Origin and Development of the LQI

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Abstract

We summarise the processes that have led to the Life Quality Index in the form $LQI = EG^{0.2}$, and give an overview of applications realised and potential. The LQI has matured into a stable format. It has found a variety of applications in risk management and hundreds of scientific publications. We suggest that further development of applications will be in the public interest, requiring activity at the level of governments. Its full potential to serve societal needs is very far from realized; this will require application beyond the scientific and professional.

1. Introduction

In the 1980s there was a growing concern over life risk and safety. With the rapid economic development resting on technology came a fear that maybe we had gone too far too fast, that some unknown risk or disaster could be waiting to strike. Fear, of radiation – from cell-phones as from nuclear power or microwave ovens -- or chemicals in the environment was on the rise. Industrial accidents as at Bhopal [1984], Chernobyl [1986] or the Exxon Valdez oil spill [1989], had enhanced the public fear of technology. The LQI came about on this background of a deep public concern over risks to life in the modern world: Amid all this fear and risk perception, professionals were looking for a rational basis to measure and manage risks to the public in a responsible way.

Concurrently, probability-based risk analysis had been developed to the point that the cost-effectiveness of hundreds of risk-mitigation options had been determined. The trouble was that there were two kinds of risk. One was risk as analysed by professionals. The other was the public perception of risk, a societal concern rooted in the psychology of fear and reliant on information as sold by the press, more often sensational and lacking in balanced perspectives. Quite understandably people had little reason to trust that technological risk was being managed in the public interest. The LQI was developed to provide a rational basis for life risk management, in full recognition that the ultimate decsions in a democracy will always rest with the politicians but the public would be better served if the reasoning is transparent and based on evidence.

2. Developing the LQI

In January 1989 the Canadian Atomic Energy Control Board, several Canadian energy producers and the Institute for Risk Research sponsored a 16-month research project at the University of Waterloo. Principal Investigators were Dr Ernest Siddall and the authors. We formulated a fundamental principle for the management of technology when there is a risk to the life and health of the public: *Risks should be managed such as to maximize the net benefit to society.* This principle extends to all public risks managed by professionals or by

regulations. Further we proposed the following measure of benefit to life and health: *Quality-adjusted life years [QALYs]*. All risk mitigation efforts should maximize the total expected net benefit measured in terms of QALYs.

The outcome of the study was documented in the book *Managing Risks in the Public Interest* (Lind et al. 1991), proposing a protocol for risk management decisions and illustrating its application by some practical examples. To compare risk mitigation prospects in terms of QALYs per dollar spent was then a technical problem, easy in principle. In practice it was also easy, as demonstrated by the seminal work of Tengs et al. (1995), who collated and analysed over 500 life-saving intervention options,. These options ranged widely, from more than 50 that would save money as well as lives, through some that were bargains in terms of lives saved, to some that saved life at high cost that in many cases consumed billions of dollars in exchange for a few days of life expectancy. Many of the former had not been implemented; yet large amounts of funds are currently spent on the latter. The central problem was about a criterion: Where exactly is the limit of those risk-saving bargains, beyond which we waste the public's money?

Throughout the project we discussed this criterion problem on and off, from several angles. At the end of one day in January 1990 Ernest Siddall, closing off the discussion, made the remark that what really matter are how long you live and the level of resource you can command – *viz.*, how much money you have - to enjoy and improve the quality of your life. A sweeping simplification, no doubt, but it could be seen as true in an overall sense for society as a whole. This was the idea that ultimately has led to the LQI. To be sure, each person would make different trade-offs with her available time and available resources, but overall the average wealth and the average life time to enjoy it would be two good measures of value available to people.

There is a striking thermodynamic analogy with an enclosed gas: Each molecule moves around, individually helter-skelter. The number of variables that would be needed to describe their motion is enormous and prohibitive. Similarly, each person has different health, risk-taking behaviour, priorities etc., and all have different risks and view them differently. Yet, overall the state of the gas 'in equilibrium' is adequately described by only three summary variables (temperature, volume and pressure). Similarly, gross national product per person and life expectancy at birth are aggregate descriptors of what one might loosely call the total average quality of life per person. The utility of wealth production is a function $h(g)$ of the GNP per person, g, while the time to enjoy it can be taken as a function $f(e)$ of the expectancy at birth, e, of life in good health. Each enhances the other, so the appropriate measure is a product of the two. Averaged over society, the utility per person can be written as the *life product* $f(e)h(g)$, where $f(.)$ *and* $h(.)$ are monotonically increasing positive functions.

