

**Risk and Safety**

**in**

**Engineering**

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# Fundamental Societal Value Settings

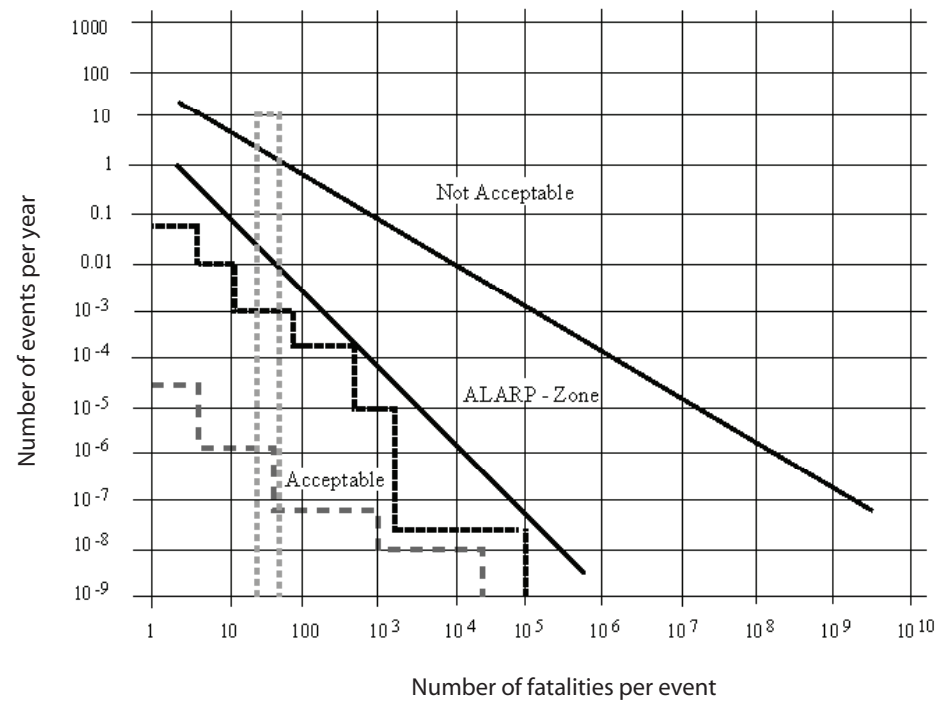
- Most nations of the world adhere to fundamental principles similar to the UN Charter on Human Rights
- *Article 1*  
All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience and should act towards one another in a spirit of brotherhood.
- *Article 3*  
Everyone has the right to life, liberty and security of person.
- *Article 7*  
All are equal before the law and are entitled without any discrimination to equal protection of the law. All are entitled to equal protection against any discrimination in violation of this Declaration and against any incitement to such discrimination.

# Preferences in Societal Decision Making

- To enable societal decision making it is required to understand the preferences of society – not least concerning investments into life saving and preservation of the environment.
- Preferences are unfortunately difficult to describe.
- Most approaches attempt to establish preferences through questionnaires – such preferences are called ***stated preferences***.
- However, by observing the behaviour of individuals as well as groups of individuals it is possible to assess ***revealed preferences*** – these are far better than stated preferences.
- The best option is to assess ***informed preferences*** – this is a dynamic process involving a high degree of knowledge.

## Commonly Applied Formats of Risk Acceptance

Most existing formats for risk acceptance take basis in *Farmer diagrams*



## Commonly Applied Formats of Risk Acceptance

Most existing formats for risk acceptance take basis in *Farmer diagrams*

The diagram is a 5x5 matrix with a purple border. The vertical axis is labeled 'Consequence of event' and has categories: large, significant, moderate, small. The horizontal axis is labeled 'Probability of event' and has categories: small, moderate, significant, large. The cells are colored as follows: (large, small) red; (large, moderate) red; (large, significant) red; (large, large) red; (significant, small) yellow; (significant, moderate) red; (significant, significant) red; (significant, large) red; (moderate, small) green; (moderate, moderate) yellow; (moderate, significant) yellow; (moderate, large) red; (small, small) green; (small, moderate) green; (small, significant) green; (small, large) yellow.

Consequence of event	Probability of event			
	small	moderate	significant	large
large	red	red	red	red
significant	yellow	red	red	red
moderate	green	yellow	yellow	red
small	green	green	green	yellow

## Commonly Applied Formats of Risk Acceptance

- In the offshore industry the concept of acceptable ***fatal accident rate (FAR)*** has been introduced

$$FAR = \frac{PLL \cdot 10^8}{N_P \cdot H_P}$$

$N_P$  : Number of exposed persons

$H_P$  : Yearly number of exposure hours

$PLL$  : Expected number of fatalities per year

- Typically accepted values for the FAR lie between 10-15.

