SUSTAINABLE DECISIONS BASED ON PRINCIPLES OF LQI

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Summary

Sustainable decisions concerning reliability of new as well as existing structures can be based on utility optimization using principles of the Life Quality Index (*LQI*). Input parameters of the *LQI* include a part of the gross national product per capita available for the risk reduction, the expected life time, the measure of the trade-off between the disposable resources, and the value of the time of healthy life. Criteria for annual societal investment, Societal Willingness to pay (*SWTP*) and Societal Value of Statistical Life (*SVSL*) are related to the compensation costs for loss of a life.

Keywords: Sustainable decisions, LQI, optimization, utility

1 Introduction

In principle sustainable design for structural reliability needs to be based on:

- A target reliability optimised with respect to the total structural costs related to an anticipated working life of the structure, including costs of safety measures and failure consequences;
- Use of an adequate method of reliability analysis that enables to achieve the required target reliability.

The present contribution aims at the former aspect while the latter one is out of the scope of this study. International documents ISO 2394 [1] and ISO 13822 [2] indicate a possibility to specify the target reliability levels by optimisation of the total cost related to an assumed working life. The total costs are commonly optimised from a perspective of a single stakeholder of the construction process. Recent studies [3,4,5] indicate an urgent need for economically optimal decisions from a perspective of the whole society.

To quantify rationally the public investments into structural safety at a societal level, a special social indicator – the Life Quality Index (*LQI*) – has been introduced [6,7,8]. This index can be applied to structural facilities to derive risk acceptability limits consistently with principles of socio-economic sciences [5]. The probabilistic optimisation based on the *LQI* concept seems to be a promising tool for specification of the target structural reliability.

2 Principal form of the Life Quality Index

Based on the theory of socio-economics, the *LQI* can be expressed in the following principal form [9]:

$$L(g,l) = g^{q}\, l \tag{1}$$

where g denotes the part of *GDP* per capita available for risk reduction purposes, l is the expected life time and q is a measure of the trade-off between the resources available for consumption and the value of the time of healthy life. The parameter q may be assessed as:

$$q = w \,/\, [\beta(1 - w)] \tag{2}$$

where β is a constant (around 0,7) taking into account the fact that only a part of the *GDP* is based on human labour (the other part is due to investments), w denotes a fraction of the life time devoted to work (around 0,15). Considering these values, q is about 0,25.

3 Societal Willingness To Pay

Assuming that any investment into life risk reduction should not decrease the *LQI*, the following risk acceptance criteria may be obtained [7]:

$$\mathrm{d}g + \frac{g}{q}\frac{\mathrm{d}l}{l} \geq 0 \tag{3}$$

Here notation dg may be also interpreted as a finite increment of g (similarly for all other variables). Using this relationship, the societal willingness to invest annually into lifesaving activities (Societal Willingness To Pay) may be assessed as [7]:

$$SWTP = \mathrm{d}g = -\frac{g}{q}\frac{\mathrm{d}l}{l} \tag{4}$$

The annual investment dg denotes the annual cost that the society is willing to pay (a negative expenditure for a society) to increase the life expectancy by dl. The relative change dl/l may be replaced by a decrease in mortality dμ:

$$\mathrm{d}l \,/\, l \approx D\, \mathrm{d}\mu = D\, \pi\, \mathrm{d}m \tag{5}$$

where dm is the rate of adverse events, D is a demographic economic constant for mortality reduction, and π denotes the probability of dying given an adverse event. Previous experience suggests that the constant D be set approximately to 20. It follows from Eqs. (4) and (5) that the annual investment into life safety dC (instead of *SWTP*) may be written as:

$$\mathrm{d}C = -(g \,/\, q)\, D\, \mathrm{d}\mu = -(g \,/\, q)\, D\, N_{PE}\, p\, \mathrm{d}m \tag{6}$$

where N_{PE} denotes the number of persons exposed to the adverse event with the probability of occurrence p.

