Probabilistic Risk Analysis
(job safety)

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Risk analysis methods

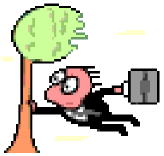
Qualitative methods

JSA, FMEA, HAZOP, MORT, ”What – if”, …

Index methods (e.g. Risk Score)

Matrix methods

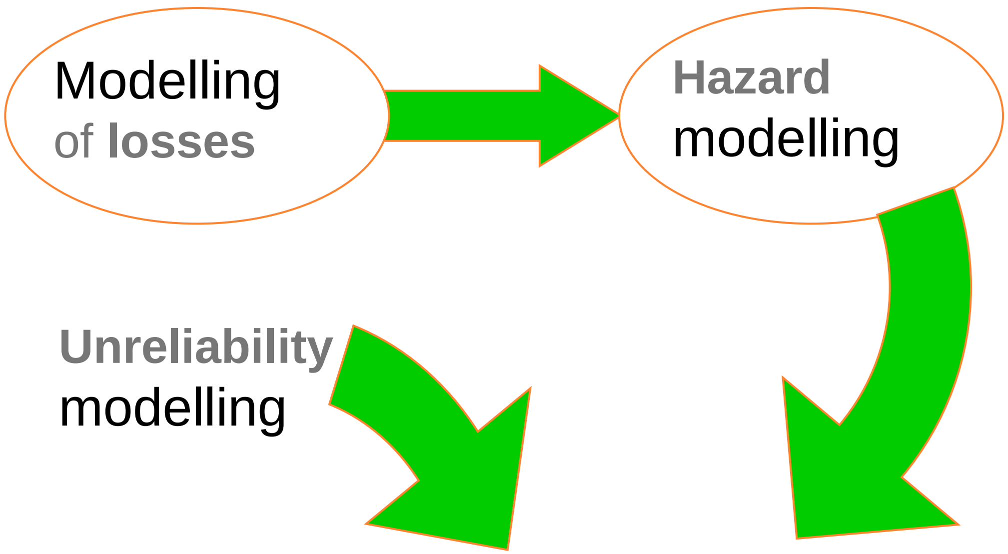
(tree methods)



Quantitative methods

- probabilistic methods
- statistic methods

Modelling of hazards and unreliability



$$\begin{pmatrix}\text{risk}\\ \text{measure}\end{pmatrix} = \begin{pmatrix}\text{unreliability}\\ \text{measure}\end{pmatrix} \cdot \begin{pmatrix}\text{hazard}\\ \text{measure}\end{pmatrix}$$

$$\Lambda_c(1) = Q(1) \cdot Z(c) \qquad c_o(1) = Q(1) \cdot Z_o$$

Risk modelling

$$\Lambda_c(1) = Q(1) \cdot Z(c)$$

$$c_o(1) = Q(1) \cdot Z_o$$

Expert & statistical methods

- reliability of machines
- human reliability

Models of consequences

Expert & statistical methods

Consequence modelling

Quantification and modelling of human losses in two cases:

c_1 – loss caused by a single undesirable event

$c(t_H)$ – loss caused by exposure to health-hazard factors in time t_H

Human loss classification

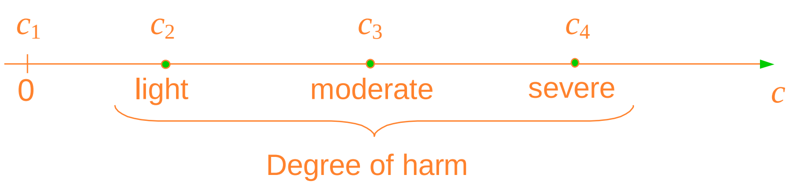
Individual human losses are characterised by:

- **severity**,
- **type** (kind of injury & possibly body part)

e.g. severity C_1 takes values $c \in (c_{min}, c_{max})$

c_{min} **= 0**

c_{max} **= loss of life (c_m)**



Collective human losses

$$\begin{pmatrix}\text{Collective}\\ \text{losses}\end{pmatrix} = \sum \begin{pmatrix}\text{individual}\\ \text{losses}\end{pmatrix}$$

for each category separately

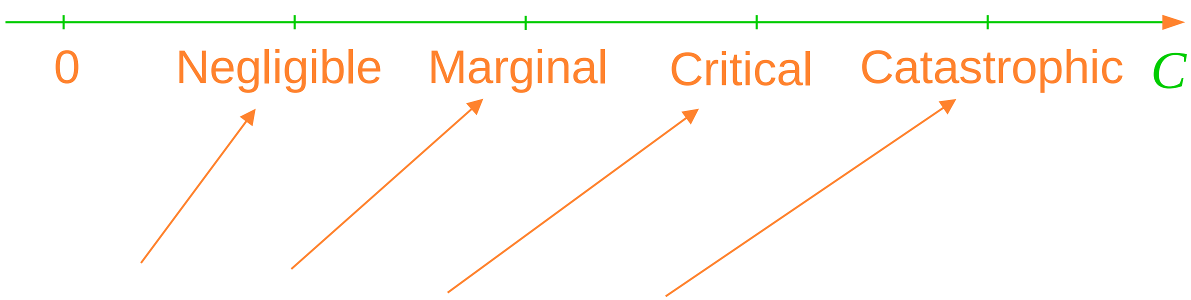
Modelling of human losses in Job Safety Assessment (JSA)

Measures for extent of losses → division into **categories**

Three categories of harm are used in **BS 8800**

MIL-STD-882

"Standard Practice for System Safety"

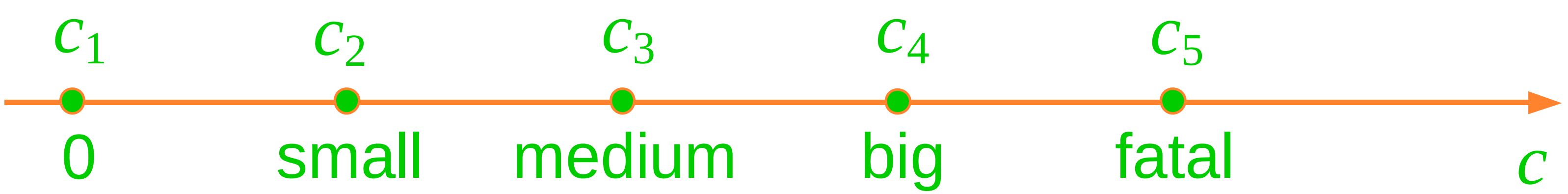


Marginal

Minor injury, minor occupational illness, or minor system or environmental damage.