Lind et al. (1991) describe how separation of the variables shows that $f(.)$ *and* $g(.)$ should be powers of e and g respectively, leading to the *life product index* format $L = e^a g^b$, where a and b are positive constants. Further, it was observed that people produce wealth by assigning some of their life to the task of work. People's choice of how much of their life they give to work thus shows how much life-value they attribute to the GDP per person. Lind et al. (1991) made a simple rough calibration by estimating the proportion of life devoted to work, giving a first estimate of the exponent ratio $a:b = 6:1$ and the one-parameter formats $L_{1a} = e^6 g$ and $L_{1b} = eg^{1/6}$ for the LPI. By several examples they illustrated the application of the calibrated LPI to risk assessment using the Societal Capacity to Control Risk [SCCR] derived from the LPI.

3. Human Development: The HDI and the CDI

Simultaneously and independently in 1990 the United Nations Development Program [UNDP] produced a Human Development Index (HDI) which, like the LPI, was a function of *e* and *g*. It was also a function of literacy (UNDP 1990). However, instead of a product format the HDI was the sum of three subindices, all normalized to the unit interval by a dozen arbitrary parameters. This has given the HDI some undesirable properties (Lind 1991, Sagara & Najam 1998, Tofallis 2012). In spite of numerous revisions to the HDI formula, including recent adoption of a product format, some of these attributes have survived to this day (There are now eight arbitrary paramenters). Nevertheless, as a function of *e* and *g* the HDI, too, implies a value of the SCCR. Accidentally this value has changed, of course, with changes in the composition of the HDI but may not be much different from the one derived by the LPI.

In the HDI the three normalized statistics (of *e, g* and the education measure *s*) were arbitrarily given equal weighting. The approach introduced by the LQI, using aggregate revealed preference of time allocation, can be extended to incorporate the education measure as well. Thus an alternative, calibrated index of human development (CDI), using the LPI product structure was proposed (Lind 2010). The CDI equals $e^5 g s^{0.25}$, with *e and g* weighted relatively as in the LQI. Thus the CDI and the LQI give identical results in applications to risk assessment.

4. Four Principles of Rational Risk Management

Nathwani et al. (1997) provided a general basis for risk management by the index method, laying down a set of three firm principles for managing risks to the public, *viz.*:

Accountability*: Decisions for the public in regards to health and safety must be open, quantified, defensible, consistent and apply across the complete range of hazards to life.*
Benefit*: Risks shall be managed to maximize the total expected net benefit to society.*
Measure: *The measure of health and safety benefit is the expectancy of life in good health.*
Further, since risk mediation policy generally confers benefit to some but disbenefit to others, the following principle due to Kaldor and Hicks (Hicks 1939) was included:
Compensation*: A policy is to be judged socially beneficial if the gainers receive enough benefits that they can compensate the losers fully and still have some net gain left over.*

Nathwani et al. (1997) also gave a more rigorous calibration of the LPI, specifically denoted the *Life Quality Index* [LQI] as $L_2 = e^{1-w} g^w$, where w is the work/total time ratio. They tabulated the hours of work per week for workers from a selection of 11 OECD countries over the period 1963-1980, to get the estimate a:b = (1-w)/w = 6.9:1. Thus Nathwani et al. (1997) proposed the LQI as $L_2 = eg^{0.146}$.

The Societal Capacity to Control Risk (SCCR), derived from the LQI was defined and applied as the yardstick for assessing life risks (Nathwani et al. 2009). This concept and terminology was introduced as a better alternative than the "societal value of a statistical life (SVSL)" and the "societal willingness to pay (SWTP)" found in the literature.