## Revealed Risks in Society

Experienced life safety risks (rate of death per 100000 persons per year)

Average over all causes		Occupational rate of death	
110	25 years	100	Lumber Jack's and timber transport
100	35 years	90	Forestry
300	45 years	50	Construction work
800	55 years	15	Chemical industry
2000	65 years	10	Mechanical productions
5000	75 years	5	Office work
Miscellaneous risks		Miscellaneous risks	
400	20 cigarettes per day	5	Mountain trekking
300	1 bottle of wine per day	3	10000 km highway transport
150	"Motor biking"	1	Air plane crash (per travel)
100	Hand-gliding	1	Fire in buildings
20	Car driving (20-24 years)	1	10000 km train transport
10	Pedestrians (household)	0.2	Death due to earth-quakes (California)
10	10000 km car transport	0.1	Death due to lightening



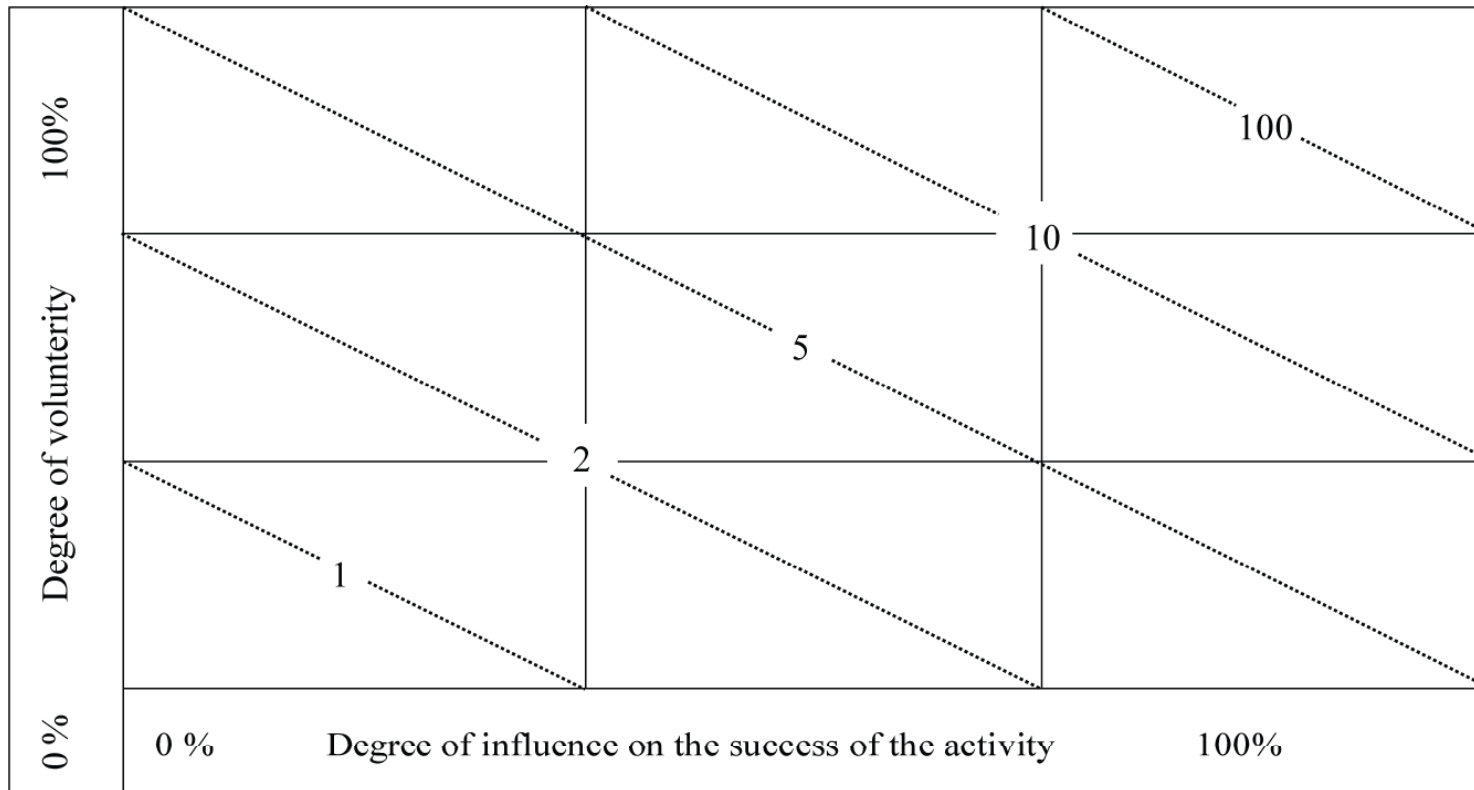
# Revealed Risks in Society

It is possible to organize activities according to the degree of voluntarism and degree of personal influence/control

Degree of voluntarism	100%	Soccer Mountain climbing Motorbiking	Hazardous mountain climbing	
		Air travel Train transport	Car transport Occupation	
	0%	Work at home		
	0%	Degree of influence on the success of the activity		100%

