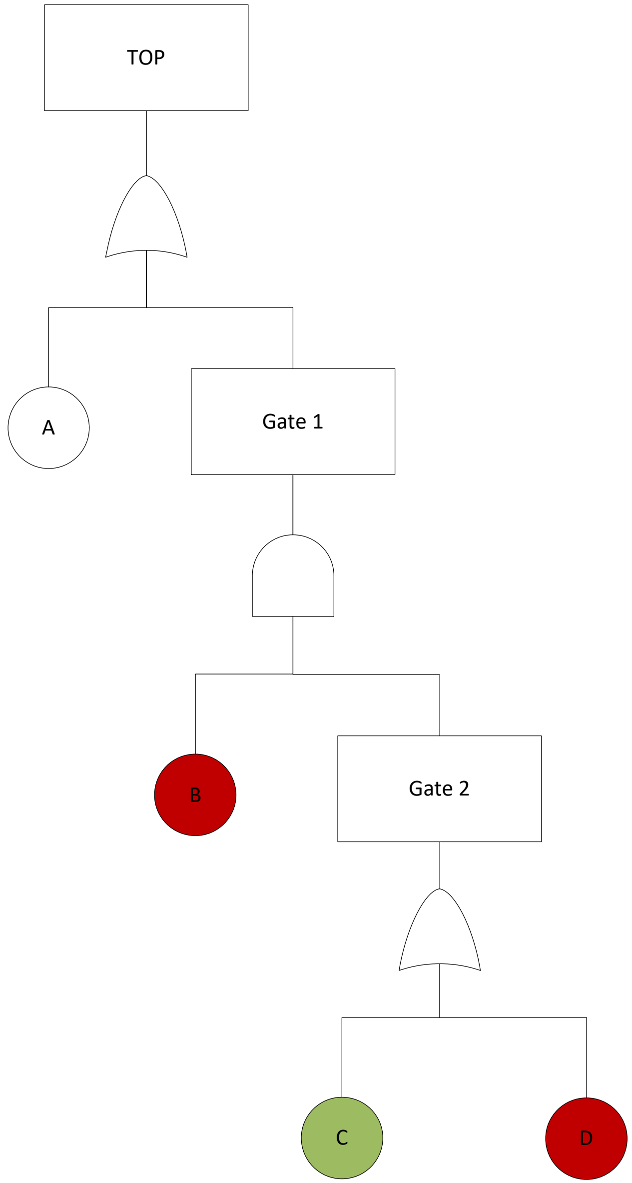


Reliability: Sub-item importance
Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Importance of sub-item A

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	B	C	D	
1	W	W	W	Y
2	W	W	F	Y
3	W	F	W	Y
4	W	F	F	Y
5	F	W	W	Y
6	F	W	F	N
7				
8				

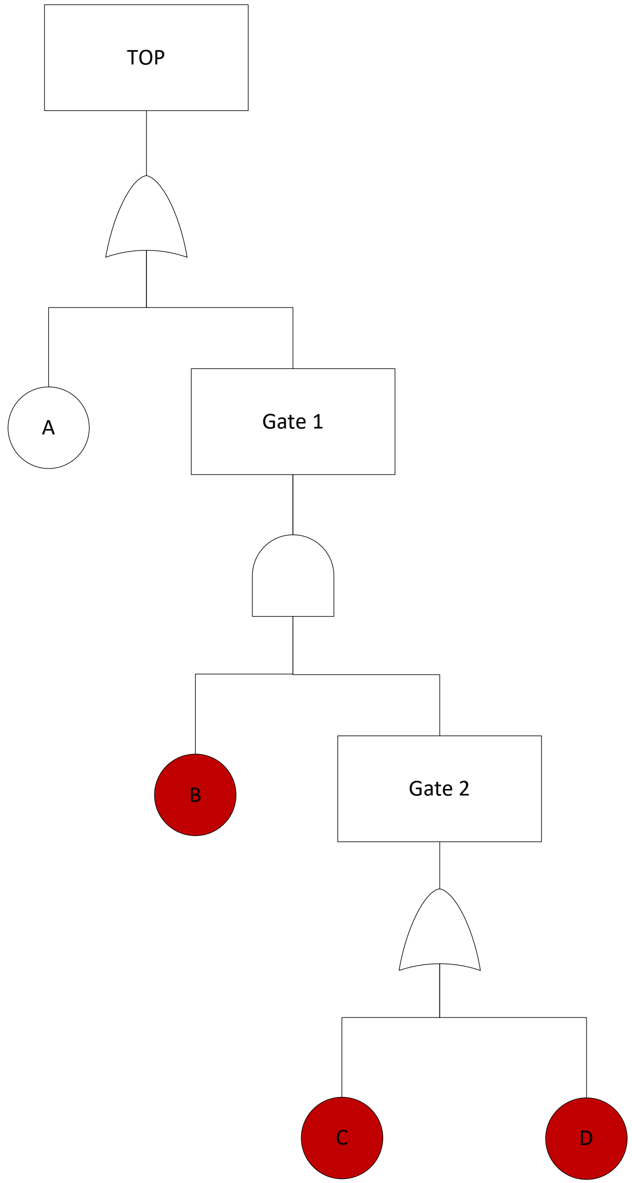


Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Importance of sub-item A

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	B	C	D	
1	W	W	W	Y
2	W	W	F	Y
3	W	F	W	Y
4	W	F	F	Y
5	F	W	W	Y
6	F	W	F	N
7	F	F	W	N
8	F	F	F	N



