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.

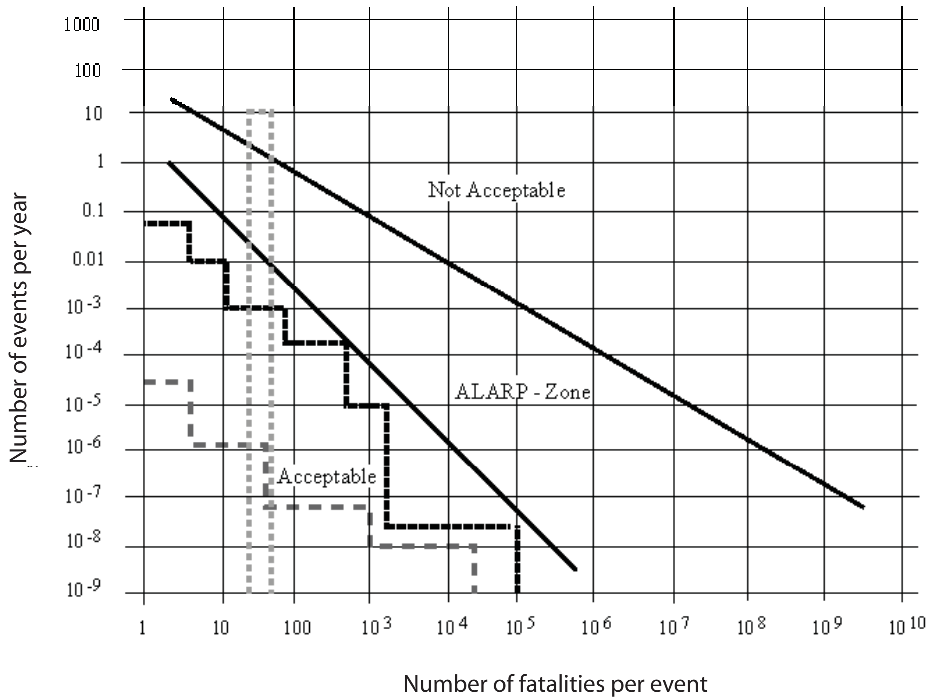
- Most approaches attempt to establish preferences through questionnaires – such preferences are called ***stated preferences.***

- 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***



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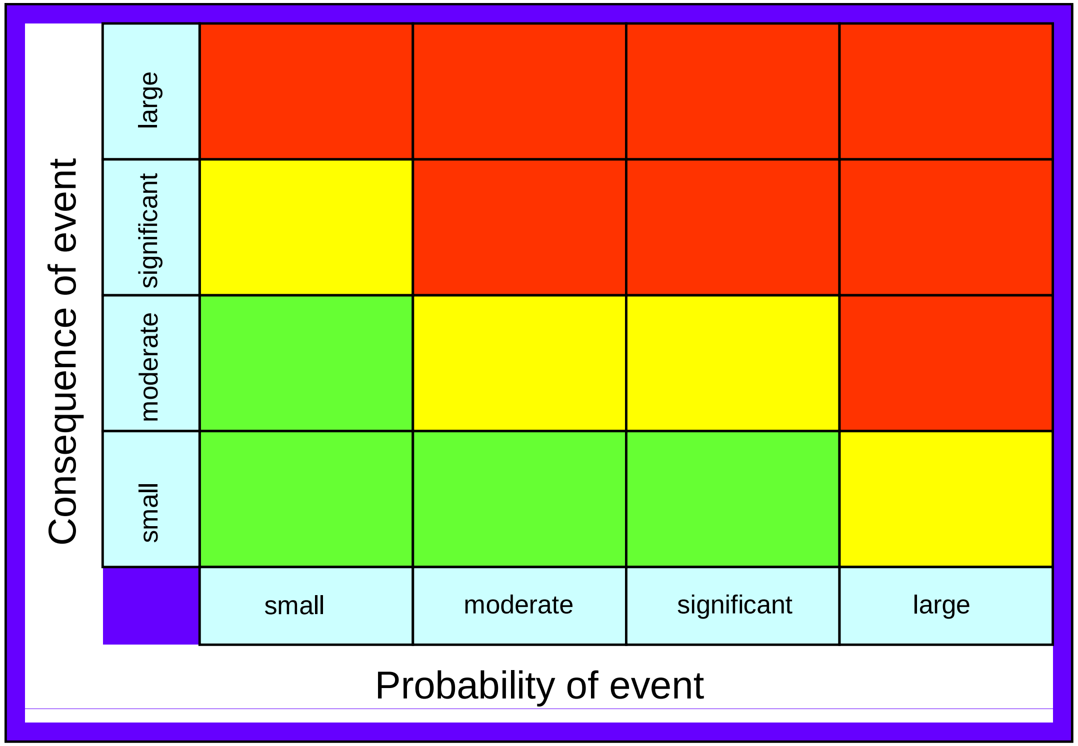