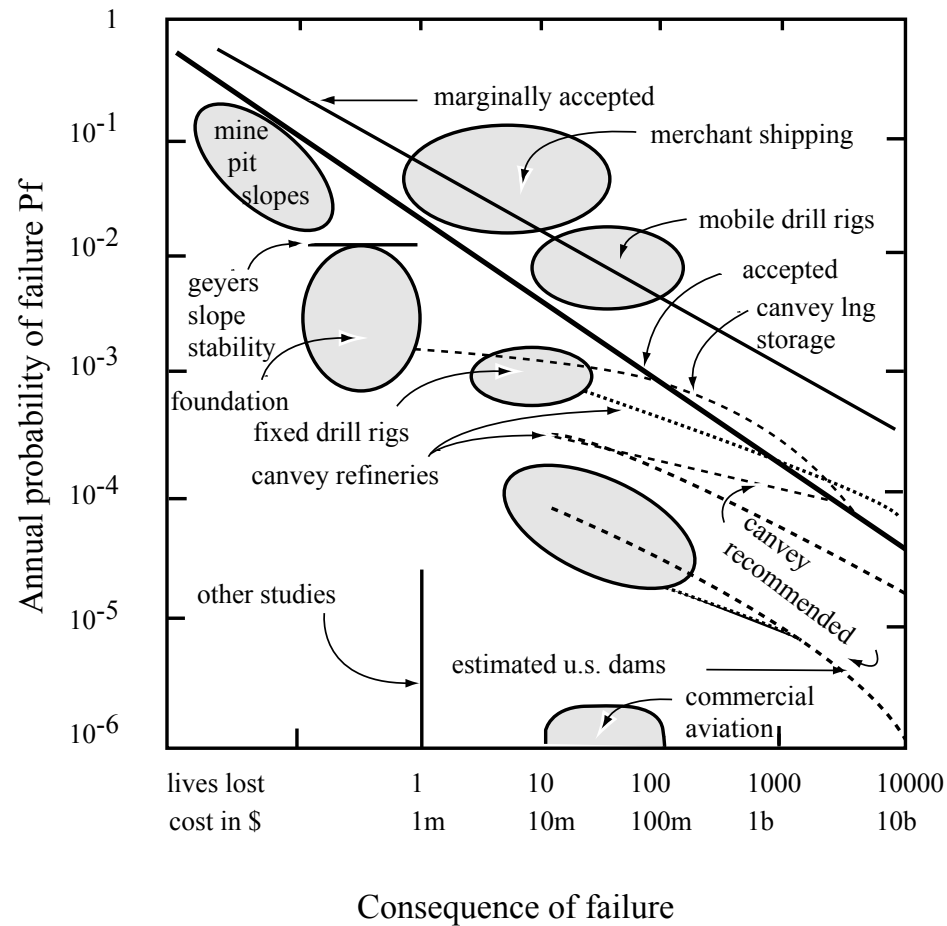
# Revealed Risks in Society

By study of statistics it is then possible to organize revealed risks according to degree of voluntarism and degree of personal influence/control.



# Revealed Risks in Society

## Experienced risks in selected commercial activities



## Life Safety – and the Performance of Society

Life safety is provided by many different sectors and through very different activities

Risk reduction cost in SFr per saved person life	
100	Multiple vaccination - third world
$1 \cdot 10^3$	
$2 \cdot 10^3$	Medical X-ray facility
$5 \cdot 10^3$	Wearing motorbike helmet
$10 \cdot 10^3$	Cardiac ambulance
$20 \cdot 10^3$	Emergency helicopter service
$100 \cdot 10^3$	Safety belts in cars
to	Crossway restructuring
	Kidney dialysis
$500 \cdot 10^3$	Structural reliability
$1 \cdot 10^6$	
$2 \cdot 10^6$	
$5 \cdot 10^6$	City railway Zurich, Alp Transit
$10 \cdot 10^6$	Earthquake standard SIA
$20 \cdot 10^6$	Mine safety USA
$50 \cdot 10^6$	DC 10 out of service
$100 \cdot 10^6$	Multi-storey buildings regulation
$1 \cdot 10^9$	Removal of asbestos from public buildings

