Principles for Managing Risk:

A Search for Improving the Quality of Decisions

J.S. Nathwani[1], N.C. Lind, M.D. Pandey

Institute for Risk Research,
University of Waterloo, Waterloo,
Ontario, Canada.

[1] Professor (Adj), Department of Management Sciences,
University of Waterloo, Waterloo, ON, Canada. N2L 3G1
Dr. Nathwani is the Senior Advisor, Strategic Development,
Ontario Hydro Services Co.,
700 University Ave., Toronto, ON. M5G 1X6

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Abstract:

The prospect of disease and death command widespread attention resulting in much effort expended to reduce risk and promote safety. The aim is to develop practical and workable policies

ACKNOWLEDGEMENTS

The authors wish to acknowledge the seminal contributions of Prof. Ernest Siddall, Prof. Jan Narveson, and Prof. F. Kenneth Hare. Members of the Joint Committee on Health and Safety of the Royal Society of Canada and the Canadian Academy of Engineering (1990-1996) also contributed to the early development of ideas in this paper.

The results and the conclusions of this study do not represent the views of any organization; we remain solely responsible for all opinions and errors in this book.

0.1 INTRODUCTION

We consider the problems of managing risks responsibly on behalf of others. “What should we do when the safe and the dangerous are inextricably intertwined?[3]” It is unrealistic to seek maximum benefit without considering the risks involved, but it is just as naïve to pursue risk minimization without regards for the cost. The demand for “zero risk” is an illusion. Risk management is a balancing act.

Our aim is to give guidance to decision-makers who have the responsibility for managing safety. We document a reasoned approach and provide methods that give important insights about problems that bedevil management of safety in our society. We lay no claim to any magical "correct" solutions. However, the approach we have developed is new, and we believe, an important first step away from today's arbitrary, chaotic, and uncoordinated risk management practices.

Good risk management not only requires a strategy for selecting risks (separating the important and consequential from the trivial risks), but also a common framework with the necessary tools for guiding the decision-maker. We have developed a tool, the Life Quality Index (LQI), for managing risk in the public interest. The Life Quality Index is a compound social indicator that can help us choose appropriate strategies for managing risk. This index is somewhat similar to a crude compass, like the Viking-age "lode stone" (just a piece of magnetite floating on a block of wood in a bucket): it gives orientation roughly but reliably. It may not be perfect, but it is better than nothing when you sail in fog. We believe that long life in good health, with few restrictions on individual choice, is a fundamental value. It is ethical and rational to pursue this objective for all in a society. The Life Quality Index gives an account of how well that objective is met. Risk mitigation that does not increase the chance of longer life in good health with a greater range of choices, detracts from that objective and cannot be justified.

The difficulty in making decisions related to risk arises from several factors. When untoward events occur, the misfortune of a few becomes amplified and a concern to many. Cultural and political assumptions govern the social amplification of risk. There is a large body of work[4] that explains why we accept some risks and not others. The aversion to certain risks, characterized as the "catastrophic," "dreaded," or "involuntary" risk is now well known. Beneath the intense controversies surrounding the acceptability of risks are fundamental issues related to trust in organizations, the role of institutions and social values, political aspects that give rise to the unequal sharing of benefits and risks, and confidence in the broader societal capabilities to provide credible assurances over the long term.

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[3] Aaron Wildavsky (1988) offers an important clarification of a fundamental problem in risk management. He observes that almost all treatments of the subject, particularly in the popular or political spheres, consider risk to be a bad thing that should be avoided, reduced, or eliminated rather than what it is: an inevitable concomitant of activities from which benefit is derived. "The good and the bad, safety and harm, are entwined in the same acts and objects. The jogger's dilemma brings us full circle to the essence of the relationship between courting danger and securing safety, for the two are different sides of the same coin. Too much or too strenuous exercise too soon is unsafe. Too little, too infrequently is also bad. The complication is that during the limited time devoted to the most strenuous exercise, the risk of heart attack rises. The good news is that for the rest of the day, as well as the days between regular exercise, the body is safer. You cannot have one - a safer organism - without the other - expanding its resilience by allowing it to face risks. Safety is [indeed] the other side of risk."

[4] Selected examples are: Sandman (1989), Wildavsky (1988,1980), Fischoff (1995, 1981,1977), Kasperson (1988), Lowrance (1976,1985), Douglas (1982), Rescher (1983), Simon (1979), Slovic (1993, 1992, 1987), Starr (1969, 1984), Schwing (1980), Henderson (1987), Fiorino (1990, 1989), Zeckhauser (1976), Freudenberg, (1988), Covello (1986, 1987), Johnson and Covello (1987), Dake (1992).

What we lack is a systematic approach that allows a decision-maker to strike a proper balance between risk and benefit. Perceptions of risk often dominate the desire for total avoidance of risk. The flight from risk may then be the greatest risk of all because it leads to paralysis in the decision-making process, denying us the opportunity to be innovative through risk-taking. Perceptions of risk at best only capture transitory shifts in preferences and are critically dependent on graphic imagery rather than balanced assessments. Opinions, when channeled uncritically, tend to distort the reality resulting in expenditures that do not contribute to real safety. One direct consequence of erratic and uncertain risk management is that the resulting safety policies and interventions are not effective.