MEASURE OF INDIVIDUAL HUMAN LOSSES

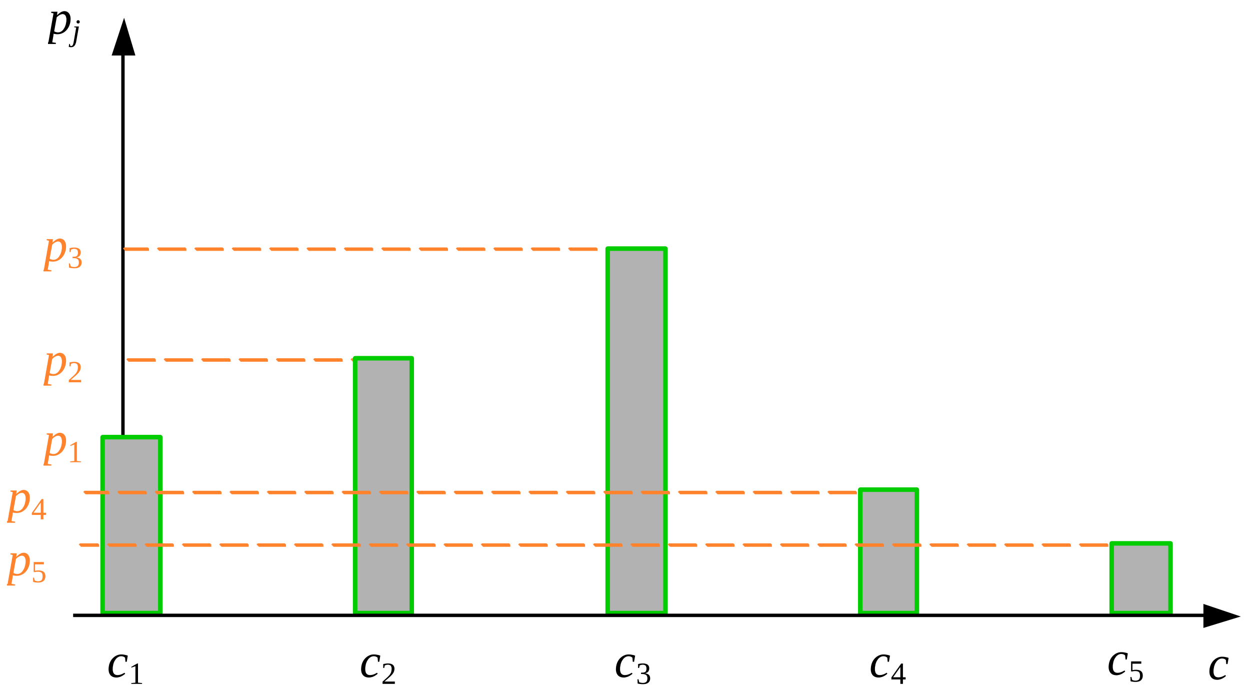
Loss category

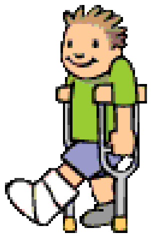


c_4 – injures and diseases causing serious, usually permanent health loss

c_5 – injures and diseases causing death

EXAMPLE of human losses





$$p_j = P\{\boldsymbol{C}_1 = c_j \mid \boldsymbol{A}\}$$

$$0 \le p_j \le 1 \qquad \sum_{j=1}^{j=5} p_j = 1$$

Hazard (consequence) modelling

Probability of loss in category j

$$p_j = \frac{N_{C_1=c_j}(\Delta\tau)}{N_{all}(\Delta\tau)}$$

$N_{all}(\Delta\tau)$ – the number of specified undesirable events (e.g. falls) that occurred in time $\Delta\tau$

$N_{C_1=c_j}(\Delta\tau)$ – the number of the events, that caused loss in the category $C_1 = c_j$

$j = 1, 2, ..., 5$

Hazard measures

$$Z(c_j) = P\{\mathbf{C_1} \geq c_j \mid \mathbf{A}\}$$

$$Z_o = \tilde{\mathbf{C}}_1$$

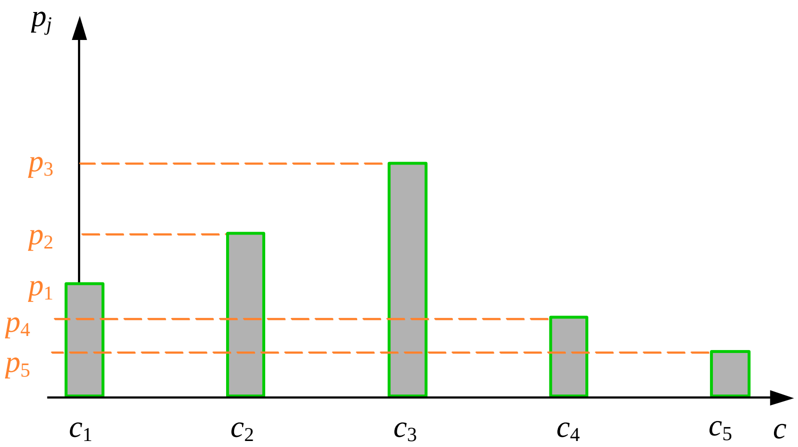
$$Z(c_1) = p_1 + p_2 + p_3 + p_4 + p_5 = 1$$

