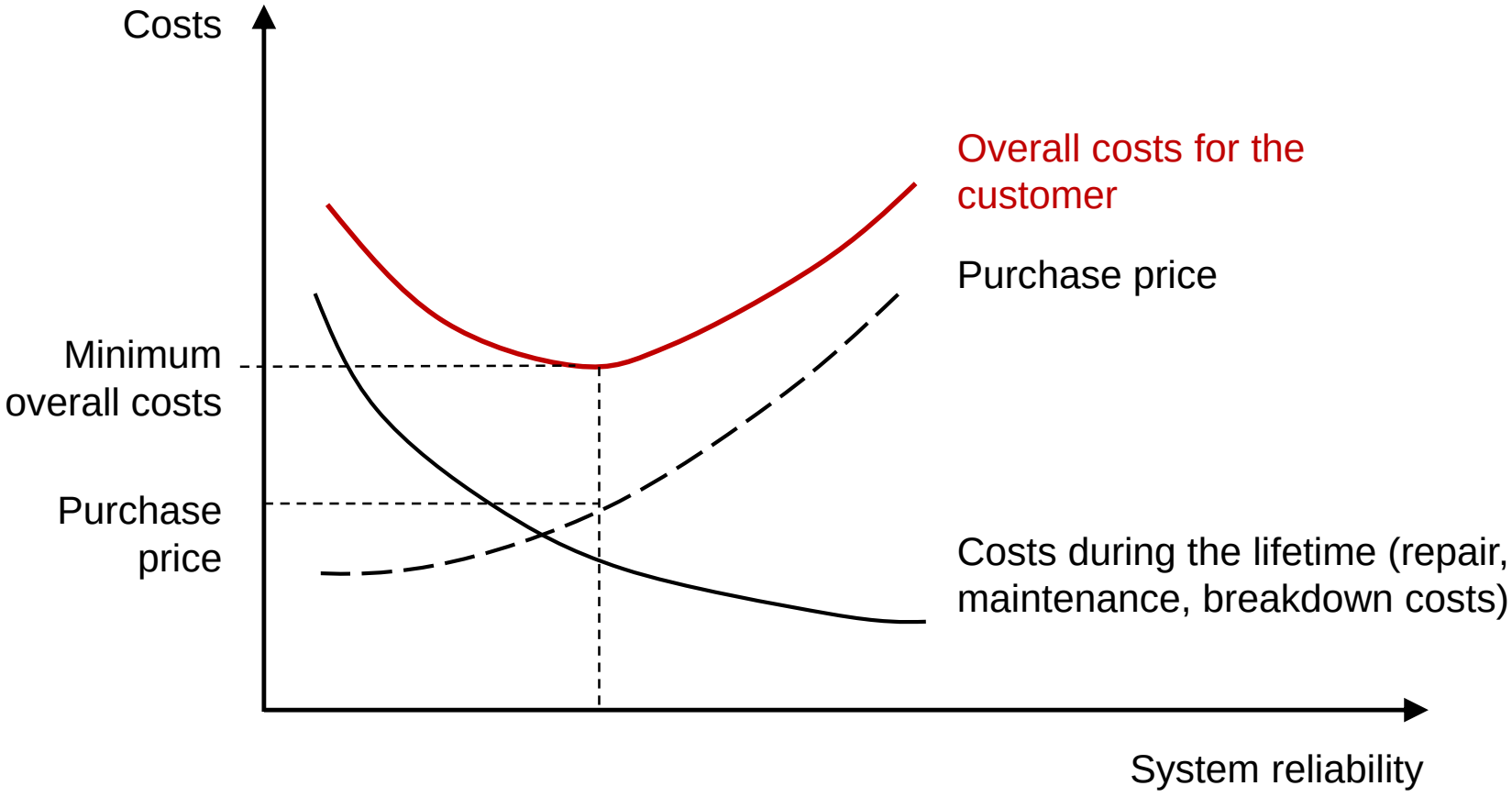
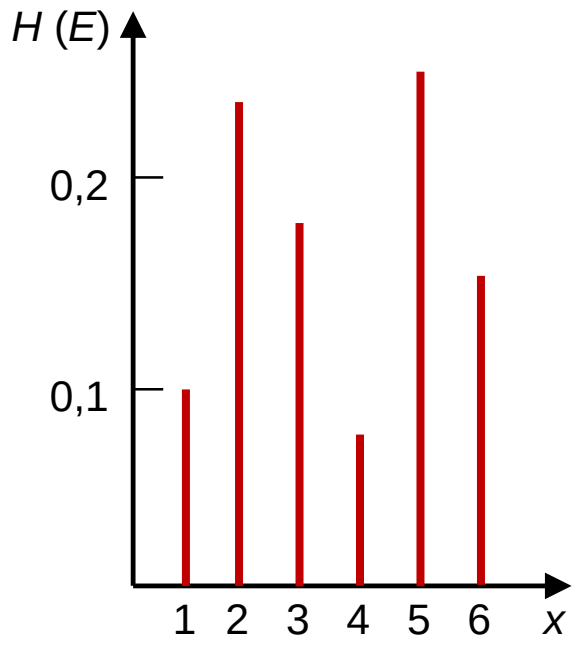