Commonly Applied Formats of Risk Acceptance

- 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 100,000 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

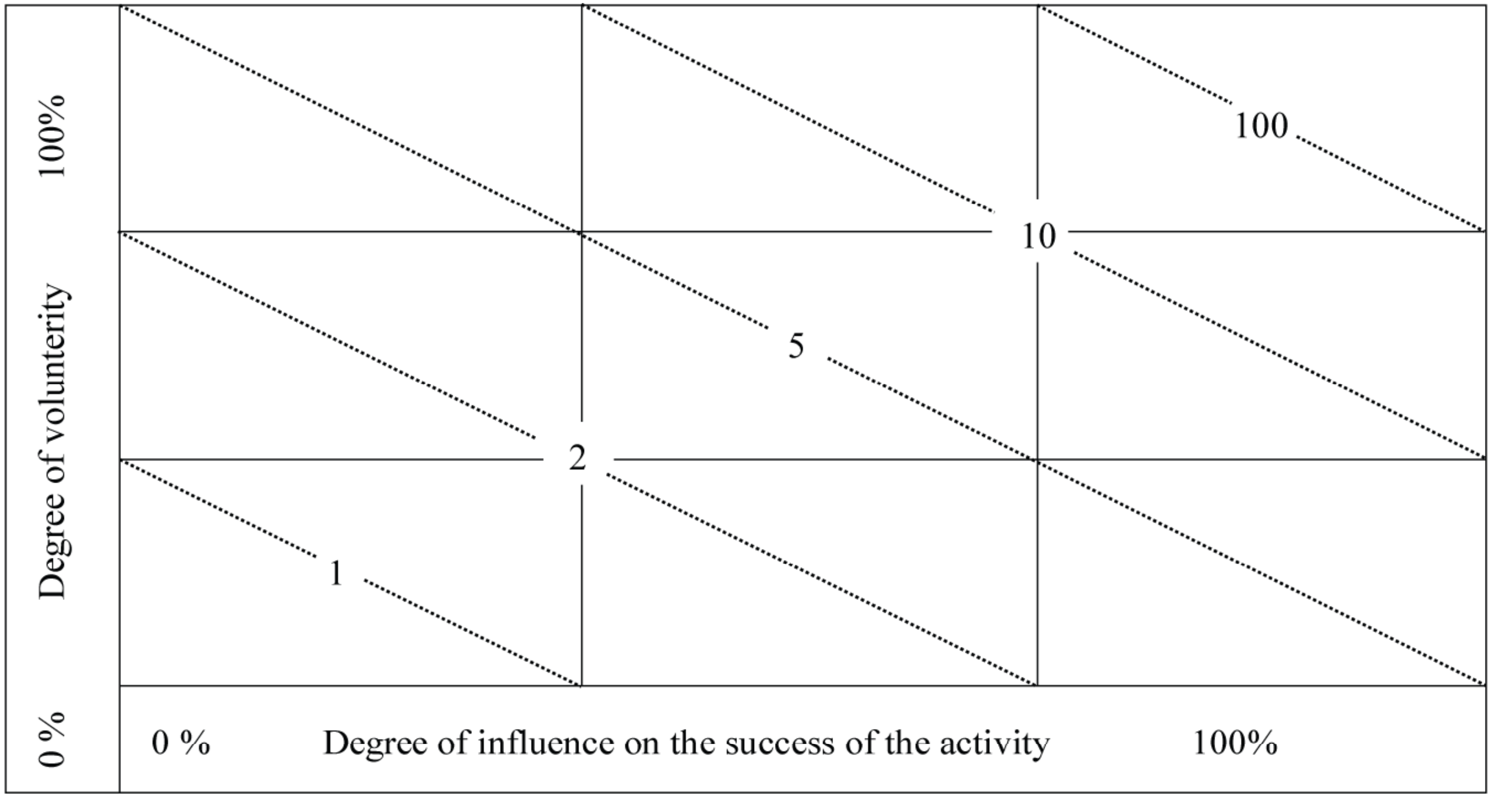
Revealed Risks in Society

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