$$Z(c_2) = p_2 + p_3 + p_4 + p_5$$

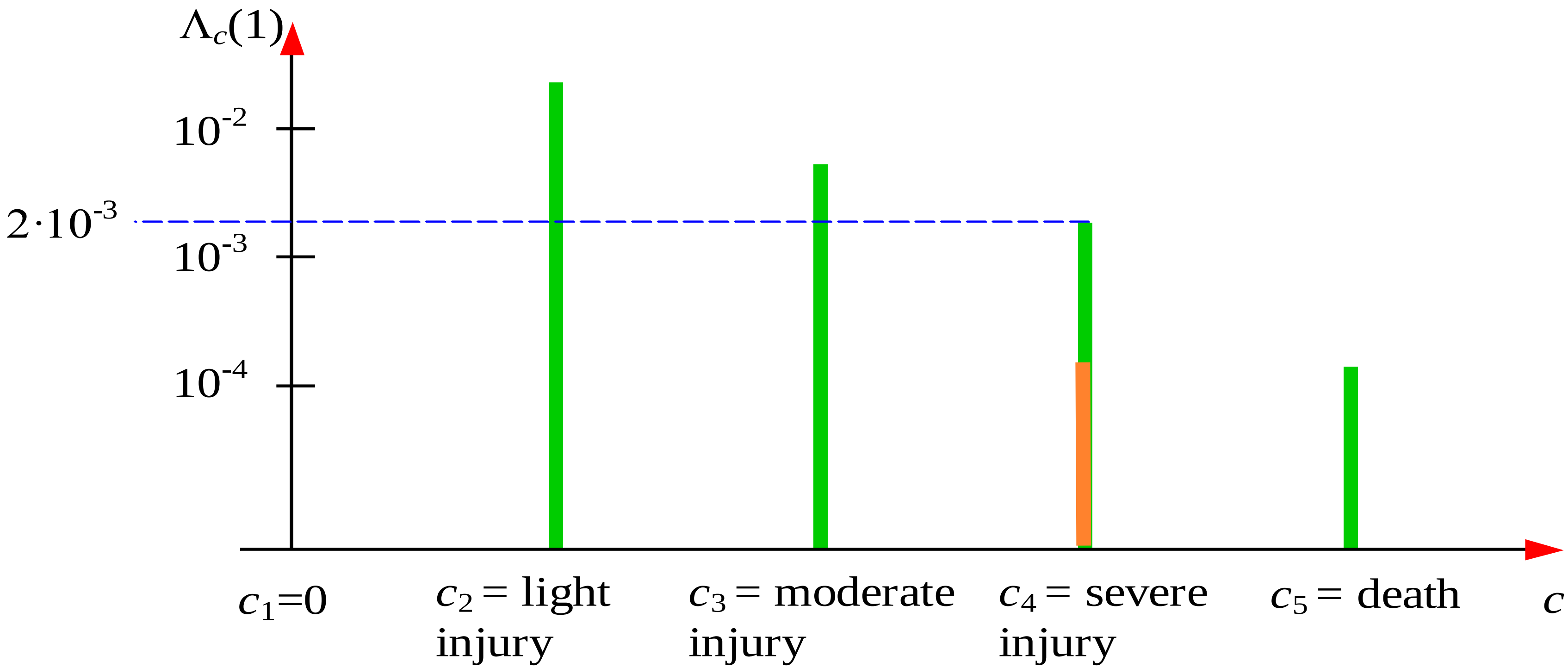
$$Z(c_3) = p_3 + p_4 + p_5$$

$$Z(c_4) = p_4 + p_5$$

$$Z(c_5) = p_5$$



Measure of individual risk



2 workers for 1000 employed sustain at least severe injury

per 1 year

severe injury + fatal injury

Exercise

Consequences of fall from stairs are presented in the table

	c_1	c_2	c_3	c_4	c_5
p_j	0,3	0,5	0,15	0,04	0,01

Occurrence likelihood of the event is Q = 10^{-6} [1/single use].