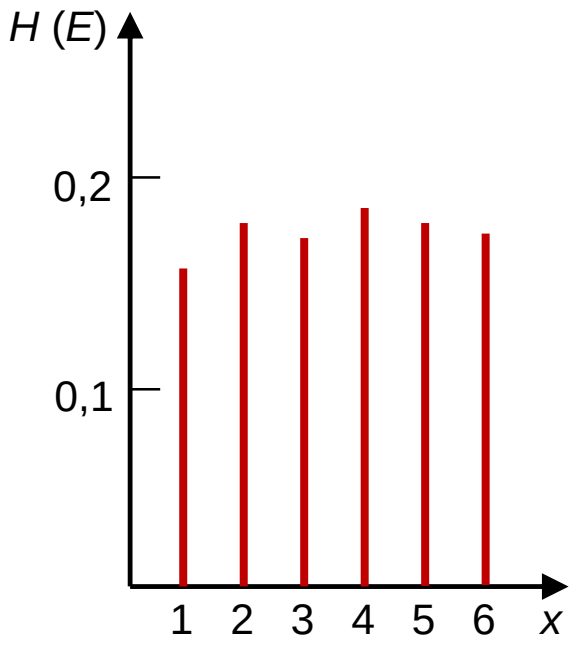
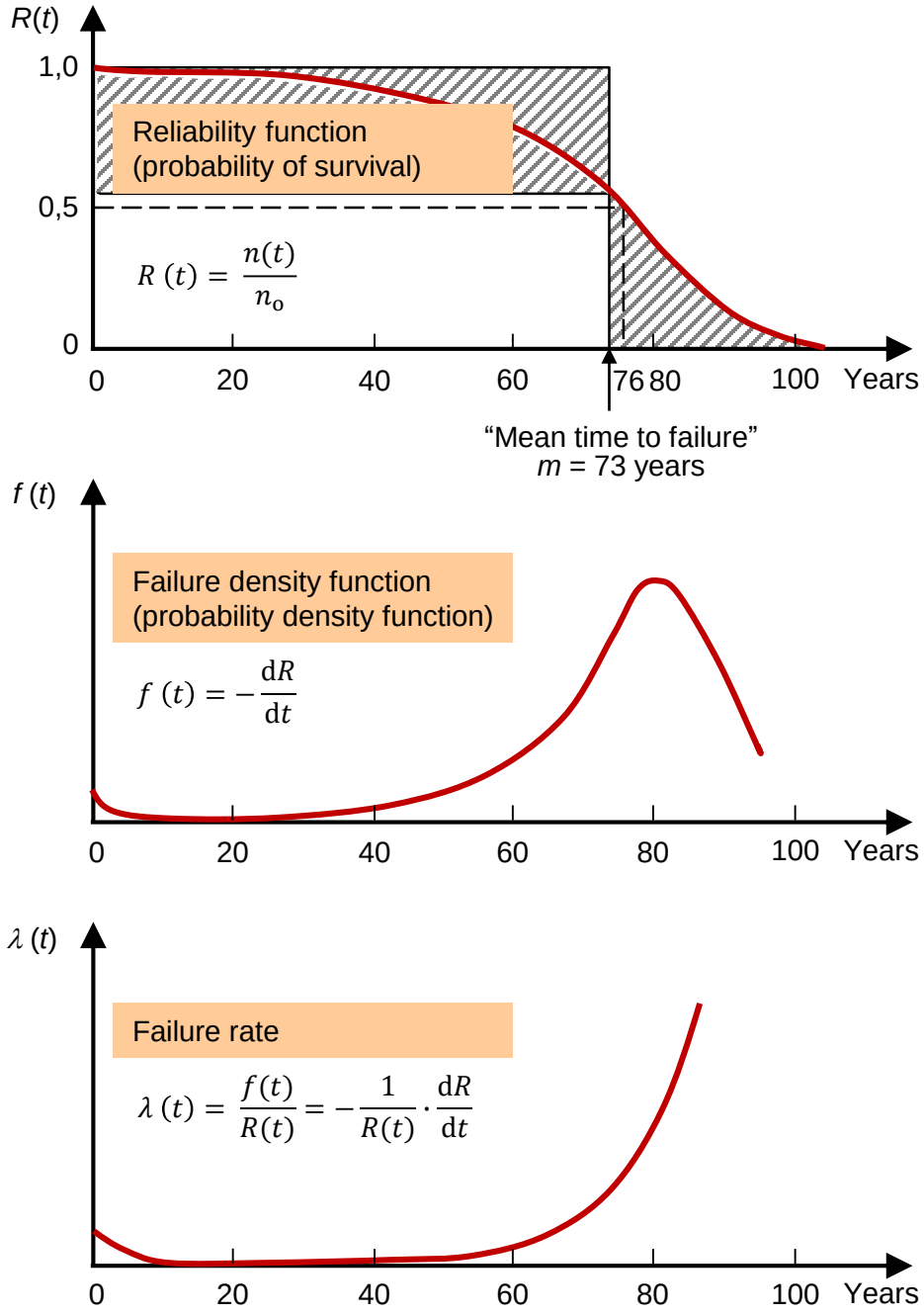