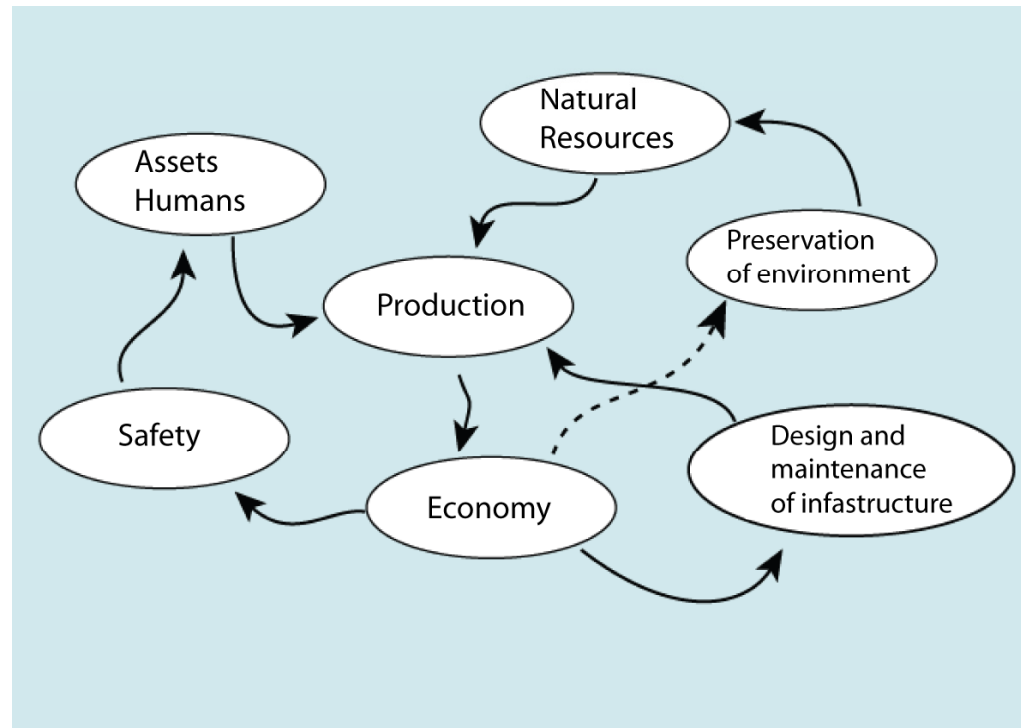
Efficiency is markedly different from sector to sector and from activity to activity.

It is a societal responsibility to spend public resources efficiently.

If this is not done – life is taken away from some individuals in society.

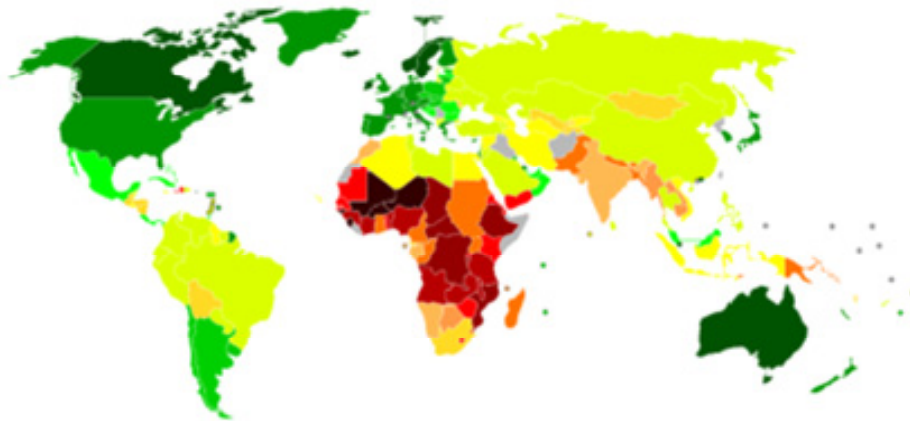
## Life Safety – and the Performance of Society

Prioritization in society must be subject to a holistic perspective

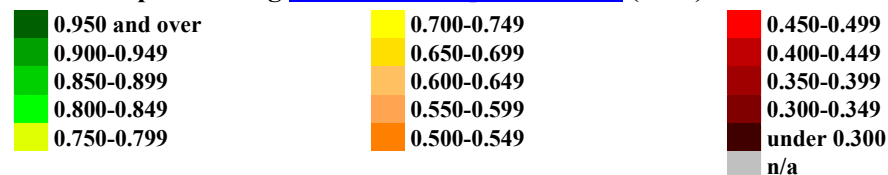


## Life Safety – and the Performance of Society

The performance of the nations of the world is measured through the *Human Development Index (HDI)*