Calculate the risk of fatal and at least moderate injury.

$$\Lambda_c = Q \cdot Z(c)$$

$$Z(c_j) = \sum_j^m p_j \rightarrow$$

	c_1	c_2	c_3	c_4	c_5
$Z(c_j)$	1	0,7	0,2	0,05	0,01

$$\Lambda_{c3} = Q \cdot Z(c_3) = 10^{-6} \cdot 0.2 = 2 \cdot 10^{-7}$$

$$\Lambda_{c5} = 10^{-8} \quad \text{[1/single use]}$$

Assume 200 days of work per year. There are 500 employees who use the staircase on average 10 times a day.

Explain to the owner of the enterprise, what is the probability of work absence due to an accident of slipping or tripping on the stairs.

For 1 employee $\Lambda_{c3}(1) = 2 \cdot 10^{-7} \cdot 10 \cdot 200 = 4 \cdot 10^{-4}$

For 500 employees $\Lambda_{c3}^{500}(1) = 4 \cdot 10^{-4} \cdot 500 = 0.2$

Exercise results

		c_1	c_2	c_3	c_4	c_5
	prob. c_j	p_j	0,3	0,5	0,15	0,04	0,01
	hazard >= c_j	$Z(c_j)$	1	0,7	0,2	0,05	0,01
risk	[1/use]	Λ_{cj}		7,0E-07	2,0E-07	5,0E-08	1,0E-08
	[1/year]	$\Lambda_{cj}(1)$		0,0014	0,0004	0,0001	2E-05
	[500/year]	$\Lambda_{cj}^{500}(1)$		0,7	0,2	0,05	0,01

We can expect **1** employee in **5 years**
not to be present at work due to an accident of slipping or tripping on the stairs

Partial risk measure

For an event $\boldsymbol{A}^{(k)}$ (event No. k) measure of the **partial risk** is:

$$\Lambda_c^{(k)}(1) = Q^{(k)}(1) \cdot Z^{(k)}(c)$$

or $$c_o^{(k)}(1) = Q^{(k)}(1) \cdot Z_o$$

Total risk measure

For each category c_j

$$\Lambda_c(1) = \sum_{k=1}^{k=r} \Lambda_c^{(k)}(1)$$

$$c_o(1) = \sum_{k=1}^{k=r} c_o^{(k)}(1)$$

Error probability estimation based on statistical data

statistical data is available for $\Delta\tau$ years

The probability $Q(1)$ of an event A occurrence in one year per one employee

$$Q(1) = \frac{W_j(\Delta\tau)}{N \cdot \Delta\tau \cdot Z(c_j)} \quad [1/\text{year}]$$

$W_j(\Delta\tau)$ – the number of accidents due to occurrence of the event A, that caused loss not less then c_j, $j = 1 \div 5$

$\Delta\tau$ – the number of data collection years

N – the number of concerned workers

$Z(c_j)$ – the probability that occurrence of the event A causes a loss in category at least c_j

Exercise

There were 7 accidents in 12 years due to occurrences of a primary undesirable event A. 18 workers are susceptible to that event.

Calculate the probability of the event A occurrence per one execution of the task, knowing that the workers repeat the task (when event A may happen) 15 times per week. The Hazard measure $Z(c_j)$ for this case is presented in the table.

	c_1	c_2	c_3	c_4	c_5
$Z(c_j)$	1	0,7	0,2	0,05	0,01

$\Delta\tau = 12$

$W_j(\Delta\tau) = 7$

$N = 18$

$Z(c_3) = 0.2$

$$Q(1) = \frac{W_j(\Delta\tau)}{N \cdot \Delta\tau \cdot Z(c_j)} = \frac{7}{18 \cdot 12 \cdot 0.2} = 0.162 \quad 1/\text{year}$$

$$Q(1exec) = \frac{Q(1)}{220 \cdot \frac{15}{5}} = \frac{0.162}{220 \cdot \frac{15}{5}} = 2.46 \cdot 10^{-4}$$

Risk calculations

In a factory 650 people are employed. In the last 10 years there were 11 accidents caused by tripping or slipping.
Calculate the probability of the undesirable event (UE) occurrence per one day of work. Assume 220 workdays per year.

