Risk assessment

Importance measures

Importance measures

Importance measures are performed within a risk assessment to <u>identify</u> and <u>rank</u> components and systems relevant to the safety of technical installations.

Importance measures

1. **The Risk Achievement Worth (MPR) is defined as the increase in risk when a component is assumed not to be there or to have failed**
2. **The Risk Reduction Worth (MSR) is defined as the decrease in risk when a component is assumed to be optimized or be made perfectly reliable**
3. **Criticality importance (V_{MK}) demonstrates the contribution of the component to the current system risk**

The Risk Achievement Worth (MPR)

Definition:
(probability of top event (system failure) with component failure probability = 1)
"divided by"
(probability of top event)

R - risk

$$MPR_K = \frac{R_{Kn}}{R_p}$$

The Risk Reduction Worth (MSR)

Definition:
(Probability of top event)
"divided by"
(Probability of top event with component failure probability = 0)

$$MSR_K = \frac{R_p}{R_{Kp}}$$

Criticality importance (VMK)

$$V_{MK} = \frac{\partial \ N_S(t)}{\partial \ K} \frac{Q(K)}{Q(N_S)}$$

N_s(t) - analytical expression for system unreliability

K – component of interest

Q(N_s) - probability of top event (system failure probability) – system unreliability

Q(K) – component unreliability

Criticality importance (VMK)

$$\frac{\Delta Q(N_S)_K}{\Delta Q(K)} = \frac{\partial \; N_S(t)}{\partial \; K}$$

$$\Delta Q(N_S)_K = \Delta Q(K) \cdot \frac{\partial \; N_S(t)}{\partial \; K}$$

$$V_{MK} = \frac{\partial \; N_S(t)}{\partial \; K} \frac{Q(K)}{Q(N_S)} = \frac{\Delta Q(N_S)_K}{\Delta Q(K)} \frac{Q(K)}{Q(N_S)}$$

The Risk Reduction Worth (MSR)

$$V_{MK} = \frac{\partial \; N_S(t)}{\partial \; K} \frac{Q(K)}{Q(N_S)} = \frac{\Delta Q(N_S)_K}{\Delta Q(K)} \frac{Q(K)}{Q(N_S)}$$

$$\Delta Q(N_S)_K = \Delta Q(K) \; V_{MK} \cdot \frac{\mathrm{Q}(N_S)}{Q(K)}$$

$$\boxed{\Delta Q(K) = Q(K)_{final} - Q(K)_{initial} = -Q(K)}$$

$$\Delta Q(N_S)_K = -V_{MK} \; \mathrm{Q}(N_S)$$

The Risk Reduction Worth (MSR)

$$MSR_K = \frac{Q(N_S)}{Q(N_S) \ \text{ when } \ Q(K) \to 0} = \frac{Q(N_S)}{Q(N_S)'}$$

$$MSR_K = \frac{Q(N_S)}{Q(N_S) + \underbrace{\Delta Q(N_S)_K}_{-V_{MK}\ Q(N_S)}} = \frac{1}{1 - V_{MK}}$$

The Risk Achievement Worth (MPR)

$$\boxed{\Delta Q(K) = Q(K)_{final} - Q(K)_{initial} = 1 - Q(K)}$$

$$\Delta Q(N_S)_K = \Delta Q(K)\ V_{MK} \cdot \frac{\mathrm{Q}(N_S)}{Q(K)}$$

$$\Delta Q(N_S)_K = [1 - Q(K)] V_{MK} \cdot \frac{\mathrm{Q}(N_S)}{Q(K)}$$

The Risk Achievement Worth (MPR)

$$MPR_K = \frac{Q(N_S)\ \text{ when }\ Q(K) \to 1}{Q(N_S)} = \frac{Q(N_S)''}{Q(N_S)}$$