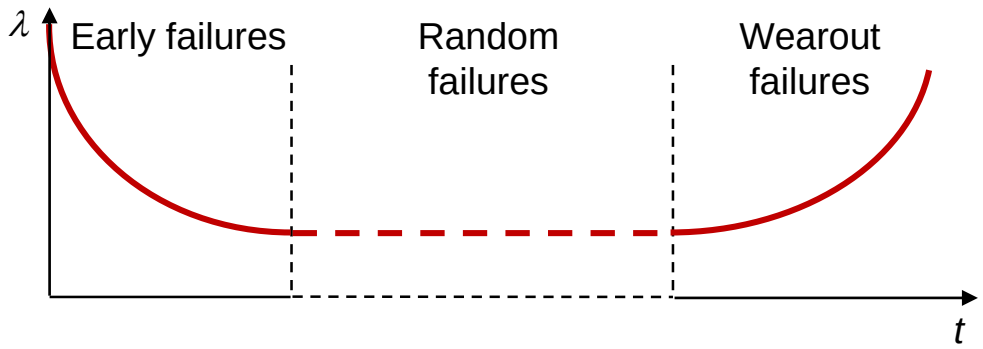
60 rolls

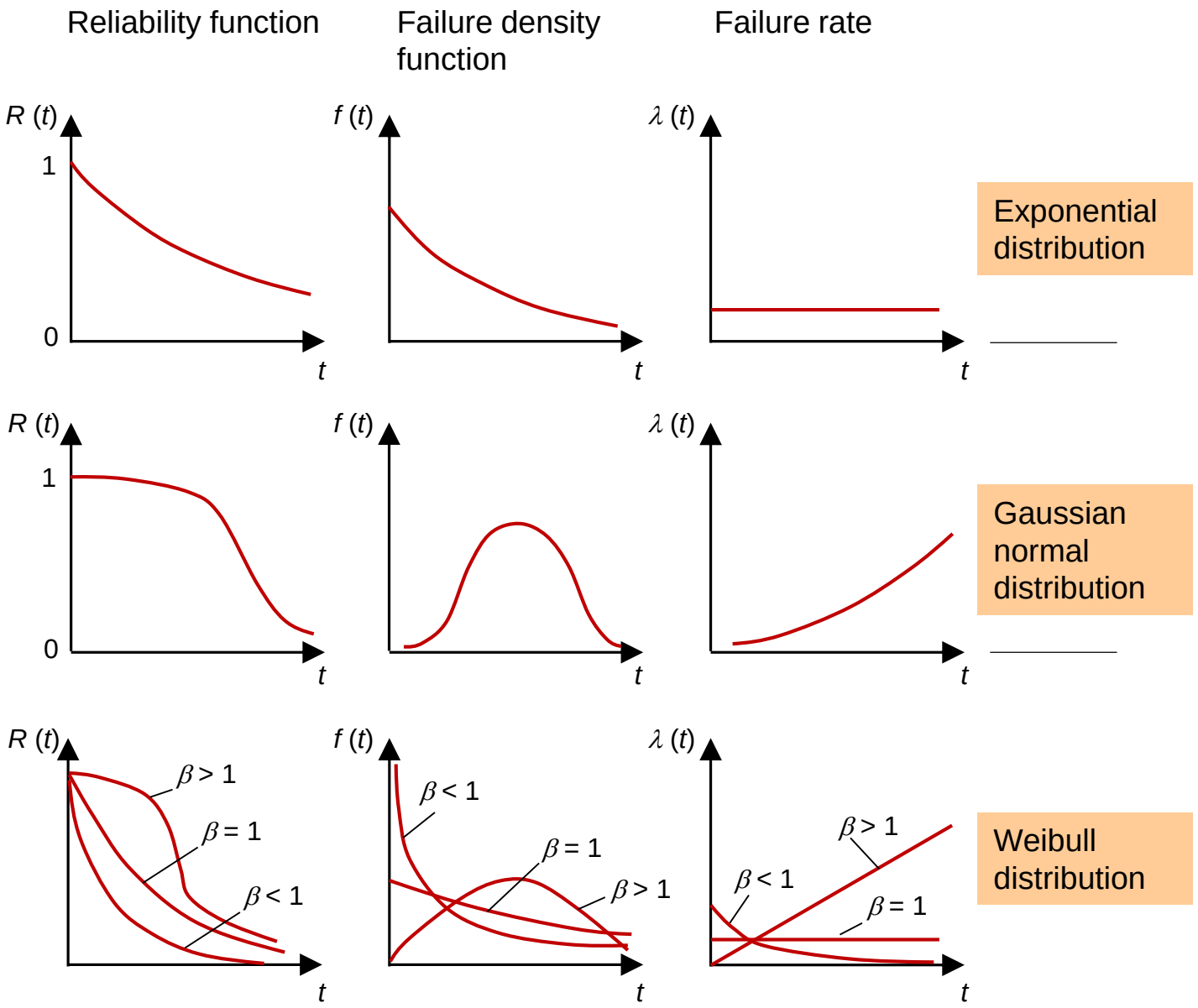


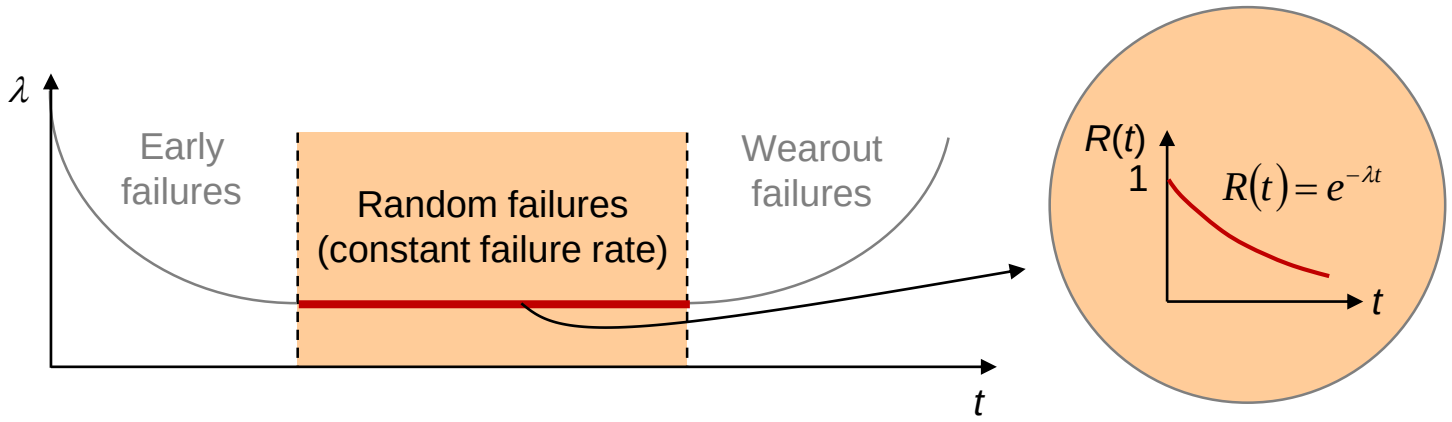
1200 rolls

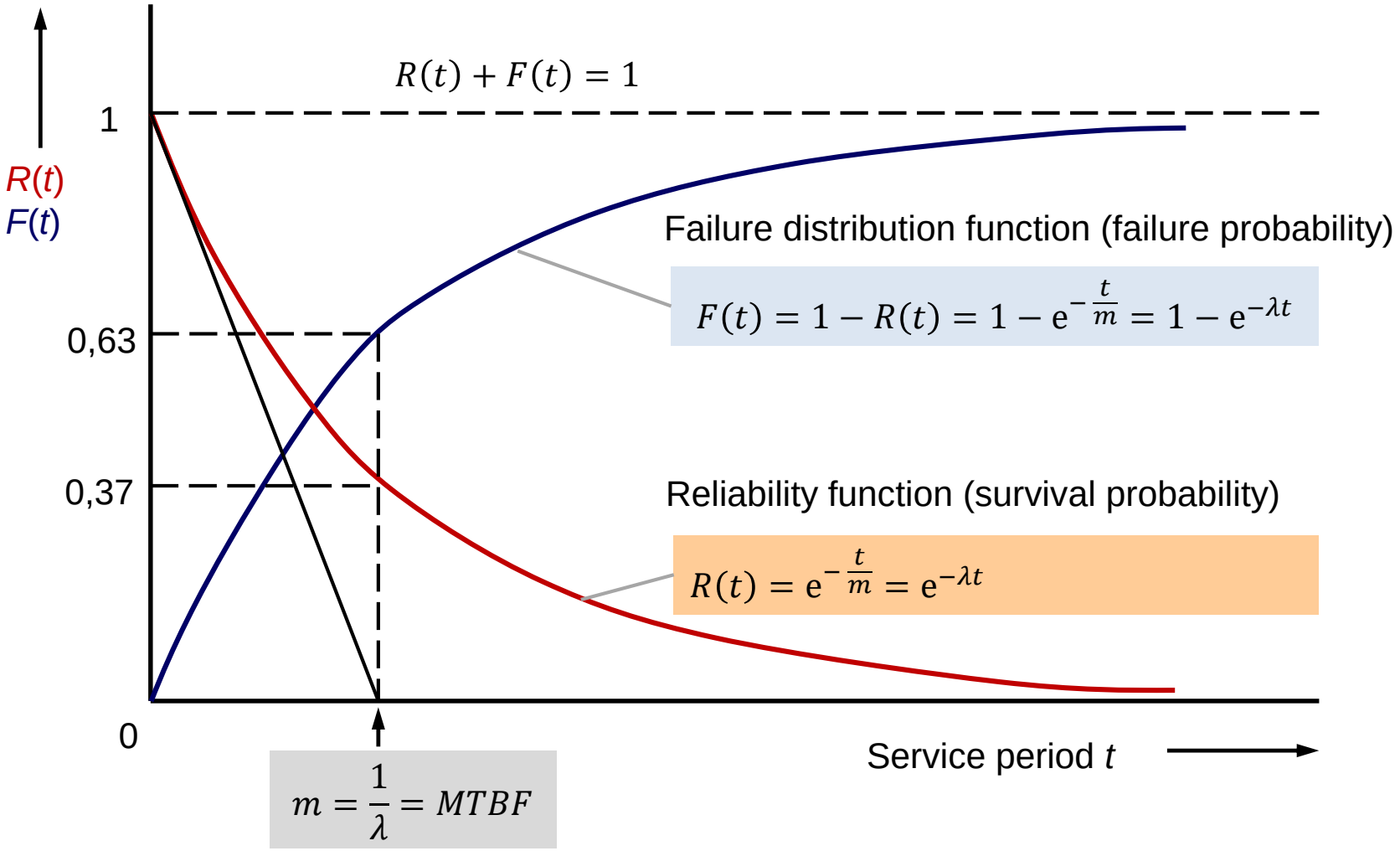



R(t)
1,0
0,5
0
Reliability function
(probability of survival)
$R\ (t) = \frac{n(t)}{n_o}$
0
20
40
60
76 80
100
Years