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

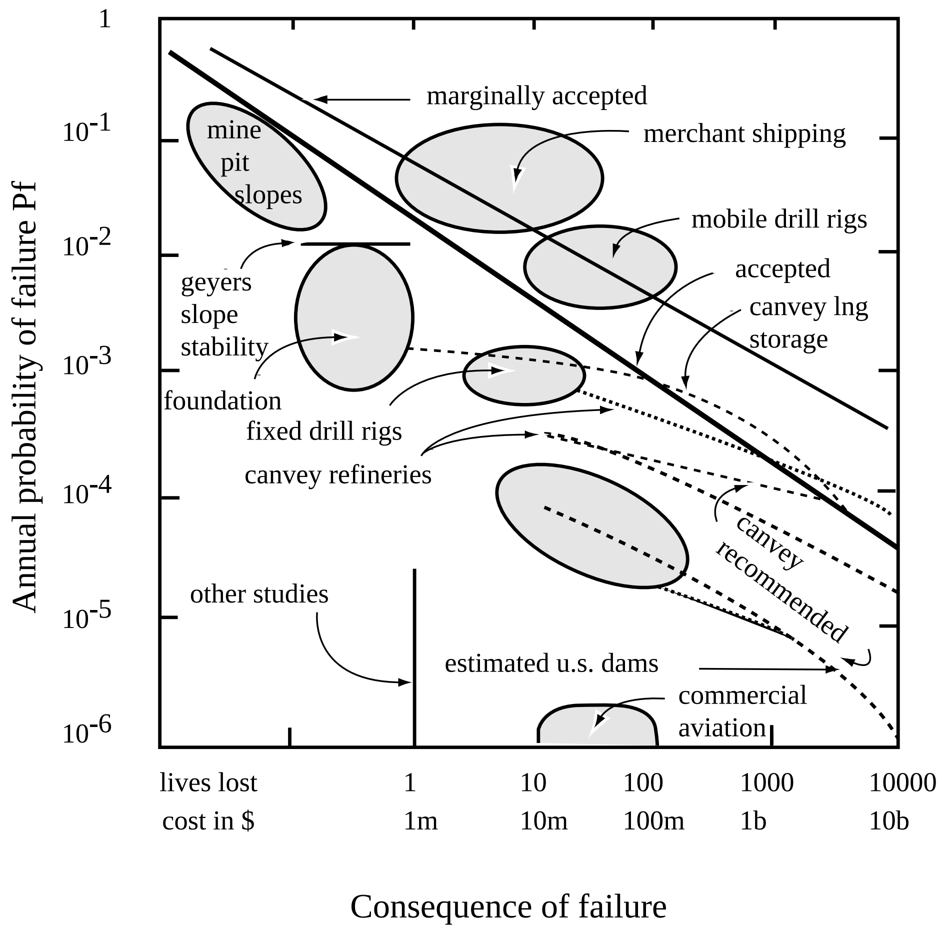
Revealed Risks in Society

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 in 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