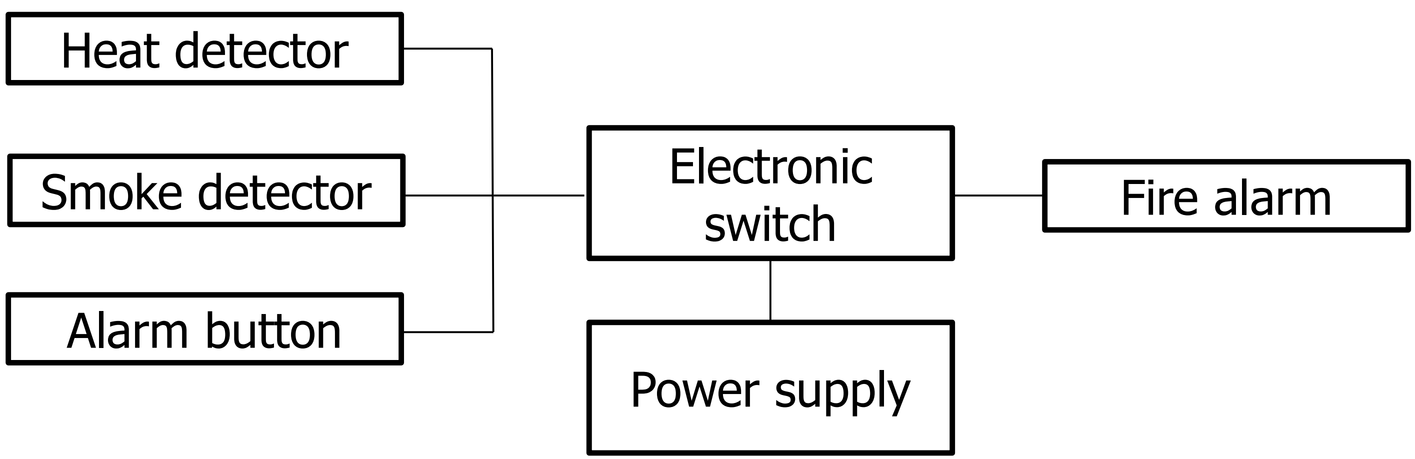
$$MPR_K = \frac{Q(N_S) + \Delta Q(N_S)_K}{Q(N_S)} =$$

$$\Delta Q(N_S)_K = \Delta Q(K)\ V_{MK} \cdot \frac{Q(N_S)}{Q(K)}$$

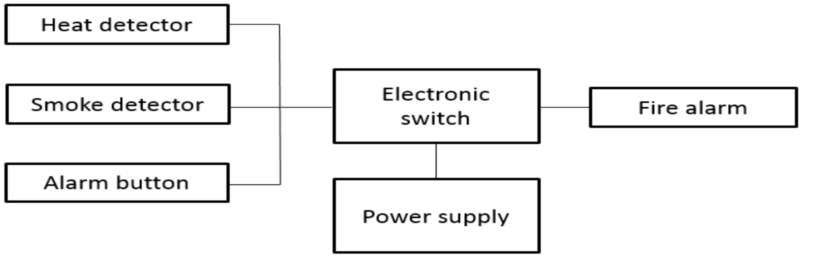
$$= 1 + V_{MK} \left[\frac{1}{Q(K)} - 1 \right]$$

Example

A fire alarm in a building is connected according to the figure below. People spend 50% of the time in the building. They will always detect the fire and know what to do in that case. The entire system is tested once a year. Determine the reliability/availability of the system after 12500 h. Suggest two actions to increase the reliability of the system.



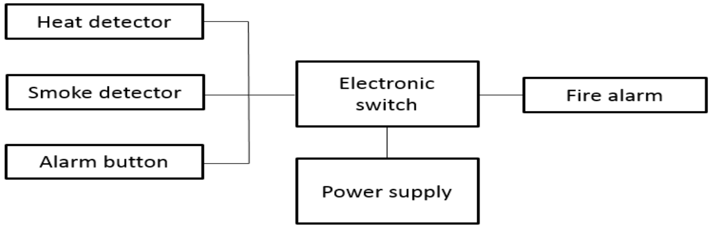
Example



Given data:

Component	MTTF [h]	MTTR [h]
Heat detector	20.000	10
Smoke detector	20.000	11
Alarm button	90.000	91
Electronic switch	20.000	87
Power supply	80.000	1
Fire alarm	80.000	125