5. Further Development

Rackwitz (2002) presents a lucid argument for optimization based on the LQI when there is risk to life, deriving from principles of human rights and equality that are found in all modern, democratic constitutions and the 1948 United Nations' Universal Declaration of Human

Rights. Rackwitz summarizes the derivation of the LQI in the transparent form $L_2 = e^{1-w} g^w$. With a 7:1 calibration he illustrated several applications in structural safety, proposing a social benefit rate for public interventions close to the long term growth rate of the GDP (around 2% for developed countries). The corresponding interest rate should then be slightly smaller. Further, he concluded broadly that optimal structures are almost always also acceptable, but that just acceptable structures are almost always suboptimal.

Ditlevsen (2004) made refinements to the original calibration. Most significant was a change in available time from 24 to 16 hours a day, considering the need for sleep and other necessities of life. The resulting calibration gave $L_{3a} = eg^{0.3}$. However, if we take account of the fact that people in general can freely choose to sleep and preen, etc. for less or more than 8 hours, it must be accepted that the time allocated to do so must be given the same value in the margin as the time to work and leisure. Hence, we maintain that the correct available time is 24 hours per day. With this change, Ditlevsen's calibration would give $L_{3b} = eg^{0.2}$.

6. Calibration by Welfare Economics

Nathwani and Pandey (2007) provided an entirely new approach to calibration, deriving the exponent parameter from the economics of human welfare (Hicks 1939) as $w\beta^{-1}\ (1\text{-}w)^{-1}$, where β is the Cobb-Douglas labour exponent (Nathwani and Pandey 2007). With this formulation, using economic data for each of 27 developed OECD countries over the period 1976-2004, Nathwani et al (2009) firmly established the LQI in the form

$$L = eg^{0.2}\,. \tag{1}$$

Lind et al. (1993, pp. 151-2) showed that the LQI parameter in practice need not be very precise. They considered a wide selection of 26 implemented risk reducing regulations in the USA analysed by Morrall (1986). Their cost to prevent [i.e., postpone] a death ranged from $100,000 to $132 million; the expected number of lives saved ranged from 0.06 to 1850 per year, and the annual cost ranged from 840,000 to $8.9 billion. 14 of the 26 regulations were found to be cost-effective with a:b = 6:1; the rest were not. The same result would be obtained with any a:b-ratio between 4 and 9.8, in particular 5:1 = 1:0.2 of the latest calibration, now widely used. So, the literature based on the various forms $L_1, L_2, L_3, \ldots$ would remain valid. Eq.1 should be generally applicable for developed countries for a long time in the future.

7. The J-Value

Thomas and Stupples (2006) further developed the LQI approach, introducing the J-value of a risk-mitigation pair, a dimensionless ratio of cost per QALY to the SCCR. A series of some twenty publications by P. Thomas and his collaborators developed multiple applications to a broad range of life- health- and environmental mitigation, e.g., (Thomas and Jones 2010).

8. Applications

The applications of the LQI are of two kinds. Conventionally, such social indicators are used to rank countries or other social groupings. Alternatively, since the indicator implies a relative valuation of its arguments, it implies a value of fair exchange, in our case between longevity and production of wealth.

In applications it is generally convenient to normalize e and g with respect to a country, date or currency, etc. We propose that the dimensionless form

$$L = EG^{0.2} \quad (2)$$

be considered the *standard* or *canonical form*, in which $E = e/e^*$ and $G = g/g^*$ respectively denote values of e and g normalized with respect to specified reference values e^* and g^* respectively. Other formats may be better for certain applications, such as E^5G, e^5g, or the logarithmic LLQI:

$$LLQI = \log L = \log e + 0.2 \log g - \log e^* - 0.2 \log g^*. \quad (3)$$

As of 2012 there are over 200 publications that apply the LQI or have developed it further. With a few exceptions the applications address problems of acceptable risk in various areas of technology or public health.

9. Future Developments

The LQI has been around for decades. Nevertheless, it has scarcely found application in risk management beyond engineering. It is uniquely qualified to provide a rational, dispassionate benchmark for acceptable public-risk management by respecting, in particular, the Principle of Accountability (Section 4). We have barely begun the task of tidying up the available life-saving options, such as the 500+ interventions documented by Tengs et al. (1995).