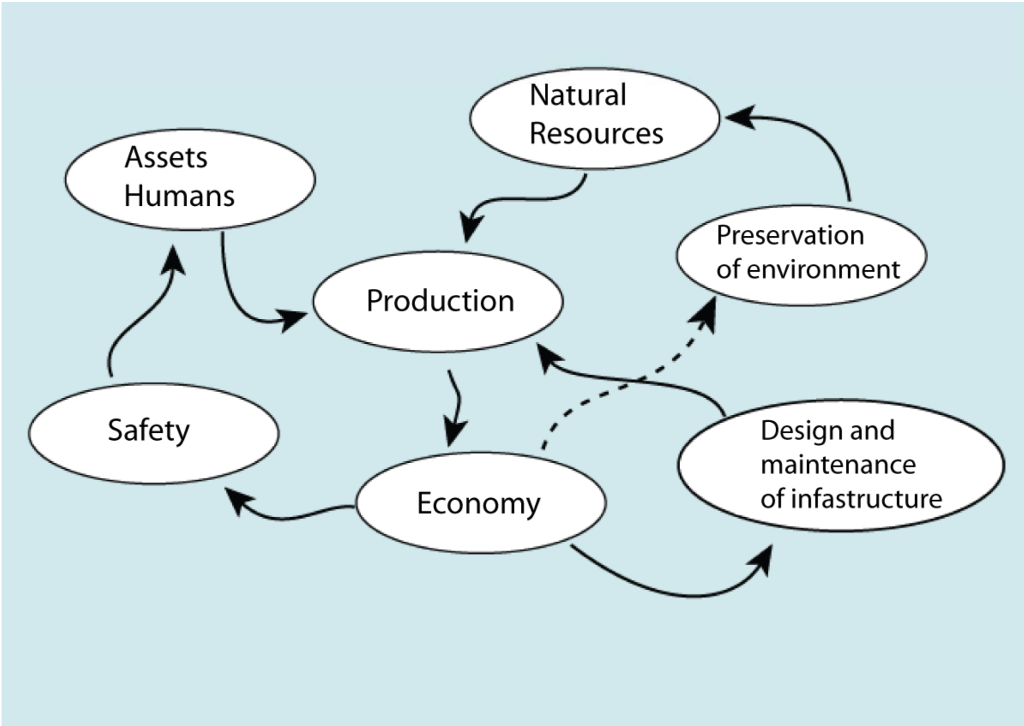
Efficiency is markedly different from sector to sector and from activity to activity.

It is a societal responsibility to spend public resources efficiently.

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

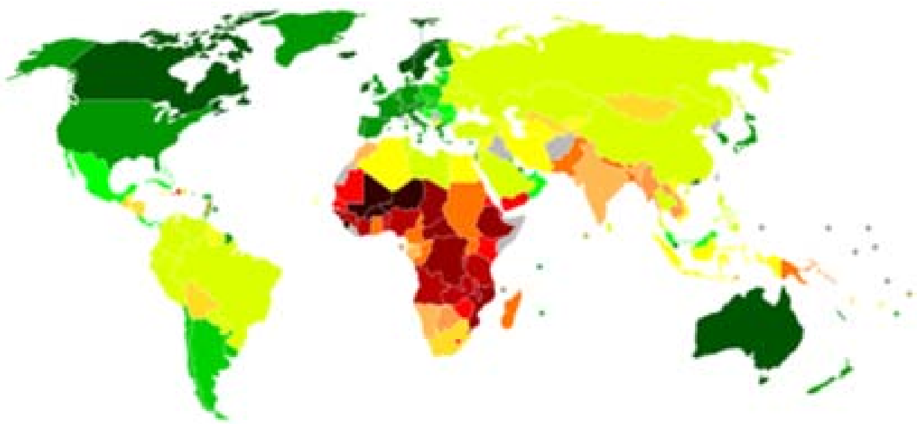
Life Safety – and the Performance of Society