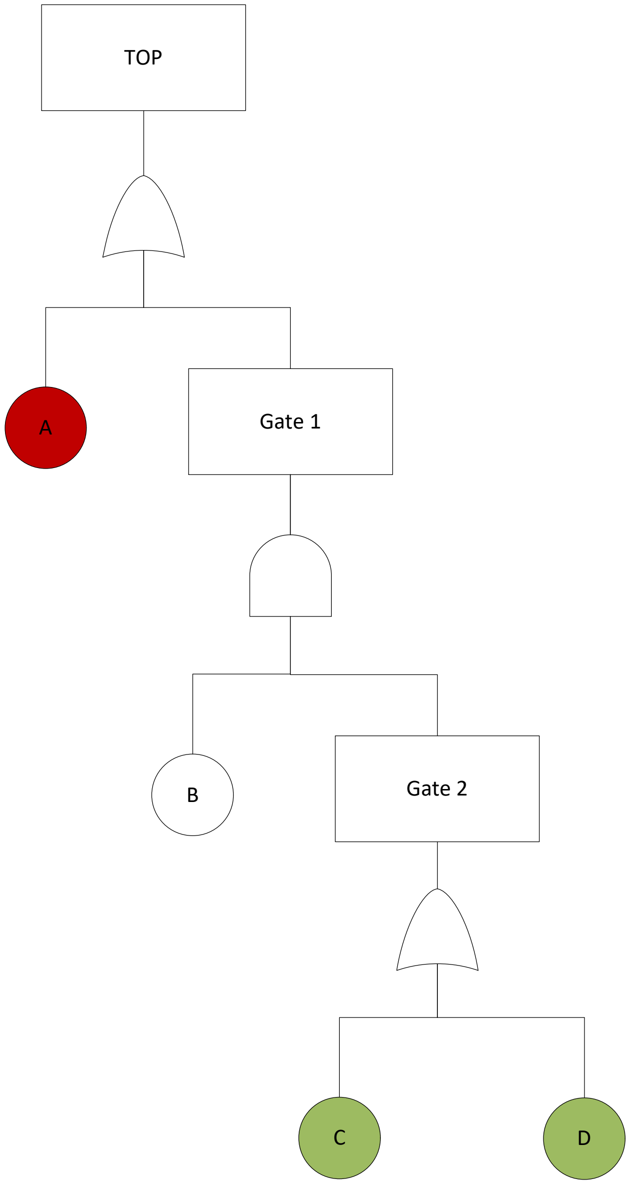
Reliability: Sub-item importance

Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Importance of sub-item B

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	A	C	D	
1	W	W	W	N
2	W	W	F	Y
3	W	F	W	Y
4	W	F	F	Y
5	F	W	W	N

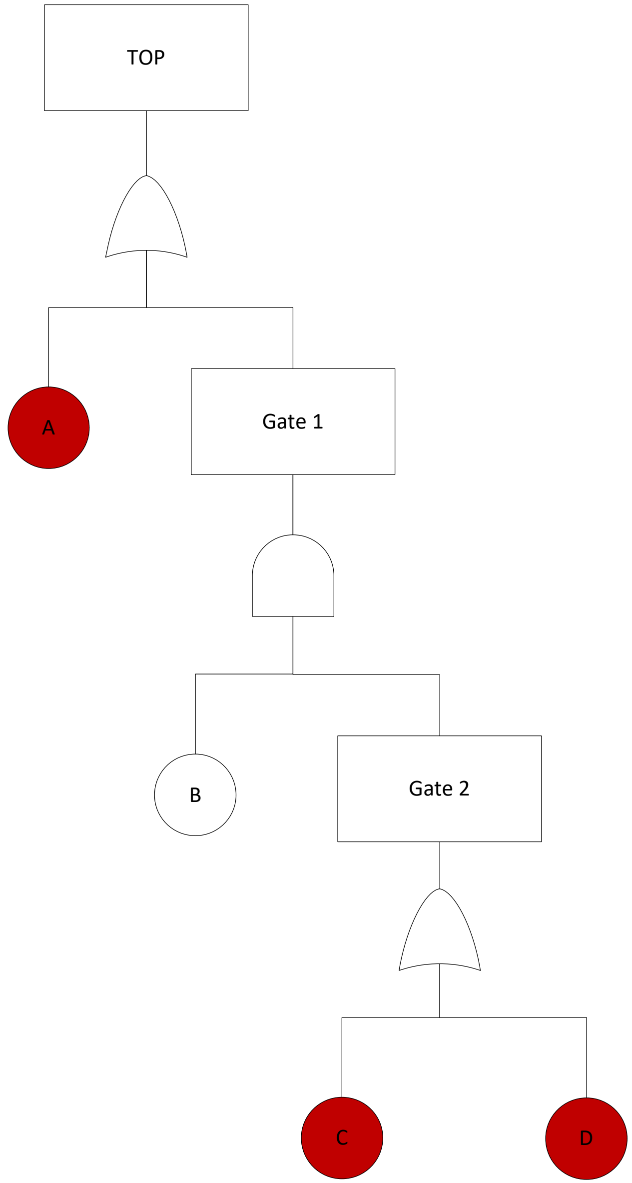


Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Importance of sub-item B

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	A	C	D	
1	W	W	W	N
2	W	W	F	Y
3	W	F	W	Y
4	W	F	F	Y
5	F	W	W	N
6	F	W	F	N
7	F	F	W	N
8	F	F	F	N