To clarify how these macroeconomic issues can be used in the assessment of individual buildings or constructed assets, an example of a road tunnel is considered with a number of escape k (a key factor affecting users' safety) to be optimised. The change in mortality dμ was determined directly using methods of risk assessment as a number of fatalities $N(k)$, see [10]. If the failure rate depends on a decision parameter k, then the acceptance criterion is:

$$\mathrm{d}C(k) \geq -(g / q)\, D\, \mathrm{d}N(k) \tag{7}$$

Here $\mathrm{d}C(k)$ denotes the amount that should be annually invested in life safety as a function of the number of escape routes k. Consider a notional value g = 10 000 USD. For q = 0,25 and D = 20, the annual investment becomes:

$$\mathrm{d}C(k) \geq -800\,000\ \mathrm{d}N(k) \tag{8}$$

Note that the criterion (7) or (8) serves as the limitation of a possible investment and not as a condition for compensation in case of accident. The minimum annual investment $\mathrm{d}C(k)$ decreases with the number of escape routes k from almost 80 000 USD to about 15 000 USD for 30 escape routes [10].

It should be noted that $N(k)$ is the number of fatalities per year. Consequently, $\mathrm{d}C(k)$ represents yearly payments. But all the costs must be raised at a certain decision point. Then, privately financed and publicly financed projects should be distinguished. Private financing makes the tunnel more expensive due to the annuity and this aspect could be included in Eq. (2), but possibly with another discount rate (market rate).

It is interesting to note that Eq. (7) may be used to specify an acceptable number of escape routes k_{acc}. Eq. (7) may be written in the form:

$$C_1 \geq -(g / q)\, D\, \mathrm{d}N(k) \tag{9}$$

Eq. (9) can be used to specify the number of escape routes k complying with the acceptance criterion (7). The minimum k satisfying Eq. (9), called the acceptable number of escape routes k_{acc}, should be considered as a lower bound for any specified number k of escape routes. The tunnel is acceptable if $k > k_{acc}$. This condition should be verified also for an optimum number of escape routes k_{opt} (derived below). Thus, the tunnel is acceptable if $k_{opt} > k_{acc}$, when $k_{opt} < k_{acc,}$ then k_{acc} should be accepted.

4 Societal value of Statistical Life

The *LQI* principles may be also used for the assessment of compensation costs. Considering the principal form of *LQI* given by Eq. (1), the Societal Value of a Statistical Life (*SVSL*) may be assessed as:

$$SVSL = (g / q)E \tag{10}$$

where E denotes the so-called age-averaged discounted life expectancy. In this concept, discounting means a societal discounting, roughly given by the natural discount rate. The age-averaging takes account of the fact that the age distribution of fatalities should mirror the age distribution of the population. Considering an effective discounting of 3 % per annum, the discounted life expectancy is about 30 years and the corresponding *SVSL* is:

$$SVSL = (g / q)E = 40\,000 \times 30 = 1\,200\,000 \text{ USD} \tag{11}$$

The *SVSL* is considered as an estimation of the compensation cost for one fatality R_1. However, in an optimization concept $R_1 = SVSL$ may give a rather high value. The real compensation cost (carried by the social system of the state or an insurance) hardly exceeds the lost income in an event, approximately $g\, l/2 = 10000 \times 70 / 2 = 350\,000$ USD.

5 Conclusions

The concept of Life Quality Index *LQI* and derived notions of the Societal Willingness To Pay *SWTP* and Societal Value of Statistical Life *SVSL* seem to provide an effective and powerful tool to balance societal and economic aspects. The compensation cost R_1= *SVSL* may give a rather high value. The real compensation cost (carried by the state or insurance) hardly exceeds the lost income in an event. Further investigations of models for their societal and economic consequences are needed. In particular, consistent values for the costs of various safety measures and compensation costs *SVSL* are required.

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