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)*



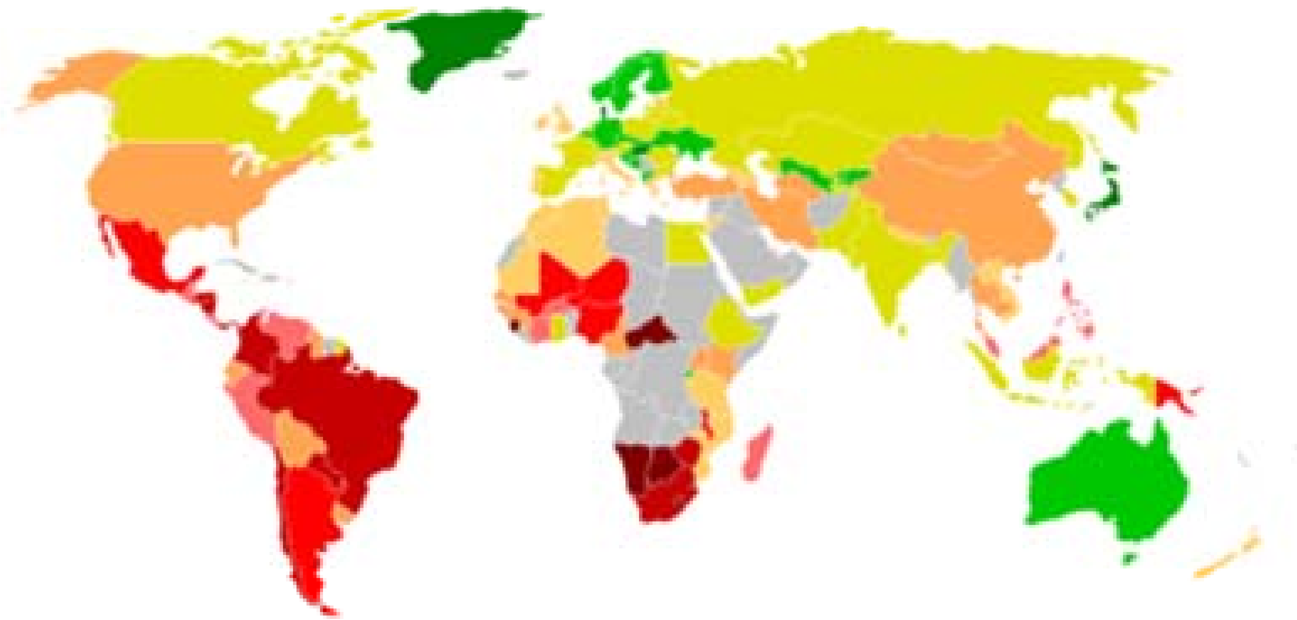
World map indicating Human Development Index (2004).

- 0.950 and over
- 0.900-0.949
- 0.850-0.899
- 0.800-0.849
- 0.750-0.799
- 0.700-0.749
- 0.650-0.699
- 0.600-0.649
- 0.550-0.599
- 0.500-0.549
- 0.450-0.499
- 0.400-0.449
- 0.350-0.399
- 0.300-0.349
- under 0.300
- n/a

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

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***)



Color	Gini coefficient
	< 0,25
	0,25 - 0,29
	0,30 - 0,34
	0,35 - 0,39
	0,40 - 0,44
	0,45 - 0,49
	0,50 - 0,54
	0,55 - 0,59
	> 0,60
	NA

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 (LQI).***

This is a preference model which at a societal level acts as a revealed preference on how we weigh 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

ℓ : is the life expectancy at birth

w : is the part of life spent for work

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

β : 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
β	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