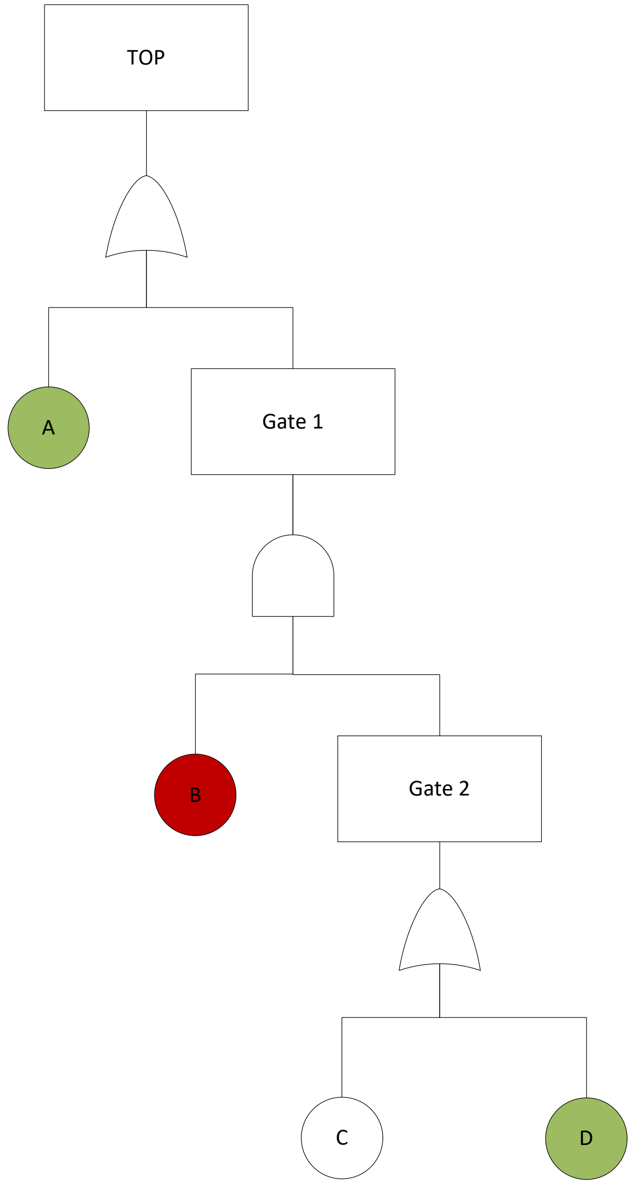
Reliability: Sub-item importance

Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Importance of sub-item C

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	A	B	D	
1	W	W	W	N
2	W	W	F	N
3	W	F	W	Y



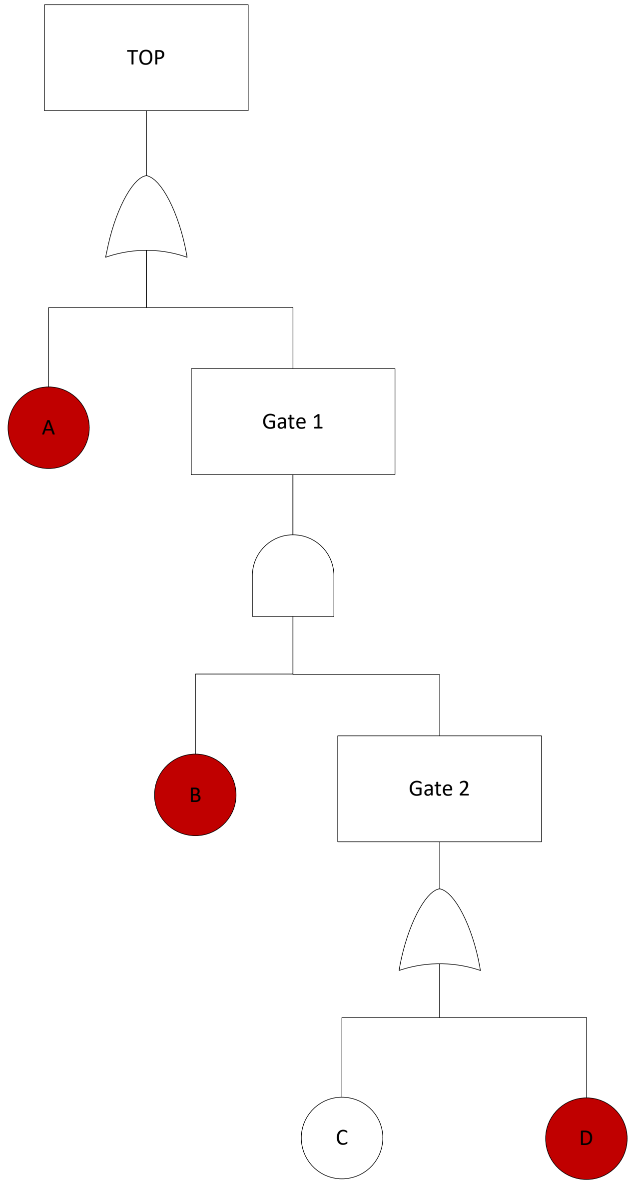
Reliability: Sub-item importance

Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Importance of sub-item C

Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	A	B	D	
1	W	W	W	N
2	W	W	F	N
3	W	F	W	Y
4	W	F	F	N
5	F	W	W	N
6	F	W	F	N
7	F	F	W	N
8	F	F	F	N

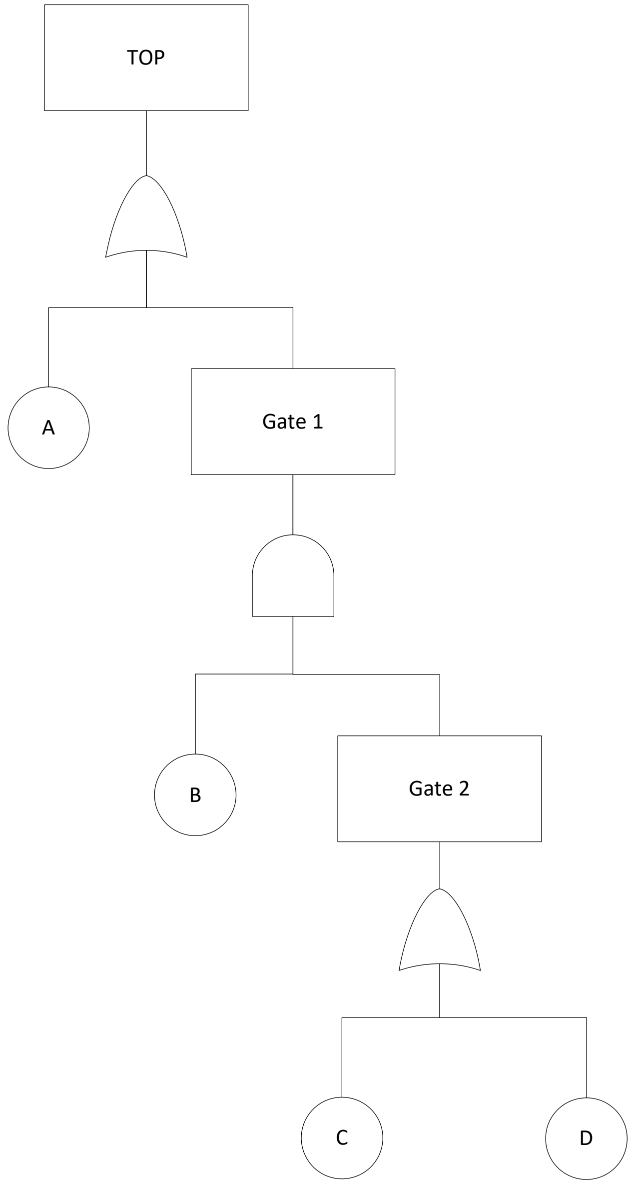


Reliability: Sub-item importance

Structural measure of importance

$$I_i = \frac{number\ of\ critical\ states\ for\ sub-item\ i}{total\ number\ of\ states\ for\ the\ (n-1)\ remaining\ sub-items}$$