Consequences of the undesirable event occurrence are classified into five human loss categories:
c_1 – no injury, c_2 – light injury, c_3 – moderate injury, c_4 – serious injury, c_5 –fatal injury. Estimated probabilities of the UE outcomes for each category are presented in the table below.
Estimate the individual risk of at least serious injury in 1 year.

Category	c_1	c_2	c_3	c_4	c_5
p_j	0,537	0,32	0,107	0,035	0,001

'

Total Risk

There are three important undesirable events that may occur for a pipe welder:

$A^{(1)}$ - contact with sharp edges,
$A^{(2)}$ - fall from height,
$A^{(3)}$ - electric shock.

$Q^{(1)}$	$Q^{(2)}$	$Q^{(3)}$
0,5	$2\cdot10^{-3}$	0,1

[1/year]

Calculate the total risk of at least moderate injuries (c_3) and fatal injuries in 1 year.

category of loss	c_2	c_3	c_4	c_5
$Z^{(1)}(c_j)$	1	0,05	0	0
$Z^{(2)}(c_j)$	0,95	0,8	0,4	0,1
$Z^{(3)}(c_j)$	0,5	0,1	0,05	0,01

$$\Lambda_{c_j}^{(k)} = Q^{(k)} \cdot Z^{(k)}(c_j) \qquad \Lambda_{c_j} = \sum_{k=1}^{k=n} \Lambda_{c_j}^{(k)}$$

$$Q(1) = \frac{W_j(\Delta\tau)}{N \cdot \Delta\tau \cdot Z(c_j)} \qquad Z(c_j) = \sum_{i=j}^{i=5} p_i$$

An example of risk analysis

POLITECHNIKA WARSZAWSKA
Wydział Mechaniczny Energetyki i Lotnictwa

QUANTITATIVE RISK ANALYSIS OF FORK-LIFT OPERATOR

Artur Jesionowski

Warsaw 2003

Probabilistic Risk Analysis

the most probable category of loss

The most likely loss

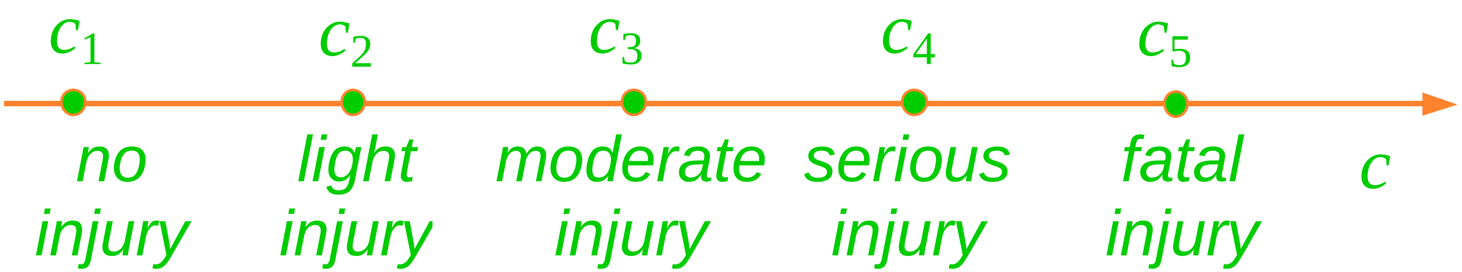
$$c_o^{(k)}(1) = Q^{(k)}(1) \cdot Z_o^{(k)}$$