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

where

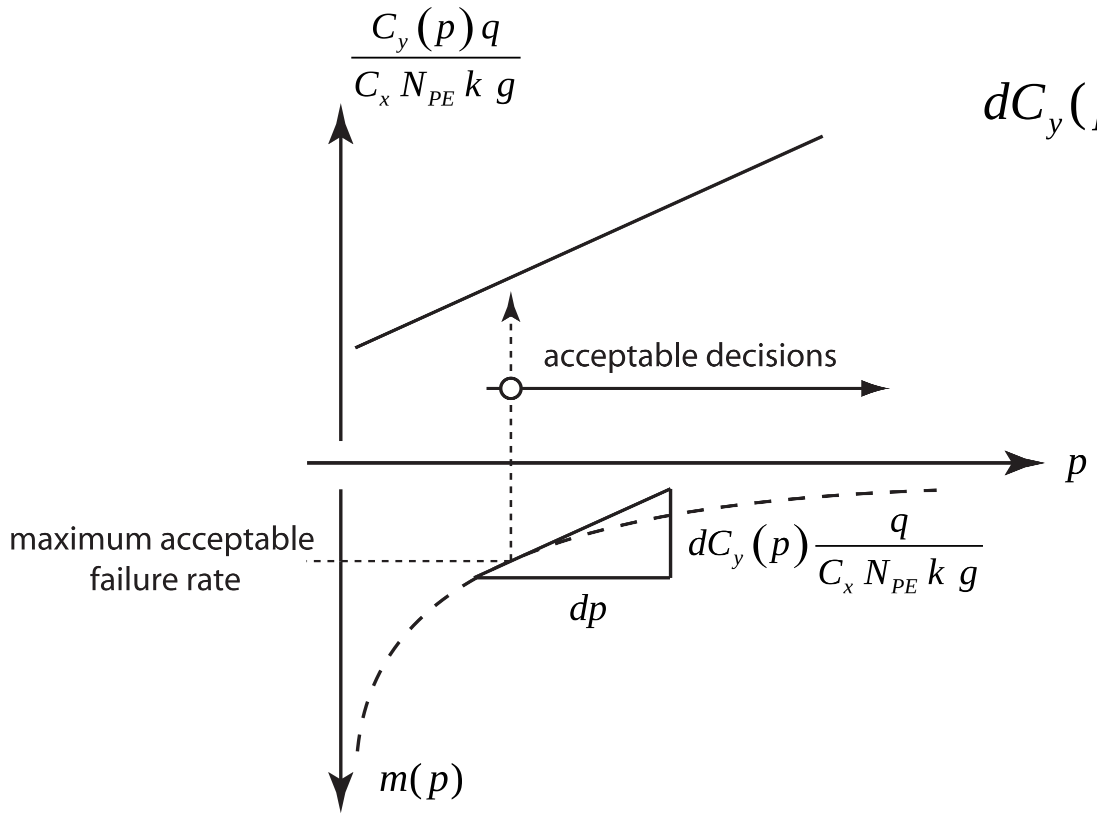
$dC_y(p)$ are the annual costs spent for risk reduction

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



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

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***).

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

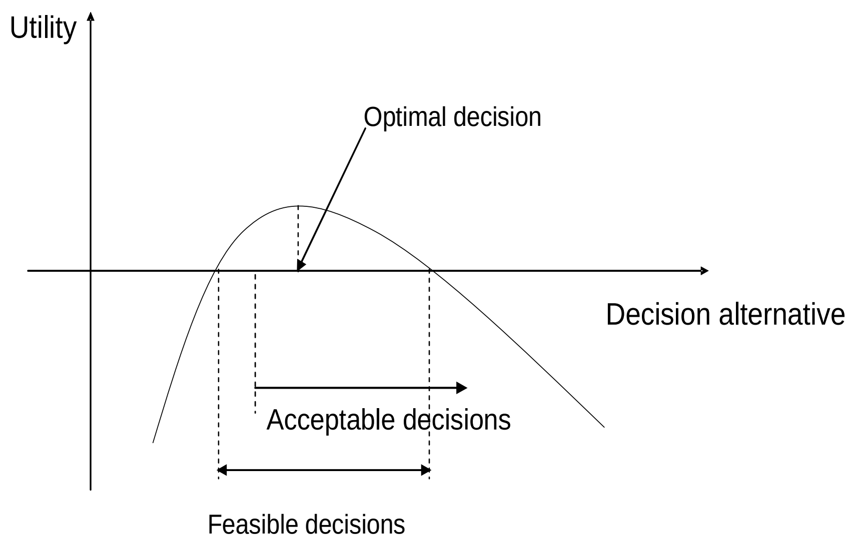
- For Switzerland this amounts to about 6 million SFr

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

Time of decision

“service life”