Mankind has been around for a good million years, during which we managed risks on an ad-hoc basis -- much like reptiles do, many of them successfully as species and for much longer. Yet, our criterion of success is different: Not just to survive as a species; as individuals we each want to live longer in good health and comfort, at the very least. Societal risk management should ultimately be rational, reasonable; this is a strategic goal.

To promote dispassionate rational risk management is a collective duty of the professions dealing with life risk: Physicians, nurses, pharmacists, public health officials, engineers etc. The several professional organisations, and especially the learned societies (national academies) is where such leadership should be found and promoted.

The sensible reduction of risk is just a part of human welfare, which the LQI purports to measure. Using such an index to rank countries may well be instructive. More important to promote welfare is going further: Pandey and Nathwani (1997) used the LQI to quantify human welfare inequality in analogy with income inequality. It would be interesting to study the inequality of [healthy] life expectancy versus income inequality, nationally and internationally. The LQI is also suitable to place specific ethnic or national groups (such as immigrants or aboriginal groups within a nation) in an international ranking. With the aging of developed nations – brought about in part by the success of life risk management -- health care is increasingly commanding a significant part of our public and private budgets. The LQI can highlight the public policies particularly valuable for our overall well-being and help illuminate the limit beyond which health care systems fail to give value for money.

10. Conclusions

Over the past twenty years the Life Quality Index and its derivatives have developed and matured into a stable format. It has found a variety of applications in risk management and

hundreds of scientific publications. However, its full potential to serve societal needs is very far from realized; this will require time and dedicated deliberate application of a political kind.

References

Lind NC, Nathwani JS, Siddall E, (1991). *Managing Risks in the Public Interest*, Institute for Risk Research, University of Waterloo, Waterloo, Ontario IRR, June 1991, 2nd ed., 1993.

Nathwani JS, Lind NC and Pandey MD, (1997). *Affordable Safety by Choice: The Life Quality Method*. Institute for Risk Research, University of Waterloo, Waterloo, Ontario.

Nathwani JS, Pandey MD and Lind NC, (2009). *Engineering Decisions for Life Quality: How Safe is Safe Enough?* Springer Verlag Series in Reliability Engineering, London, 189 pp.

Sagara AD & Najam A, (1998). The human development index: a critical review. *Ecological Economics, 25,* 249-264.

Rackwitz R *(*2002*).*Optimization and Risk Acceptability Based on the Life Quality Index. *Structural Safety.* 24, 297-332.

Tengs TO, Adams ME, Pliskin JS et al. (1995). Five hundred life-saving interventions and their cost-effectiveness. *Int J Risk Anal.* 15:369-390.

Hicks JR (1939). The foundation of welfare economics. *The Econ. Journal* 49(196):696-712.

Ditlevsen O (2004). Life Quality Index Revisited. *Structural Safety*. 26, 4, 443-451.

Morrall JF (1986). A review of the record. *Regulation*, November/December 25-34.

Lind NC (1991). "Some Thoughts on the Human Development Index", *Social Indicators Research*, 25, 1991, pp.107-119.

Lind N (2010). A Calibrated Index of Human Development, *Social Indicators Research*, 98, 2, 2010, 301-319 published online Nov 3, 2009, DOI 10.1007/s11205-009-9543-5.

Pandey MD and Nathwani JS (1997). Measurement of Socio-Economic Inequality using the Life-Quality Index. *Social Indicators Research*, 39 (2), 187-202.

Thomas P and Stupples D (2006). J-value: a universal scale for health and safety spending, *Special Feature on Systems and Risk, Measurement + Control*, 39/9, 273-276, November. [Awarded the Best Paper Prize, 2006, by the Worshipful Company of Scientific Instrument Markers].

Thomas PJ and Jones RD (2010). Extending the J-value framework for safety analysis to include the environmental costs of a large accident, *Process Safety and Environmental Protection*, 88, 5, September, 297-317.

Tofallis C (2012). An automatic-democratic approach to weight setting for the new human development index. *Journal of Population Economics*, Online first 13 July.