the most probable category of loss in time $t = 1$

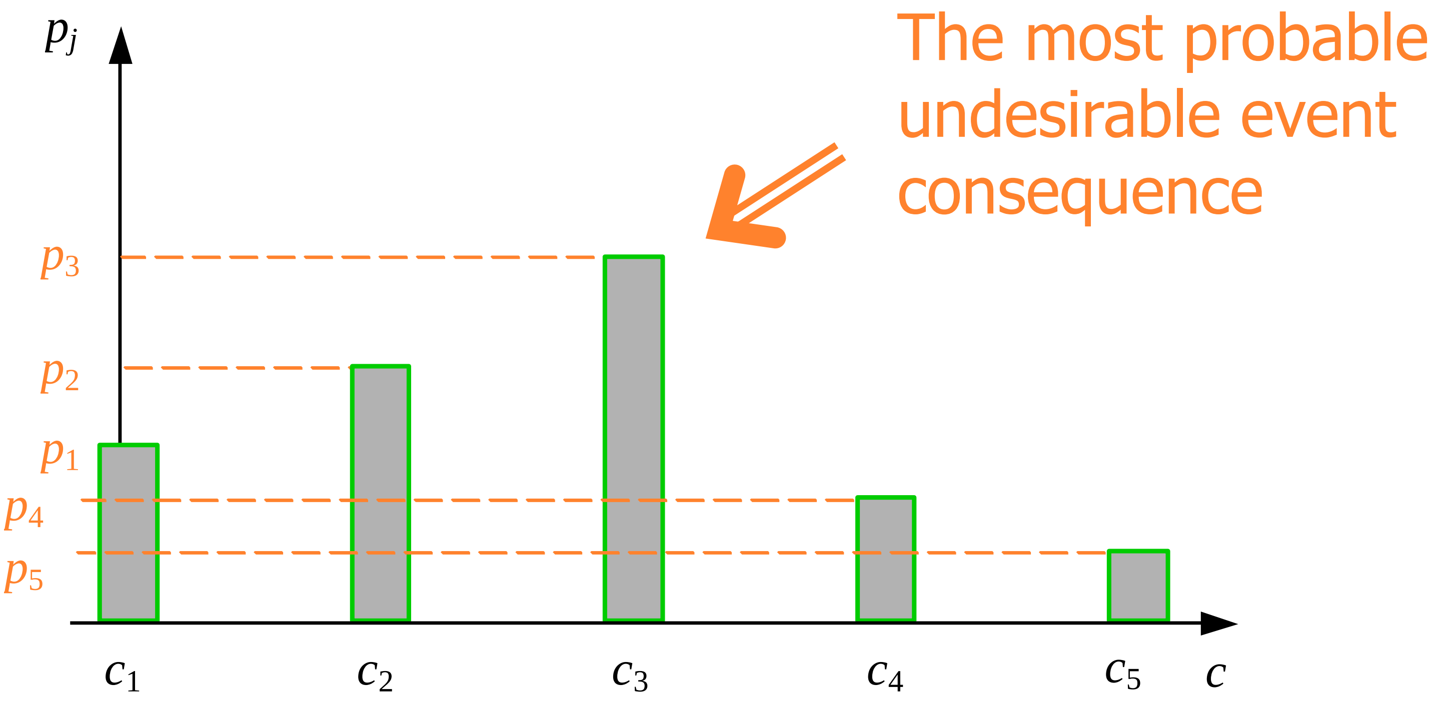
$$c_o(1) = \sum_{k=1}^{k=r} c_o^{(k)}(1)$$