Total utility

$$U(\mathbf{a}(0)) = \int_0^T \upsilon(t, \mathbf{a}(0))\gamma(t)\,dt$$

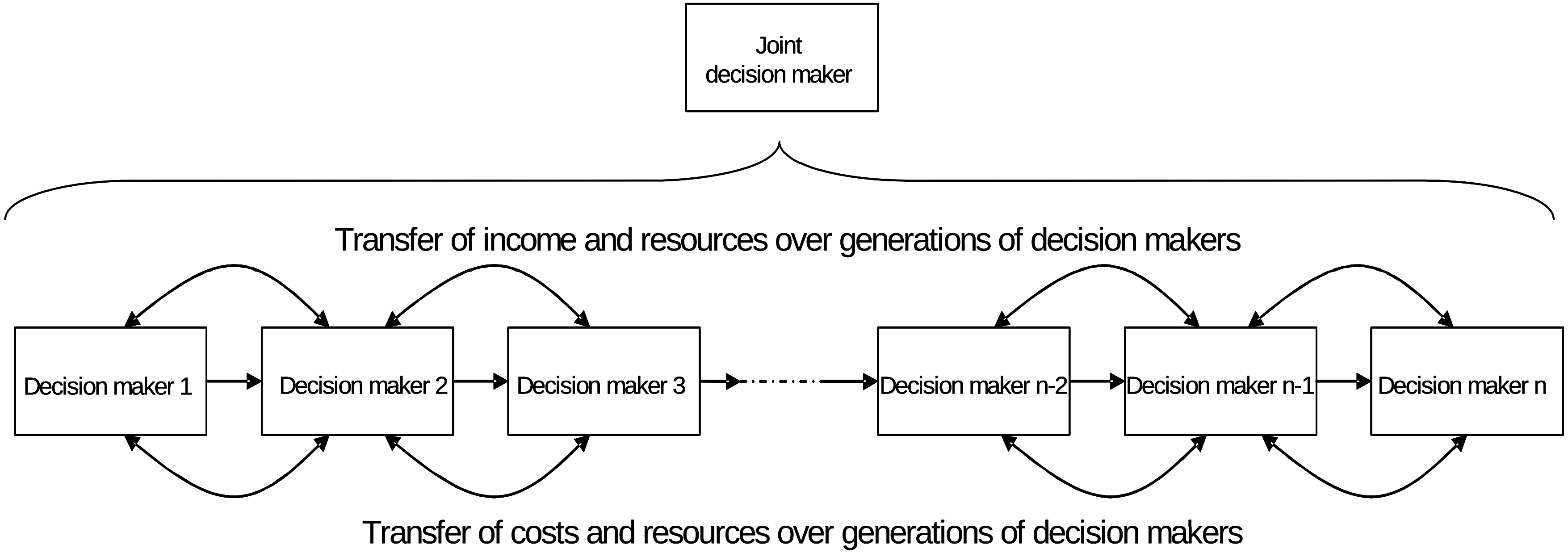
Discounting function

Utility per time unit

Decision alternatives

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

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

Economic growth

Usual discounting

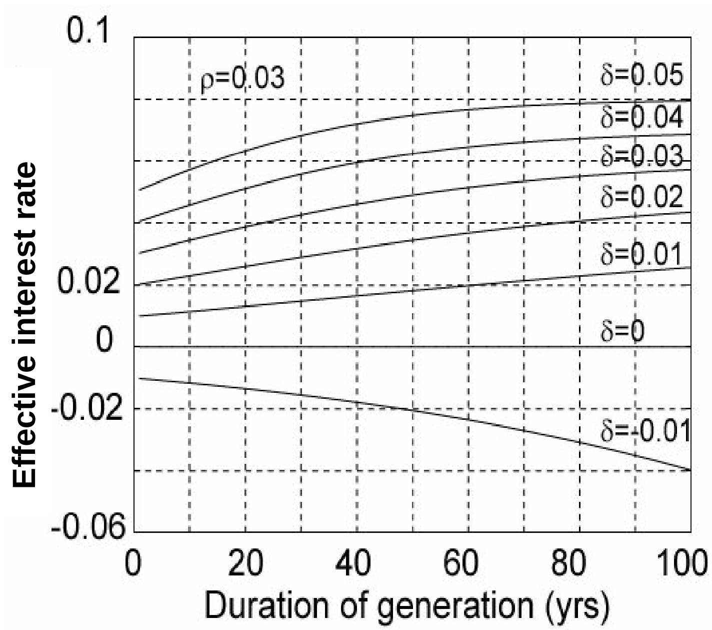
Sustainable Decision Making

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

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

$$\Downarrow$$

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



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.