"Mean time to failure"
m = 73 years
f (t)
Failure density function
(probability density function)
$f\ (t) = -\frac{dR}{dt}$
0
20
40
60
80
100
Years
λ (t)
Failure rate
$\lambda\ (t) = \frac{f(t)}{R(t)} = -\frac{1}{R(t)} \cdot \frac{dR}{dt}$
0
20
40
60
80
100
Years


λ
Early failures
Random failures
Wearout failures
t

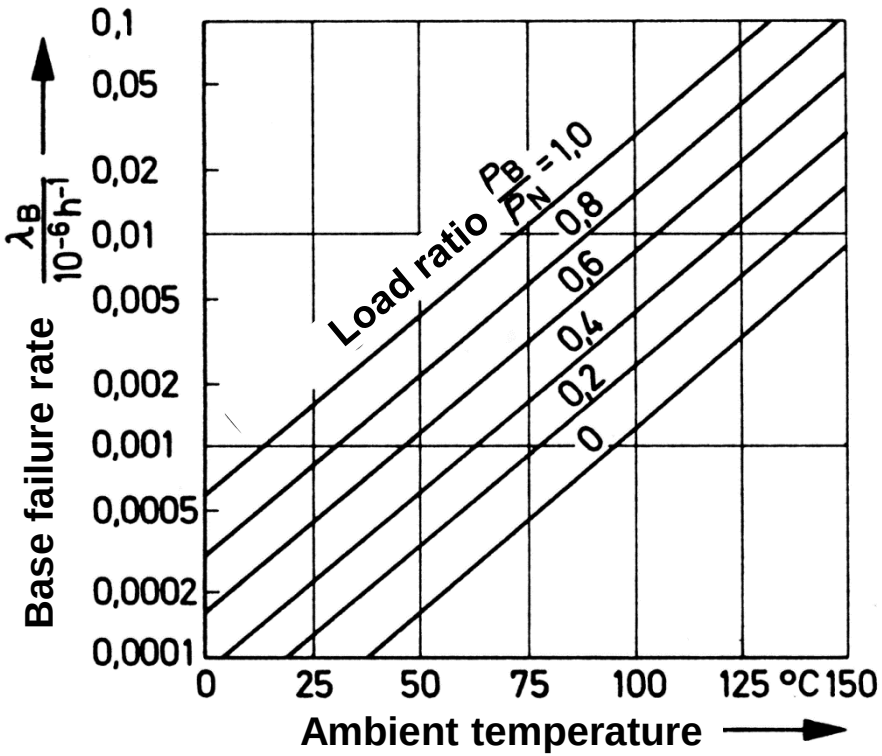

Reliability function
Failure density function
Failure rate
R (t)
1
0
t
f (t)
t
λ (t)
t
Exponential distribution
R (t)
1
0
t
f (t)
t
λ (t)
t
Gaussian normal distribution
R (t)
β > 1
β = 1
β < 1
t
f (t)
β < 1
β = 1
β > 1
t
λ (t)
β > 1
β < 1
β = 1
t
Weibull distribution