Measure	Sub-items			
	A	B	C	D
Structural importance	0.625	0.375	0.125	0.125



Reliability: Sub-item importance

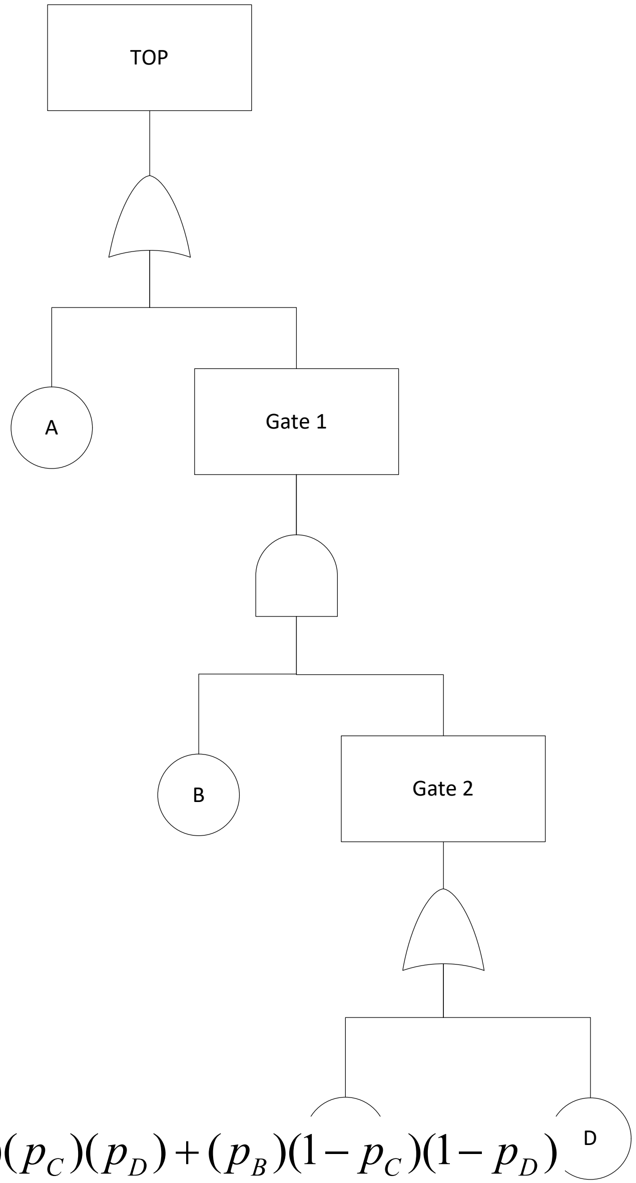
Birnbaum measure of importance

- the probability that the item is in a state in which the failure of sub-item *i* will cause failure of the item

$$I_i^B = \sum_j^J p_j^{cs_i}$$

j = item state

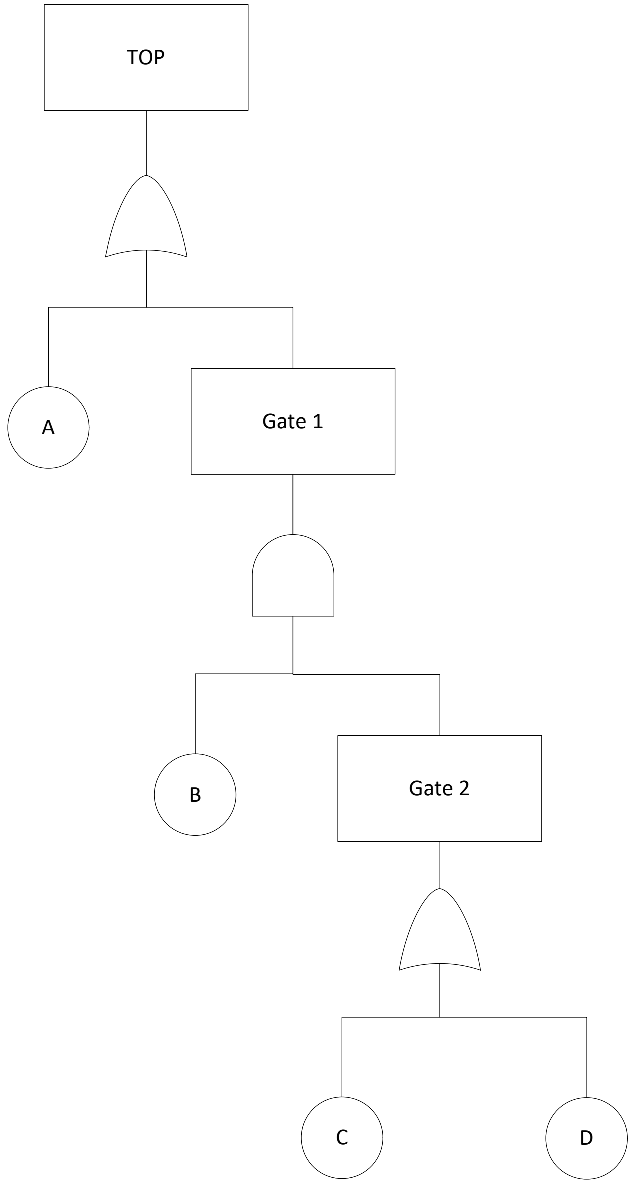
Item state	Sub-item states			Does failure of sub-item A cause failure of item?
	B	C	D	
1	W	W	W	Y
2	W	W	F	Y
3	W	F	W	Y
4	W	F	F	Y
5	F	W	W	Y
6	F	W	F	N
7	F	F	W	N
8	F	F	F	N



$$I_A^B = (1-p_B)(1-p_C)(1-p_D) + (1-p_B)(1-p_C)(p_D) + (1-p_B)(p_C)(1-p_D) + (1-p_B)(p_C)(p_D) + (p_B)(1-p_C)(1-p_D)$$
$$= 0.944$$