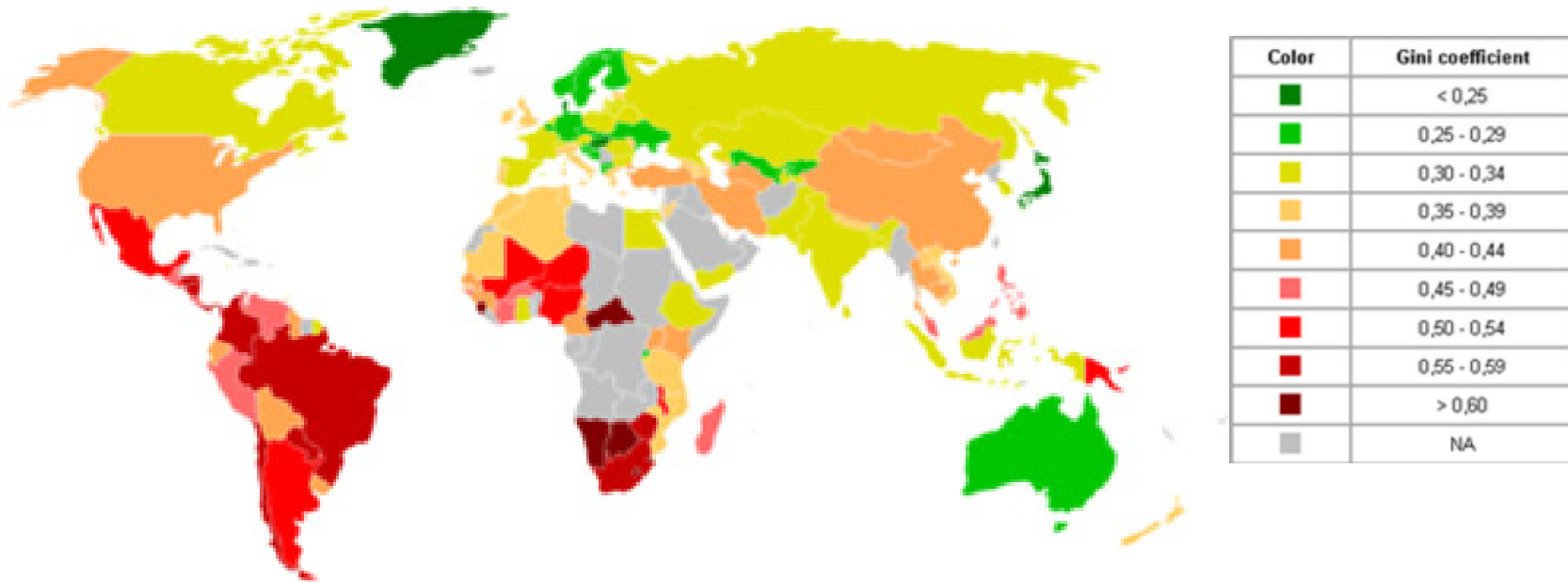
World map indicating [Human Development Index](#) (2004).



$$HDI = \frac{1}{3} GDP Index + \frac{1}{3} EI + \frac{1}{3} LEI$$

## Life Safety – and the Performance of Society

It is also interesting to observe how the income of nations is distributed between the individuals of the nations (*Gini Index*)



## Modelling Socio-Economic Acceptable Risks

Taking basis in the philosophical insight that the basic asset individuals have is time – Nathwani, Pandey and Lind developed the *Life Quality Index*.

This is a preference model which at a societal level acts as a revealed preference on how we weight money against lifetime and time for private activities.

$$L(g, \ell) = g^q \ell$$

$g$  : is the part of the GDP available for investment into life safety

$\ell$  : is the life expectancy at birth

$w$  : is the part of life spent for work

$$q = \frac{1 - w}{\beta}$$

$\beta$  : is a factor which takes into account that only a part of the GDP is based on human labour



## Modelling Socio-Economic Acceptable Risks

Based on the LQI – the consideration that every investment into life safety should lead to an increase in life-expectancy results in a risk acceptance criterion:

$$\frac{dg}{g} + \frac{1}{q} \frac{d\ell}{\ell} \geq 0$$

which leads to the important **Societal Willingness To Pay (SWTP)** criterion:

$$SWTP = dg = -\frac{g}{q} \frac{d\ell}{\ell}$$

GDP	59451 SFr
$l$	80.4 years
$w$	0.112
$\beta$	0.722
$g$	35931 SFr
$q$	0.175

## Modelling Socio-Economic Acceptable Risks

The SWTP criterion is readily applied for the purpose of determining acceptable structural failure probabilities

$$\frac{d\ell}{\ell} \approx C_x d\mu = C_x kdm$$

where

$C_x$  is a demographical constant

$k$  is the probability of dying in case of structural failure

$m$  is the failure rate of a considered structural system

## Modelling Socio-Economic Acceptable Risks

The SWTP criterion is readily applied for the purpose of determining acceptable structural failure probabilities