Measure of individual human losses

Loss category

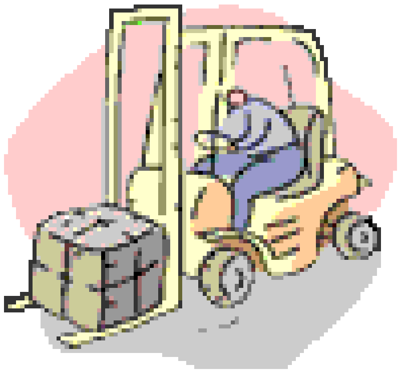


The most likely category



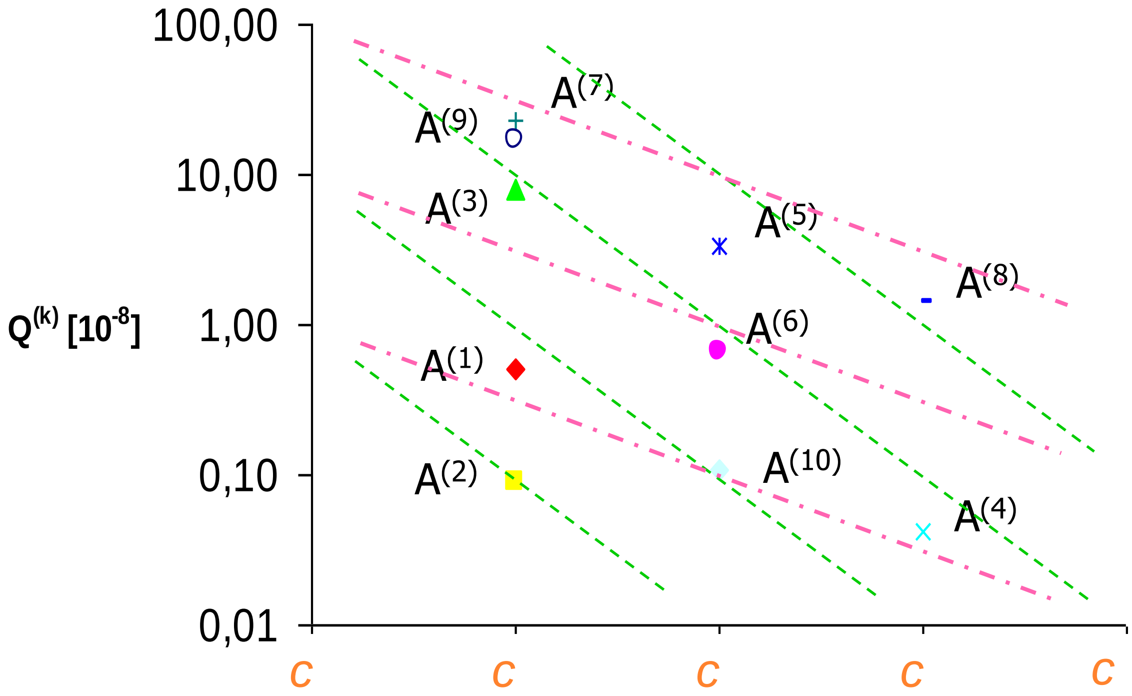
$$p_j = P\{\boldsymbol{C}_1 = c_j \mid \boldsymbol{A}\}$$

Chosen Primary Undesirable Events



- $A^{(1)}$ forklift overturn
- $A^{(2)}$ collision of two forklifts
- $A^{(3)}$ crashing into an object
- $A^{(4)}$ fall of the forklift from the loading ramp
- $A^{(5)}$ hitting the operator by the other forklift
- $A^{(6)}$ crushing of the operator with cement pallete
- $A^{(7)}$ contact with hot fluids
- $A^{(8)}$ crushing of the operators legs protruding from the cabin
- $A^{(9)}$ crushing of the operator with forklift gear
- $A^{(10)}$ crushing of the operator with the doors

Risk analysis results



$A^{(8)}$ crushing of the operators legs protruding from the cabin
$A^{(5)}$ hitting the operator by the other forklift
$A^{(7)}$ contact with hot fluids
$A^{(9)}$ crushing of the operator with forklift gear

MIL-STD-882

"Standard Practice for System Safety"

	Negligible	Marginal	Critical	Catastrophic
frequent	13	7	3	1
probable	10	9	5	2
occasional	18	11	6	4
remote	19	14	10	8
improbable	20	17	15	12