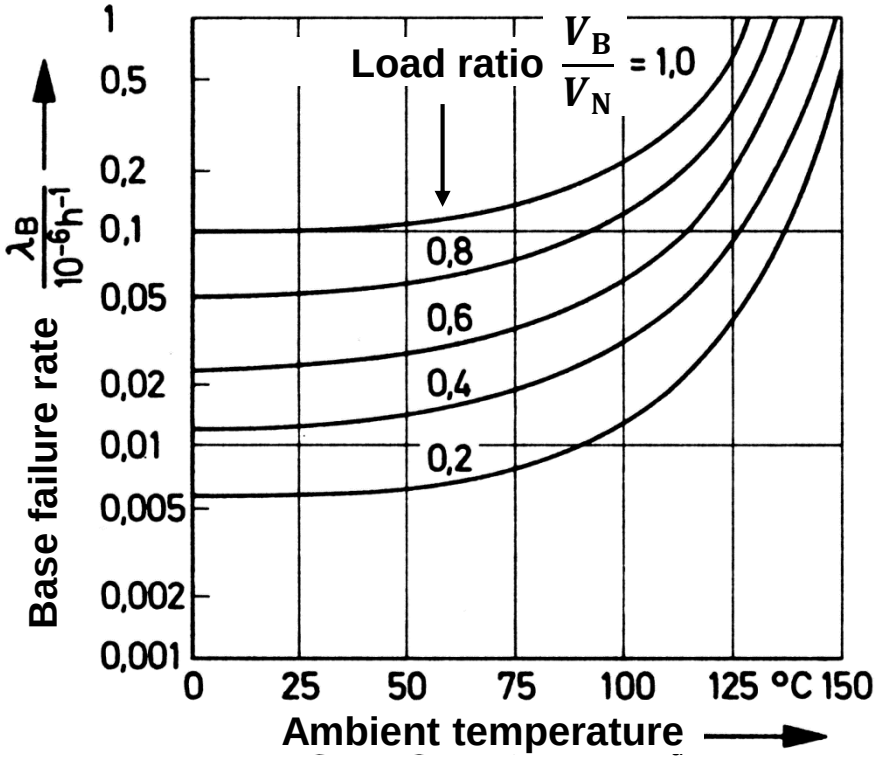

λ
Early
failures
Random failures
(constant failure rate)
Wearout
failures
t
R(t)
1
R(t) = e^{−λt}
t


$R(t) + F(t) = 1$
1
0,63
0,37
0
R(t)
F(t)
Failure distribution function (failure probability)
$F(t) = 1 - R(t) = 1 - e^{-\frac{t}{m}} = 1 - e^{-\lambda t}$
Reliability function (survival probability)
$R(t) = e^{-\frac{t}{m}} = e^{-\lambda t}$
Service period t
$m = \frac{1}{\lambda} = MTBF$

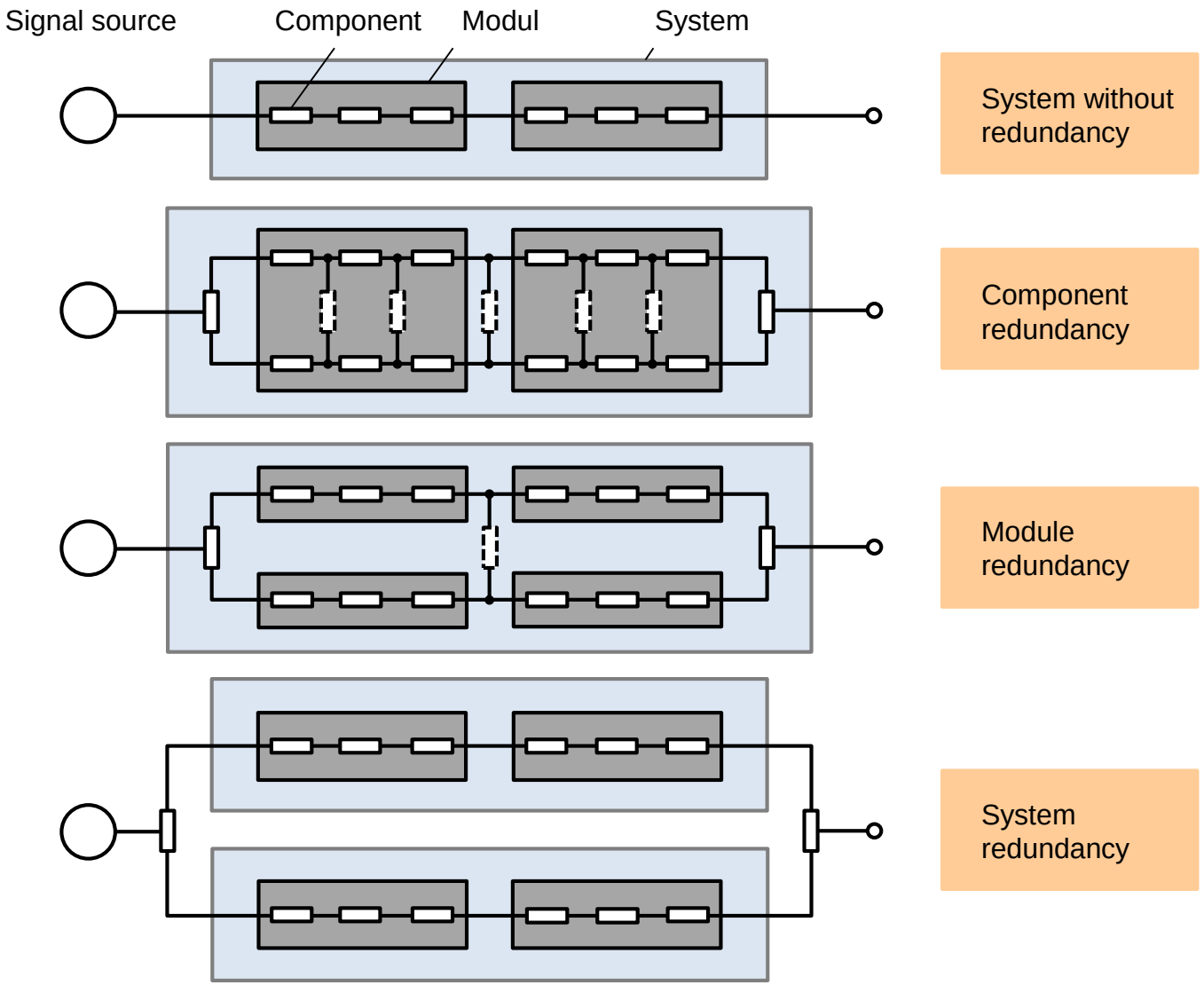
Type of stress		Reference stress
Ambient temperature		$T_U = 40°C$
Relative humidity		30%
Air pressure for electronic components negligible in the range (0.860...1.060) · 10^5 Pa		1.013 · 10^5 Pa
Mechanical stress	vibration stress	frequency: (10... 55) Hz acceleration: 20 m/s^2
	shock stress	acceleration: 150 m/s^2 duration: 11 ms
Other stresses: wind, rain, snow, ice, dripping, spraying, splashing water or water jets, dust, the effects of pests, corrosive gases, radioactive radiation, temperature change, etc.		none