$$dC_y(p) \geq -\frac{g}{q} C_x N_{PE} kdm(p)$$

where

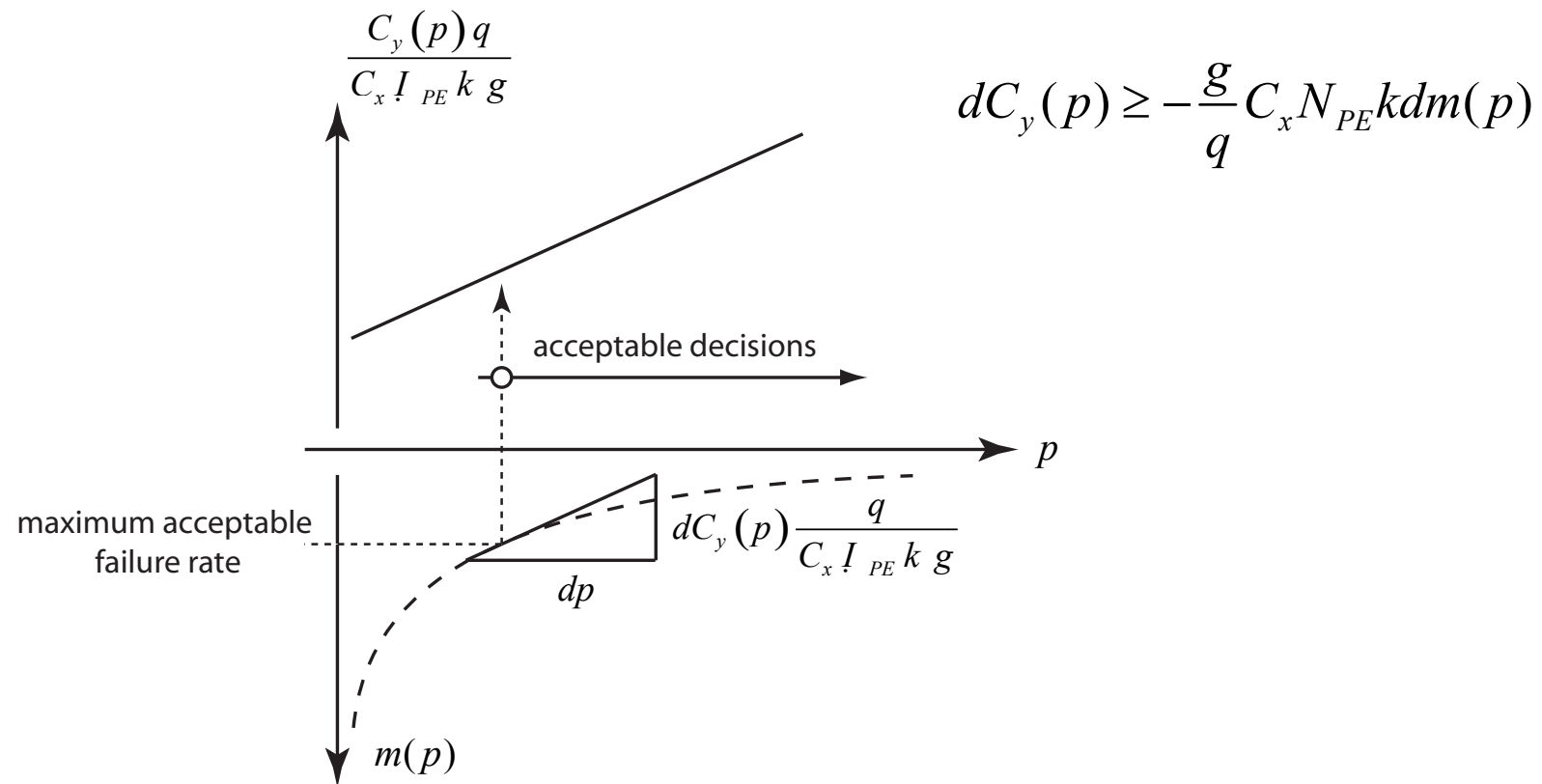
$dC_y(p)$  are the annual costs spent for risk reduction

$N_{PE}$  is the number of people exposed to the structural failure

$p$  is a decision alternative e.g. a structural dimension

# Modelling Socio-Economic Acceptable Risks

The SWTP criterion can be visualized



# Modelling Socio-Economic Acceptable Risks

- Based on the LQI – also the costs of compensation for a lost life can be assessed – ***Societal Value of a Statistical Life (SVSL)***.

$$SVSL = \frac{g}{q} E$$

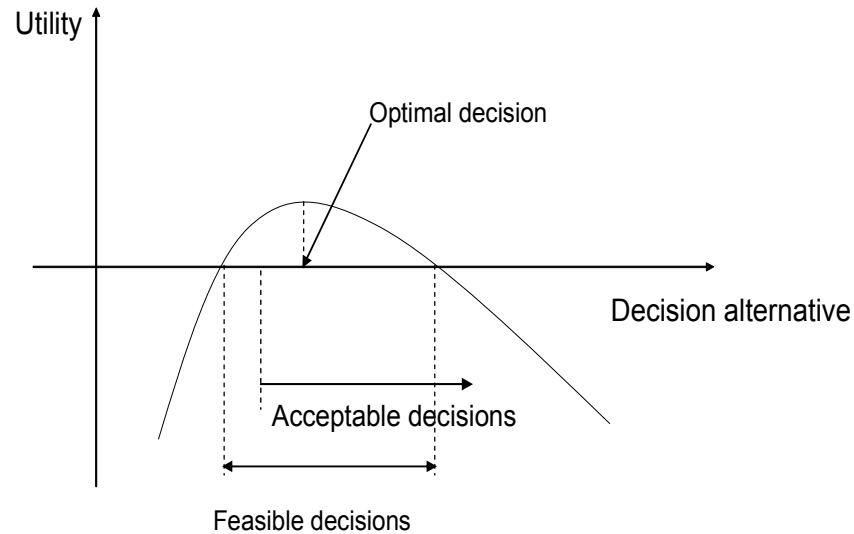
- For Switzerland this amounts to about 6 million SFr