Example



Failure and repair rates:

$$\lambda = \frac{1}{MTTF} \qquad \mu = \frac{1}{MTTR}$$

Component	λ [h⁻¹]	μ [h⁻¹]
Heat detector	$5 \cdot 10^{-5}$	0,1
Smoke detector	$5 \cdot 10^{-5}$	0,09
Alarm button	$1{,}11 \cdot 10^{-5}$	0,011
Electronic switch	$5 \cdot 10^{-5}$	0,0115
Power supply	$1{,}25 \cdot 10^{-5}$	1
Fire alarm	$1{,}25 \cdot 10^{-5}$	0,008

Example

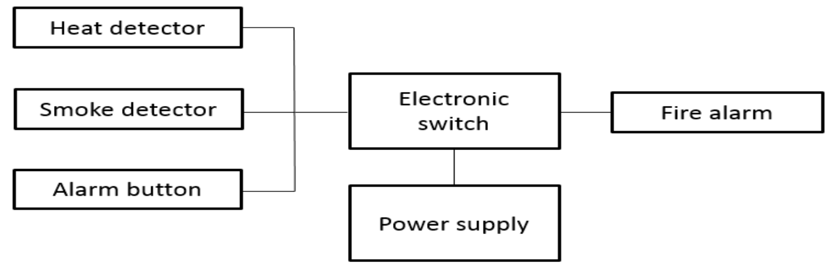
Reliability and availability of the components after t = 12500 – 8760 = 3740 h (testing resets the time):

Component	R(3740)	A(3740)
Heat detector	0,829	0,9995
Smoke detector	0,829	0,9994
Alarm button	0,959	0,999
Electronic switch	0,829	0,996
Power supply	0,954	0,99999
Fire alarm	0,954	0,998

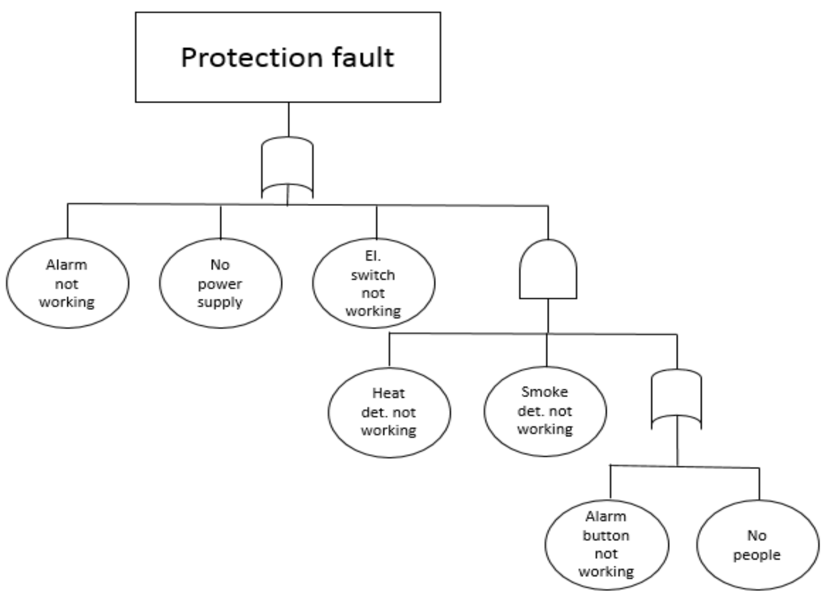
$$A(t) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} e^{-(\lambda+\mu)t}$$