Birnbaum measure of importance

Measure	Sub-items			
	A	B	C	D
Structural importance	0.625	0.375	0.125	0.125
Birnbaum importance	0.944	0.252	0.144	0.162



Criticality measure of importance

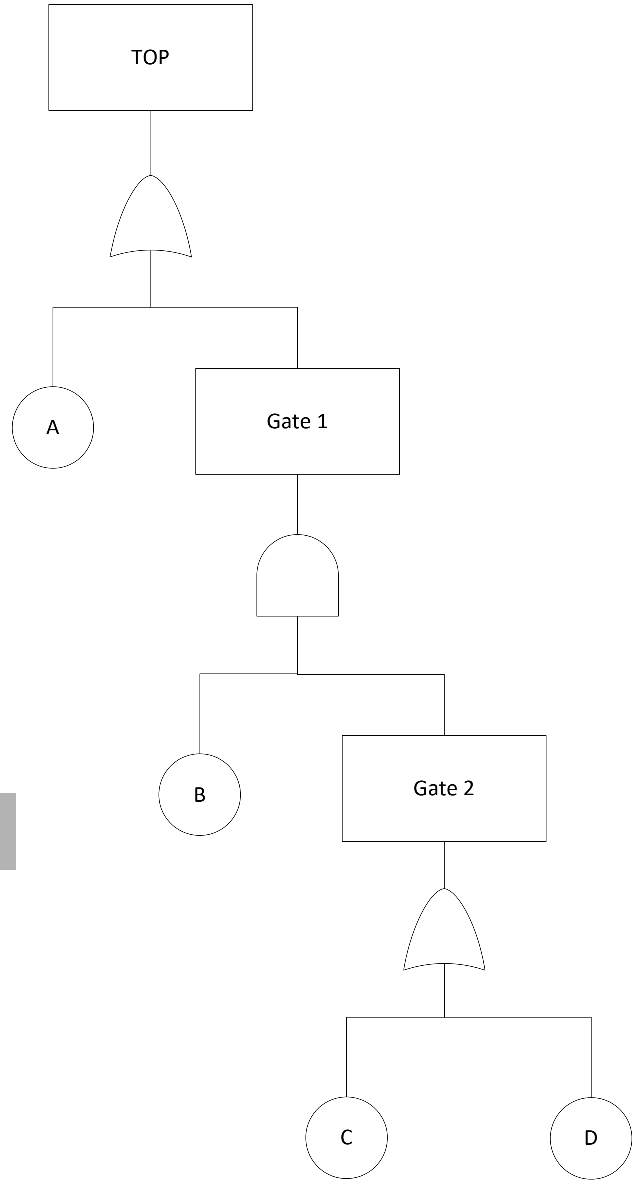
- the contribution of the sub-item to the probability of failure of the item due to the item being in a state in which the failure of the sub-item would cause failure of the item and the sub-item failing

$$I_i^{CR}(t) = \frac{\sum_j^J p_j^{cs_i} \cdot (1 - R_i(t))}{1 - R(t)}$$

Prob. of item being in a state where failure of sub-item would cause failure

Prob. of failure of sub-item

Prob. of failure of item



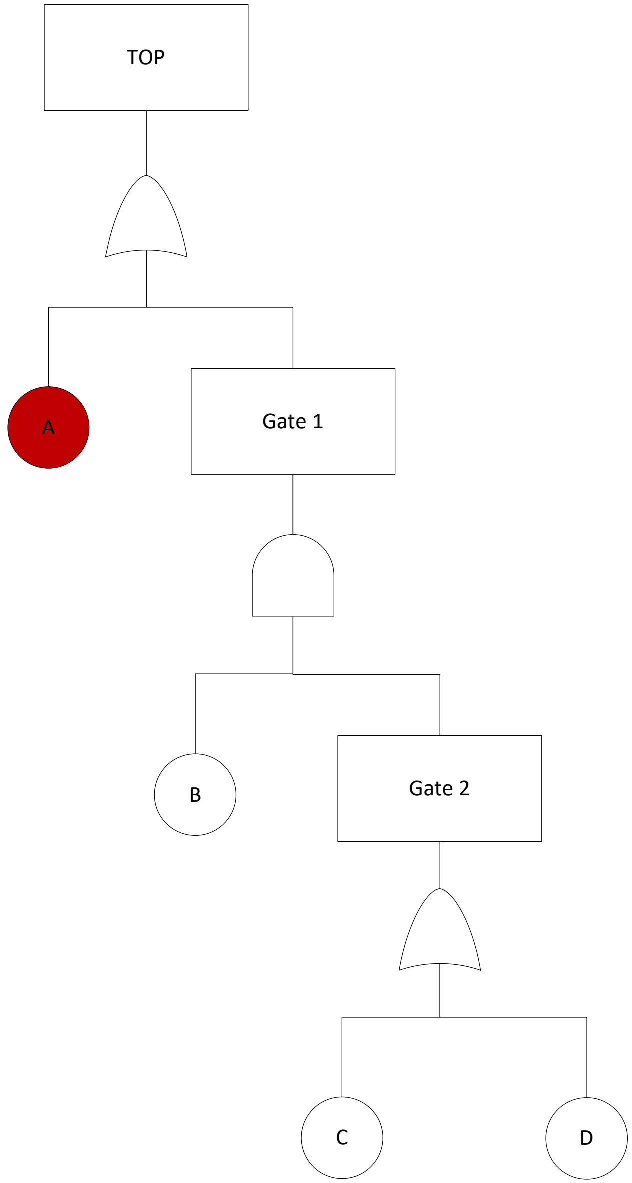
Reliability: Sub-item importance

Criticality measure of importance

- the contribution of the sub-item to the probability of failure of the item due to the item being in a state in which the failure of the sub-item would cause failure of the item and the sub-item failing