# Modelling Socio-Economic Acceptable Risks

Now the optimization problem can be reassessed –

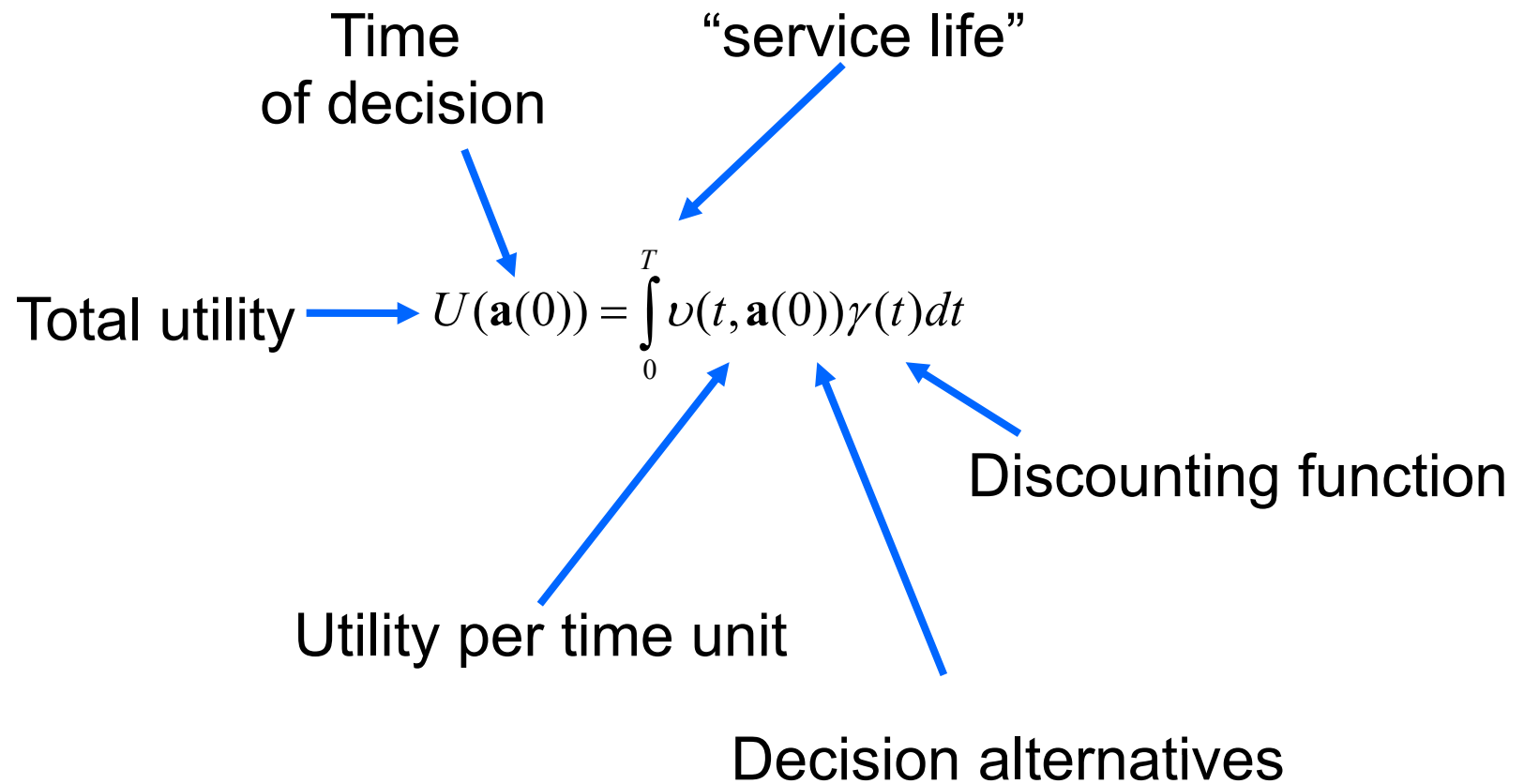
Acceptable decisions are limited by the SWTP criterion