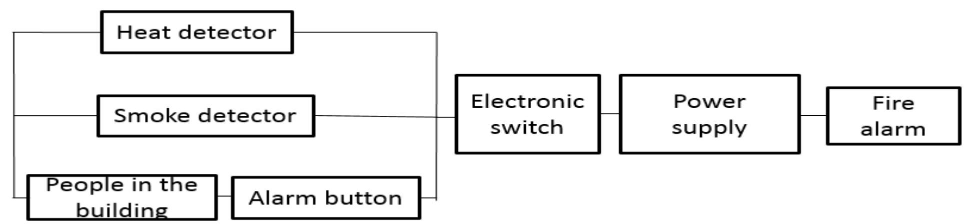
$$R(t) = e^{-\lambda t}$$

Example

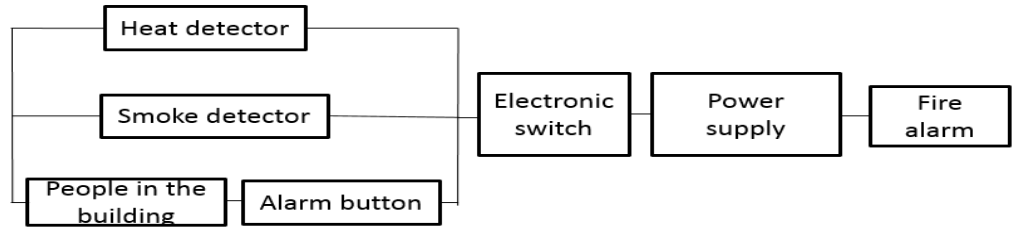


Solution: Fault tree and reliability/ availability diagram





Example



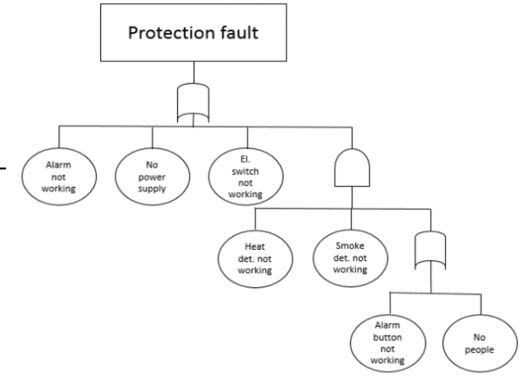
Calculation:

R = [1 – (1 – 0,829)·(1 – 0,829)·(1 – 0,959·0,5)]·0,829·0,954·0,954 = 0,743

A = [1 – (1 – 0,9995)·(1 – 0,9994)·(1– 0,999·0,5)]·0,996·0,99999·0,998 = 0,994

Component	R(3740)	A(3740)
Heat detector	0,829	0,9995
Smoke detector	0,829	0,9994
Alarm button	0,959	0,999
Electronic switch	0,829	0,996
Power supply	0,954	0,99999
Fire alarm	0,954	0,998

Example

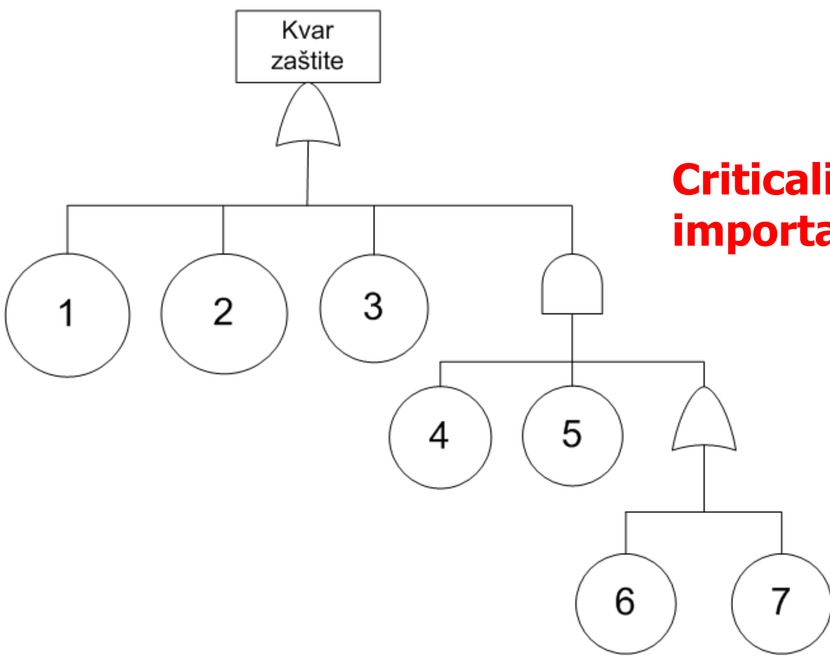


Importance measures

$$KZ = K1 + K2 + K3 + K4K5(K6 + K7)$$

$$KZ = K1 + K2 + K3 + K4K5K6 + K4K5K7$$

Protection fault



Criticality importance (V_{MK})

$$V_{MK} = \frac{\partial \; N_S(t)}{\partial \; K} \frac{Q(K)}{Q(N_S)}$$

Risk Reduction Worth (MSR)

$$MSR_K = \frac{1}{1 - V_{MK}}$$

$$MPR_K = 1 + V_{MK} \left[\frac{1}{Q(K)} - 1 \right]$$

The Risk Achievement Worth (MPR)