$$I_i^{CR}(t) = \frac{\sum_{j}^{J} p_j^{cs_i} \cdot (1 - R_i(t))}{1 - R(t)}$$

- The minimal cut sets are

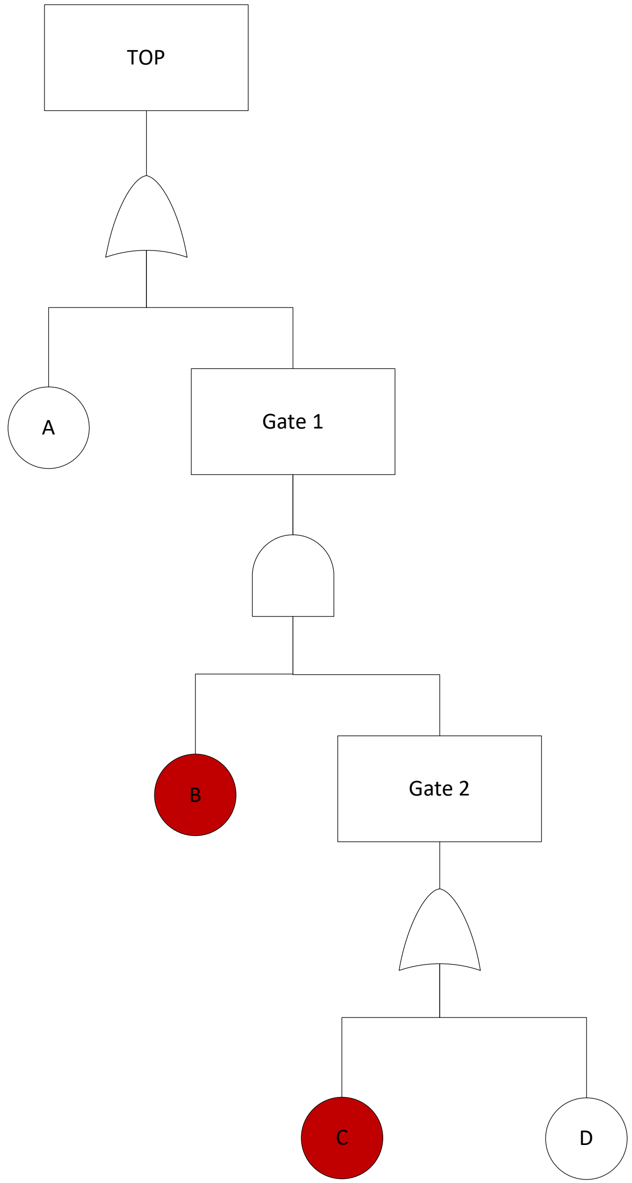


Criticality measure of importance

- the contribution of the sub-item to the probability of failure of the item due to the item being in a state in which the failure of the sub-item would cause failure of the item and the sub-item failing

$$I_i^{CR}(t) = \frac{\sum_j^J p_j^{cs_i} \cdot (1 - R_i(t))}{1 - R(t)}$$

- The minimal cut sets are

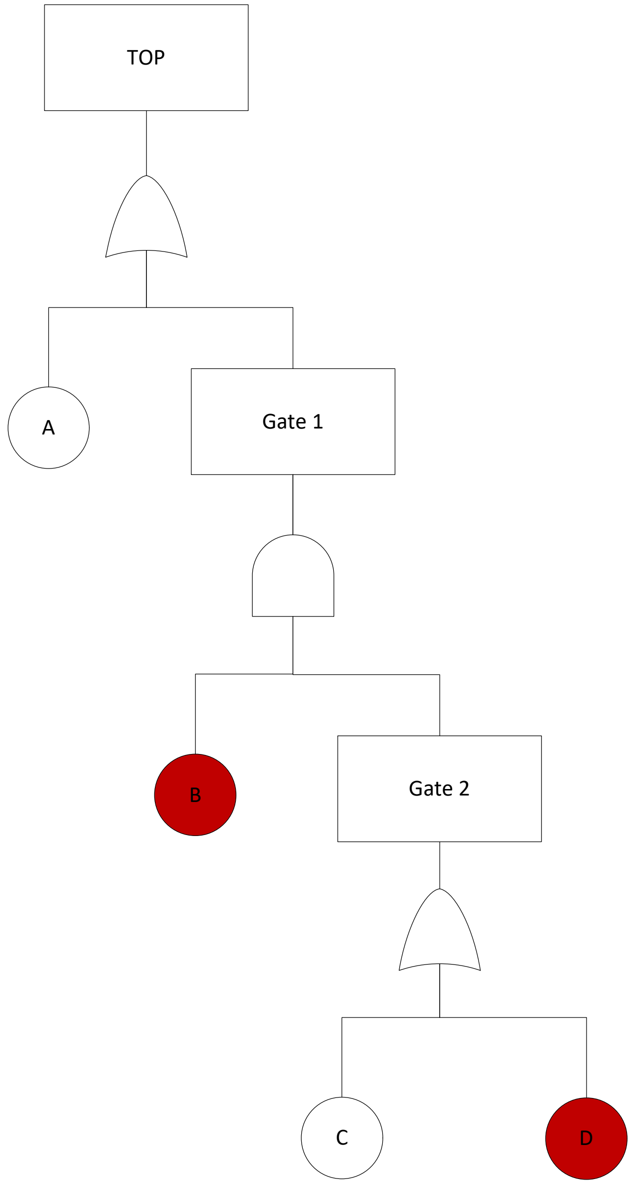


Criticality measure of importance

- the contribution of the sub-item to the probability of failure of the item due to the item being in a state in which the failure of the sub-item would cause failure of the item and the sub-item failing

$$I_i^{CR}(t) = \frac{\sum_j^J p_j^{cs_i} \cdot (1 - R_i(t))}{1 - R(t)}$$

- The minimal cut sets are



Reliability: Sub-item importance

Criticality measure of importance

- the contribution of the sub-item to the probability of failure of the item due to the item being in a state in which the failure of the sub-item would cause failure of the item and the sub-item failing