Costs of failure include compensation – through the SVSL



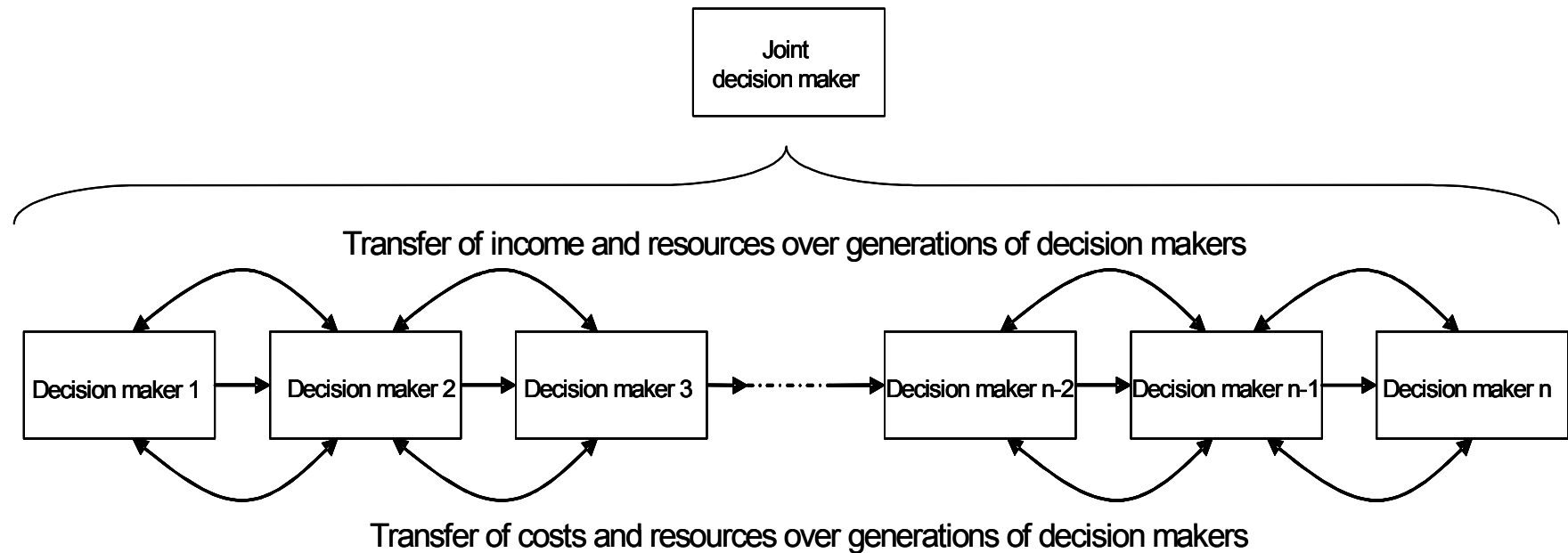
# Sustainable Decision Making

In intra-generational decision making we use



# Sustainable Decision Making

If we assume intergenerational equity as a principle we get



Utility may be assessed as the sum of the utility for all generations



# Sustainable Decision Making

- The discounting to be considered for present and future generations should include
  - economic growth (2 % per annum)
  - preference to spend early rather than late (3% per annum)
- Equity implies that the utility for future generations should be reduced corresponding to the assumed economic growth

$$U(\mathbf{a}(\mathbf{T})) = \sum_{i=1}^n \delta(t_i) \left[ \int_{t_i}^{t_{i+1}} v_{G_i}(\tau, \mathbf{a}(t_i), t_i) \gamma(\tau - t_i) d\tau \right]$$

Economic growth      Usual discounting

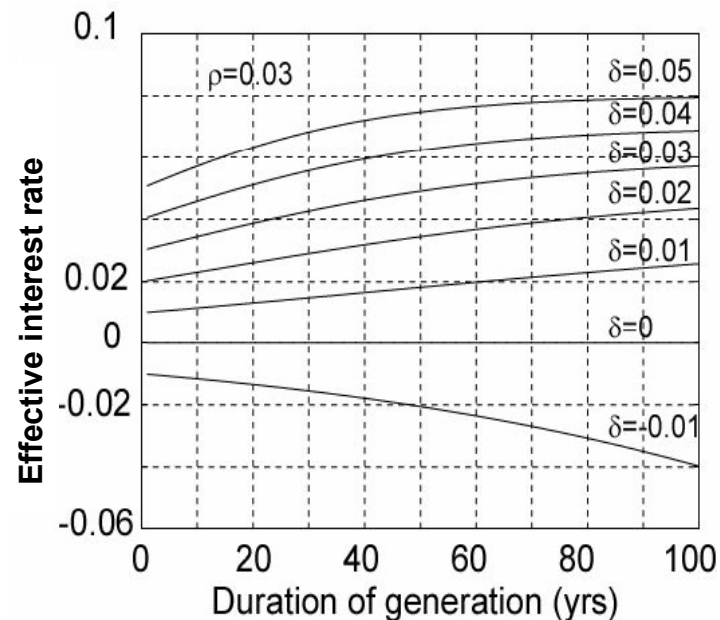
# Sustainable Decision Making

Assuming that the rate of benefit is constant over time we get

$$\int_0^T v(t, \mathbf{a}(0)) \gamma^*(t) dt = \sum_{i=1}^n \delta(t_i) \left[ \int_{t_i}^{t_{i+1}} v_{G_i}(\tau, \mathbf{a}(t_i), t_i) \gamma(\tau - t_i) d\tau \right]$$

⇓

$$\gamma^* = \frac{1 - \exp(-\delta L)}{1 - \exp(-\gamma L)} \gamma$$



# Sustainable Decision Making

- All benefits and investments must be discounted – also expenditures of life saving.
- Effective discounting rates to be applied in usual formulations of design and inspection and maintenance problems is close to the rate of economic growth.
- Differences in discounting rates observed in different economic activities become irrelevant.