Example

Importance measures

$$V_{MK} = \frac{\partial \; N_S(t)}{\partial \; K} \frac{Q(K)}{Q(N_S)}$$

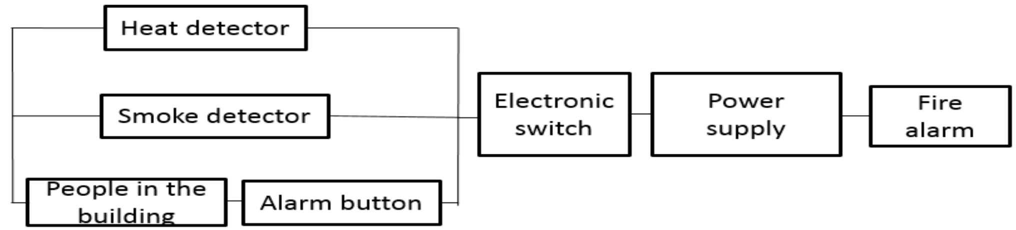
KZ = K1 + K2 + K3 + K4K5K6 + K4K5K7

$$\frac{\partial N_s}{\partial K_1} = 1 \qquad \frac{\partial N_s}{\partial K_4} = K5\left(K6 + K7\right) = Q(K5)(Q(K6) + Q(K7))$$

$$\frac{\partial N_s}{\partial K_2} = 1 \qquad \frac{\partial N_s}{\partial K_5} = K4\left(K6 + K7\right)$$

$$\frac{\partial N_s}{\partial K_3} = 1 \qquad \frac{\partial N_s}{\partial K_6} = K4K5 \qquad \frac{\partial N_s}{\partial K_7} = K4K5$$

Example



Importance measures

Component	R(3740)	Q(3740)
Heat detector (K4)	0,829	0,171
Smoke detector (K5)	0,829	0,171
Alarm button (K6)	0,959	0,041
Electronic switch (K3)	0,829	0,171
Power supply (K2)	0,954	0,046
Fire alarm (K1)	0,954	0,046
No people (K7)	0,5	0,5

$$V_{MK} = \frac{\partial \ N_S(t)}{\partial \ K} \frac{Q(K)}{Q(N_S)}$$

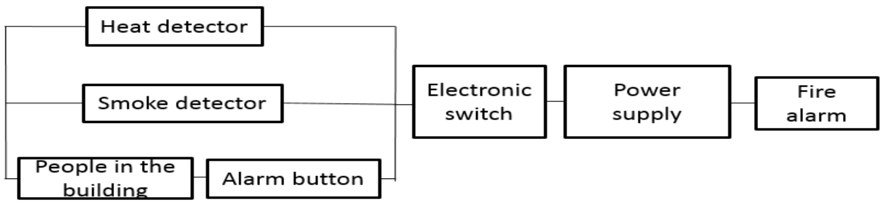
$Q(N_s) = 1 – R = 1 – 0,743 = 0,257$

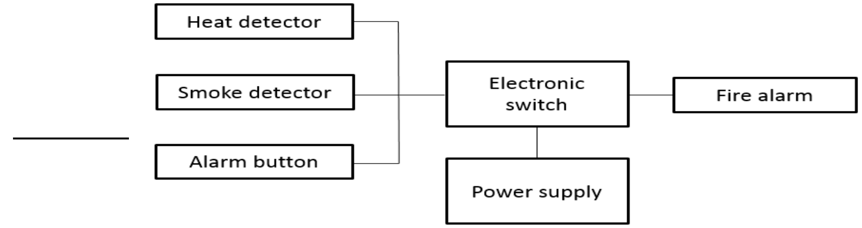
$$V_{MK1} = 1 \cdot \frac{0,046}{0,257} = 0,179 \qquad V_{MK2} = 1 \cdot \frac{0,046}{0,257} = 0,179$$

$$V_{MK3} = 1 \cdot \frac{0,171}{0,257} = 0,665$$

$$V_{MK4} = \left(0,171 \cdot (0,041 + 0,5)\right) \cdot \frac{0,171}{0,257} = 0,0616 \qquad V_{MK6} = 0,171 \cdot 0,171 \cdot \frac{0,041}{0,257} = 0,00466$$

$$V_{MK5} = \left(0,171 \cdot (0,041 + 0,5)\right) \cdot \frac{0,171}{0,257} = 0,0616 \qquad V_{MK7} = 0,171 \cdot 0,171 \cdot \frac{0,5}{0,257} = 0,0569$$