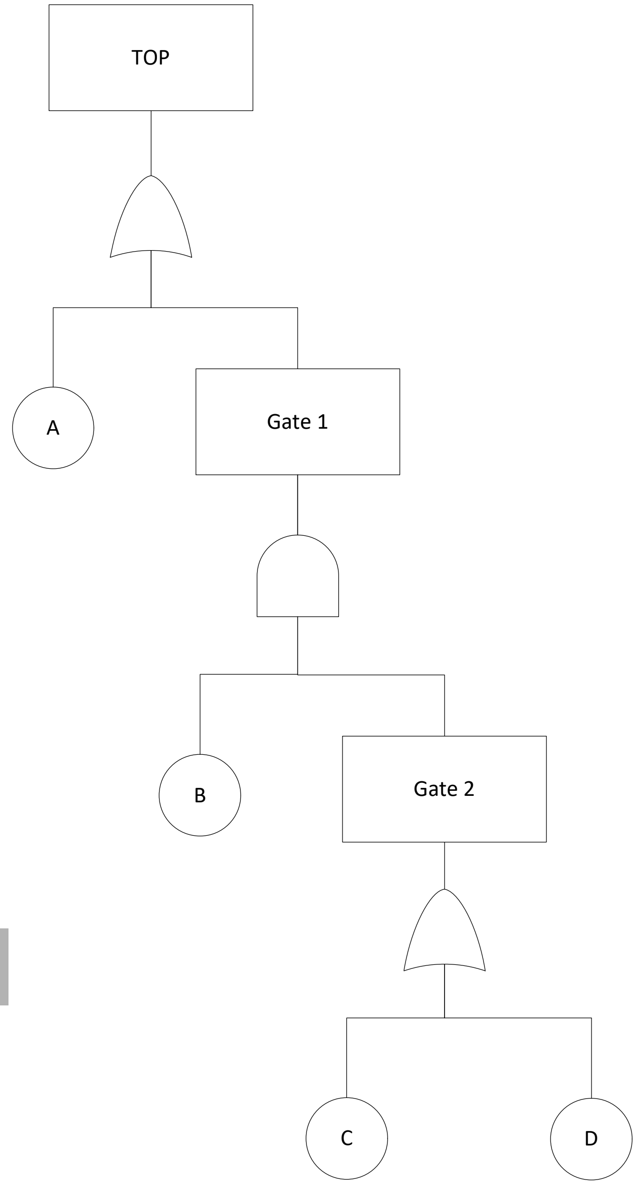
$$I_i^{CR}(t) = \frac{\sum_{j}^{J} p_j^{cs_i} \cdot (1 - R_i(t))}{1 - R(t)}$$

- The minimal cut sets are

$$P_i = p_A + p_B q_C + p_B p_D - p_A p_B p_C - p_A p_B p_D - p_B p_C p_D + p_A p_B p_C p_D$$

$$P_i = 0.1 + 0.02 + 0.04 - 0.002 - 0.004 - 0.004 + 0.0004$$

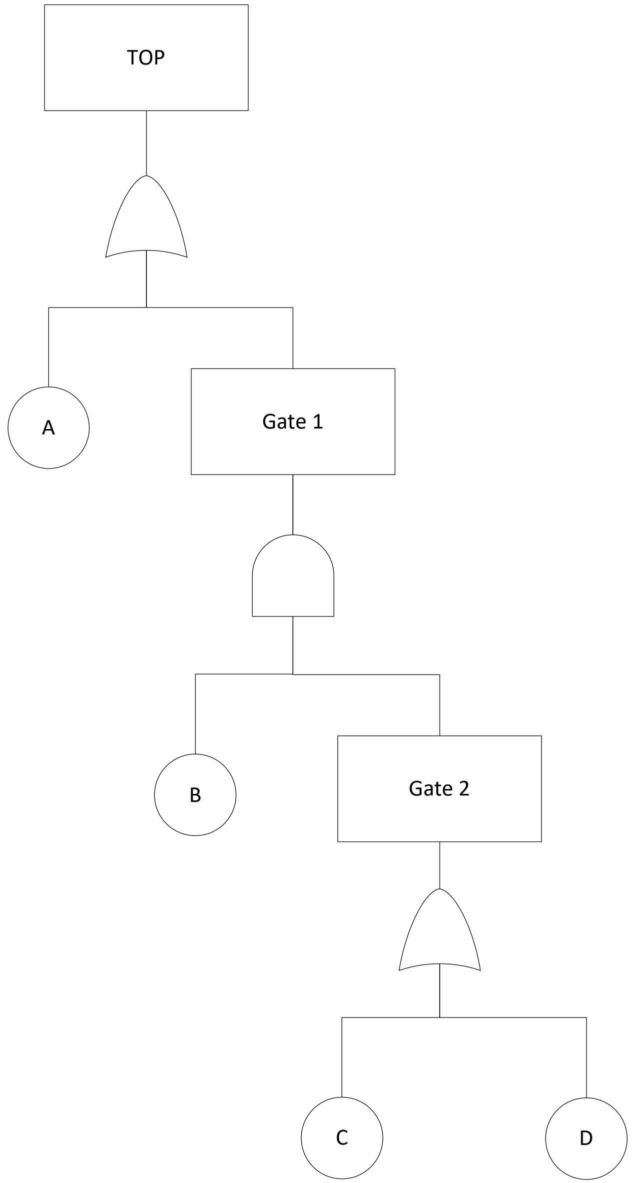
$$P_i = 0.1504$$



Reliability: Sub-item importance

Criticality measure of importance

- the contribution of the sub-item to the probability of failure of the item due to the item being in a state in which the failure of the sub-item would cause failure of the item and the sub-item failing



$$I_i^{CR}(t) = \frac{\sum_j^J p_j^{cs_i} \cdot (1 - R_i(t))}{1 - R(t)}$$

$$I_A^{CR}(t) = \frac{0.944 \cdot 0.1}{0.1504} = 0.6277 \qquad I_B^{CR}(t) = \frac{0.252 \cdot 0.2}{0.1504} = 0.3351$$

$$I_C^{CR}(t) = \frac{0.144 \cdot 0.1}{0.1504} = 0.0957 \qquad I_D^{CR}(t) = \frac{0.162 \cdot 0.2}{0.1504} = 0.2154$$