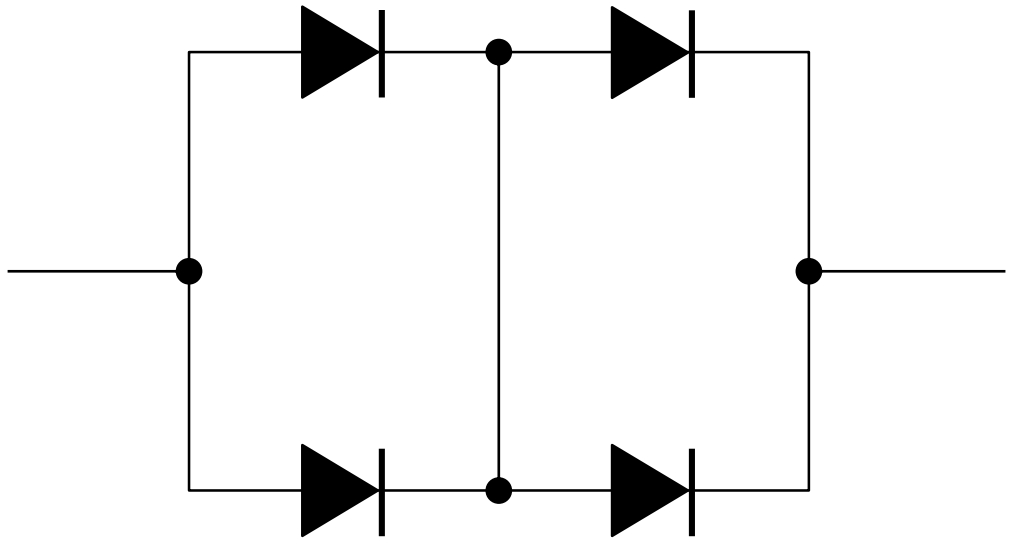
Element	λ_{min} in FIT = 10^{-9} h^{-1}	λ_{max} in FIT = 10^{-9} h^{-1}
Transistors		
thyristor, Triac	2.2	
transistor, bipolar	0.74	
transistor, FET	4.5	12
Diodes		
signal	1	3.8
Z	2	
power	5	
IC		
digital, bipolar	2.5	80
digital, MOS	10	290
digital, CMOS	160	240
Resistors		
carbon film	0.07	4.8
wire	3.3	33
thermistor	21	105
potentiometer	8.9	650
Capacitors		
electrolyte	9.5	2000
film	0.53	490
ceramic	0.67	23
tantalum	2.1	240
Piezoelectric resonators	11	38
Interconnects		
- vias	0.041	0.26
- solder joint, automatic	0.069	
- solder joint, manual	0.14	2.6
- plug connection	0.12	
- crimped connectors	0.26	