Importance measures

Component	Q(3740)	VMK	MSR	MPR
Heat detector (K4)	0,171	0,0616	1,0656	1,299
Smoke detector (K5)	0,171	0,0616	1,0656	1,299
Alarm button (K6)	0,041	0,00466	1,00468	1,109
Electronic switch (K3)	0,171	0,665	2,985	4,224
Power supply (K2)	0,046	0,179	1,218	4,712
Fire alarm (K1)	0,046	0,179	1,218	4,712
No people (K7)	0,5	0,0569	1,060	1,0569

$$MSR_K = \frac{1}{1 - V_{MK}}$$

$$MPR_K = 1 + V_{MK}\left[\frac{1}{Q(K)} - 1\right]$$

$$V_{MK} = \frac{\partial N_S(t)}{\partial K}\frac{Q(K)}{Q(N_S)}$$

Reliability increase:
Eq. installing a more reliable switch so that its MTTF is comparable with the power supply and the fire alarm; perform system testing several times a year

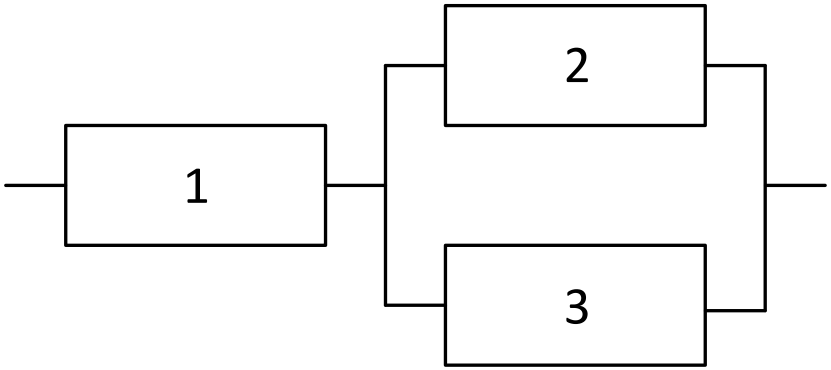
Example 2

Calculate the probability of successful activation of the system after a received request. The system is maintained every three months. The component failure rates are as follows:

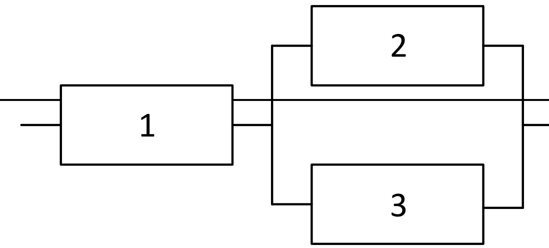
$\lambda_1 = 10^{-4}\ h^{-1}$

$\lambda_2 = 5 \cdot 10^{-4}\ h^{-1}$

$\lambda_3 = 10^{-3}\ h^{-1}$



Example 2



$$R_{avg} = \frac{1}{T}\int_0^T e^{-\lambda t}dt = \frac{1-e^{-\lambda T}}{\lambda\, T}$$

$T = 2190$ h

$\lambda_1 = 10^{-4}\ h^{-1}$ $\qquad$ $R_{sr1} = 0.898$

$\lambda_2 = 5\cdot 10^{-4}\ h^{-1}$ $\qquad$ $R_{sr2} = 0.608$

$\lambda_3 = 10^{-3}\ h^{-1}$ $\qquad$ $R_{sr3} = 0.406$

$R_{avg} = P(x_1)P(x_2+x_3) = \ldots = R_{sr1}(R_{sr2} + R_{sr3} - R_{sr2}R_{sr3}) = 0.689$