Fussel-Vessely measure of importance

- the sum of the probabilities of each of the minimal cut sets with the sub-item occurring divided by probability of failure of the item

$$I_i^{FV}(t) = \frac{\sum_{j=1}^{J} F_i^j(t)}{F(t)}$$

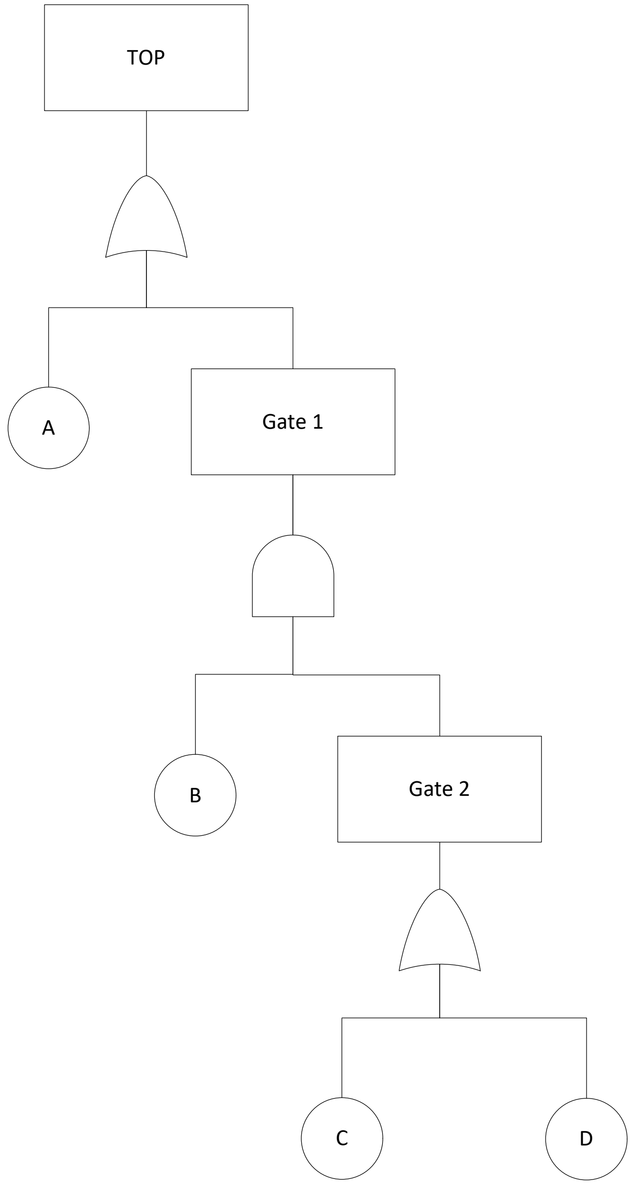
j = the minimal cut sets with the sub-item

$$I_A^{FV}(t) = \frac{p_A}{P} = \frac{0.1}{0.1504} = 0.6649$$

$$I_B^{FV}(t) = \frac{p_B \cdot (p_C + p_D - p_C \cdot p_D)}{P} = \frac{0.2 \cdot (0.1 + 0.2 - 0.002)}{0.1504} = 0.3723$$

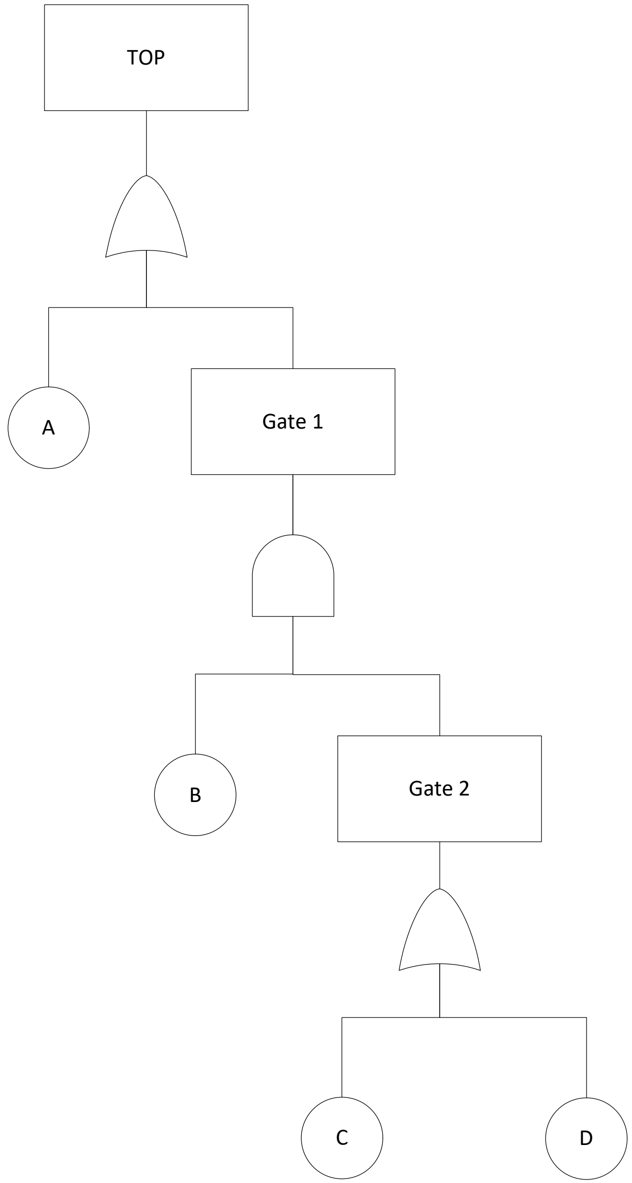
$$I_C^{FV}(t) = \frac{p_C \cdot p_B}{P} = \frac{0.1 \cdot 0.2}{0.1504} = 0.1330$$

$$I_D^{FV}(t) = \frac{p_D \cdot p_B}{P} = \frac{0.02 \cdot 0.02}{0.1504} = 0.2660$$



Comparison

Measure	Sub-items			
	A	B	C	D
Structural importance	0.625	0.375	0.125	0.125
Birnbaum importance	0.944	0.252	0.144	0.162
Criticality importance	0.6277	0.3351	0.0957	0.2154
Fussel-Vessely importance	0.6649	0.3723	0.1330	0.2660



Conclusion
Main points

- When using reliability as a performance indicator
  - prioritization of interventions with respect to net benefit is rarely possible
  - for an item, there are multiple ways to estimate the reliability.
  - or a sub-item – don’t forget that the LOS it provides depends on how it is integrated into the item as a whole and the reliability of the other sub-items in the item.

- Expectation of you (after this class, reading the script, the handouts, and doing the assignments):
  - to be able to estimate the reliability of interconnected sub-items
  - to be able to determine which objects within an interconnected sub-item should be repaired to maximize reliability