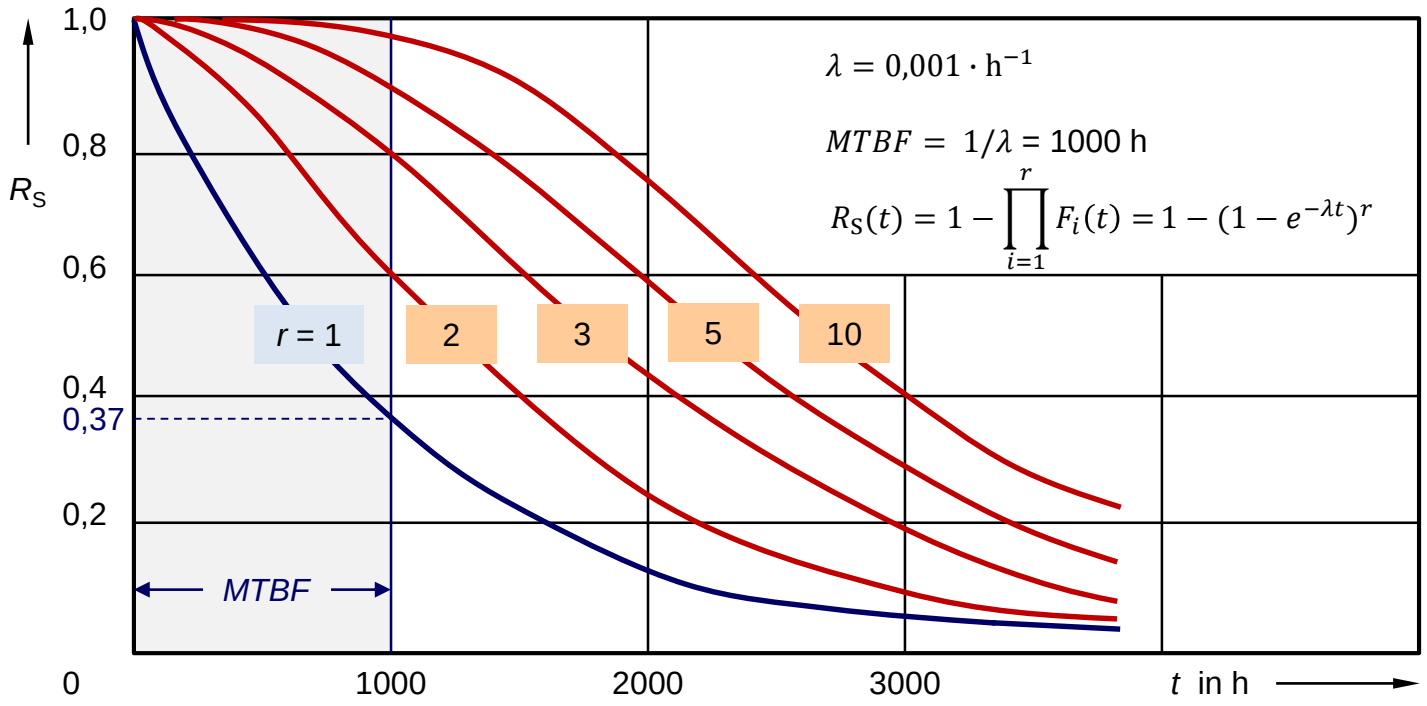

Base failure rate $\frac{\lambda_B}{10^{-6}h^{-1}}$
0,1
0,05
0,02
0,01
0,005
0,002
0,001
0,0005
0,0002
0,0001
Load ratio $\frac{P_B}{P_N}$ = 1,0
0,8
0,6
0,4
0,2
0
0
25
50
75
100
125 °C 150
Ambient temperature

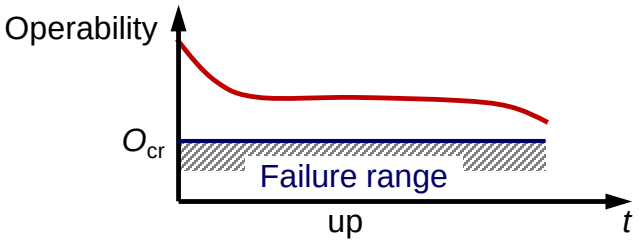

Base failure rate $\frac{\lambda_B}{10^{-6}h^{-1}}$
1
0,5
0,2
0,1
0,05
0,02
0,01
0,005
0,002
0,001
Load ratio $\frac{V_B}{V_N}$ = 1,0
0,8
0,6
0,4
0,2
0
25
50
75
100
125 °C 150
Ambient temperature

Component	Number of cycles · 10^6		
	min.	typical	max.
Pushbutton switch	0.01	0.1	10
Relay, heavy-duty	1	2	10
Relay, light-duty	1	10	100
Reed relay, DIL enclosure	5	10	1000
Reed contact, dry	0.5	50	5000

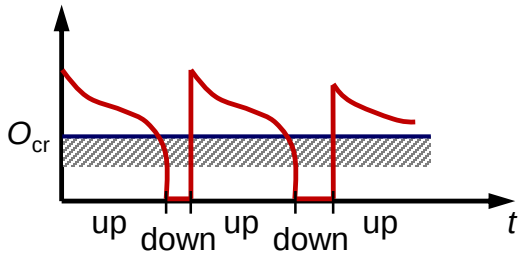

Signal source
Component
Modul
System
System without redundancy
Component redundancy
Module redundancy
System redundancy



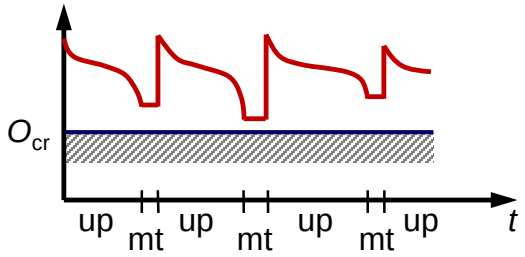

1,0
0,8
0,6
0,4
0,37
0,2
0
R_S
1000
2000
3000
t in h
$\lambda = 0{,}001 \cdot \mathrm{h}^{-1}$
$MTBF = 1/\lambda$ = 1000 h
$R_S(t) = 1 - \prod_{i=1}^{r} F_i(t) = 1 - (1 - e^{-\lambda t})^r$
r = 1
2
3
5
10
MTBF



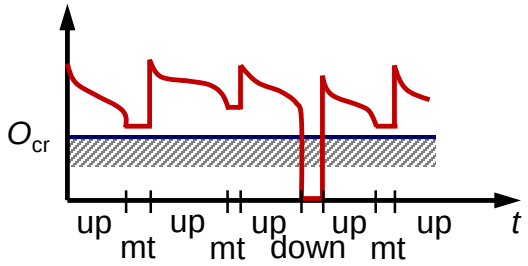
Non-maintained system
with no failure



Non-maintained system with
failures and repairs



Maintained system
with no failure



Maintained system with
failure

up: uptime (operating time)
down: downtime (repair)
mt: maintenance time
O_{cr}: critical value of operability