Activities associated with creation of wealth entail risks. The risks can always be reduced but at some cost that reduces the efficiency of production of that wealth. For decision-makers - whether regulators, public health officials or risk managers - striking a balance between the benefits and risks is, at root, a professional obligation. We have proposed[5] that the maximization of healthful life for all is the proper basis for managing risk in the public interest. This is achieved when the net contribution to the total saving of life from the wealth produced is balanced against the loss of life.

We first address some of the broader philosophical issues that have played a prominent role in risk debates. In Section 1 we describe the background to the current issues in risk management and discuss the various facets of the problem and what makes the problem so difficult to approach. Next in Section 2 we propose some key principles and a framework of reasoning for managing risk. In Section 3 we provide the supporting rationale for the use of social indicators in the management of health and safety risks. We believe the public interest is best served by using a rational process for evaluating the effectiveness of expenditures devoted to safety. If enhancing the safety of the people is a desirable goal, it is necessary to ask a simple question: what are we prepared to pay for life extension? Risk reduction schemes for any technology come at a cost and, thus, we must be mindful of the number of life years gained against the cost of achieving that goal.

In Section 4 we describe the development of a social indicator, the life quality index (LQI), that gives a criterion for answering a simple question: What is the level of expenditure beyond which it is no longer justifiable to spend resources in the name of safety? We then illustrate application of the LQI criterion by developing appropriate models for use in a variety of contexts through case studies in Sections 5 and 6. The case studies rely on data available in the literature. With all the inherent limitations of such data, our modest objective is to show the wide-ranging applicability of the life quality index as a tool for assessing the available information in support of a decision; we are less concerned about proving whether a past decision was correct or not.

1.0 Managing Health and Safety Rationally

When faced with risk, we are attempting to answer, intuitively, three related questions: Is it safe? Is it a big and important risk? and if so, at what cost and level of effort would a life-saving proposition be worthwhile to reduce the risk? It is necessary to understand risk if we are to make intelligent decisions about risk.

Risk, commonly understood as the chance of injury or loss, can be defined as a measure of the probability and severity of an adverse effect to health and life, property, the environment or other things we value. Risk pervades everything we do. Risk touches all aspects of our health, wealth and welfare. Whether to fly, to sail, or to ride as passengers in a car speeding down a mountain road late on a rainy evening; whether to smoke, to drink alcohol or coffee or tap water, or whether to accept a medical treatment with an uncertain

[5] See Lind et al. (1991), Joint Committee of the Royal Society of Canada and the Canadian Academy of Engineering, Report JCHS-1 (1993), Nathwani (1995).

outcome: all such situations require that we decide. Sometimes consciously, but all too often unconsciously, we decide for ourselves and others on a course of action that we judge as acceptably safe. As a matter of individual choice, some of us may be inclined towards behaviour that would be considered risk-prone (for example, hang gliding, bungee jumping or deep-sea fishing). Alternatively, we may be risk-averse (buying trip cancellation insurance or refusing to fly in a small aircraft). We rarely have all the information at hand for all the decisions, but decide we must. Yet, in spite of all uncertainties and doubts, we do choose and make the necessary trade-offs in the hope that the decision will yield the most good and least bad.

Intuitive risk management may be appropriate when the risks and the costs are small and when we personally bear the risk. But the risks and the expected benefits must be analyzed carefully when they are major issues that affect lives and health of others, or when decisions are made in the interest of the public and at the public's expense. The principles are simple statements of values that are widely shared. The tools required for evaluation of the options, as a matter of necessity, rely on quantitative methods.

A commitment to use quantitative methods is a hallmark of professional quality in risk management. We seek to be quantitative not just for academic reasons but to improve on our often "meagre and unsatisfactory" understanding of the processes we manage. We seek to be quantitative to aid the process of judgement, to foster consistency among risk management decisions and to support accountability.

All activities and all decisions involve an element of risk. The most relevant question is how much of our limited resources can we devote to maximizing safety and minimizing harm. Important risks that involve the potential for harm to life and health of the public and the environment should be managed rationally and the processes supported by thorough and defendable methods. Whether something is adequately safe, whether the benefits outweigh the risks must be ascertained in the context of the risks and benefits of the feasible alternatives. Risk comparisons are essential to allow us to judge the value of risk reduction initiatives. Only when we put the risks to life from one source in perspective with other similar risks can we begin to address the problems associated with efficient allocation of resources across many diverse activities.

Currently, fear of cancer and the risks associated with low-level exposures to carcinogenic substances drives much of the regulatory efforts aimed at minimizing health risks. Diet and smoking, however, cause an estimated two out of three cancer deaths. They are major causes of cardiovascular disease and deaths. Industrial activities, highly regulated, have been estimated to cause only a few per cent of cancer deaths.[6] The regulatory attention devoted to industrial risks and risk of cancer is large, partly because public risk perception is influenced by the media attention given to dramatic events and partly because of the “dread” factor that accompanies such stories. There is no transparent process for rendering an account of the hidden costs and lost opportunities resulting from a 'flight from risk.'

We believe the central issue in managing risk to life and health is to develop an understanding of the effectiveness of risk mitigation efforts. We proceed to show an objective way to assess the efficiency of life-saving interventions using a social indicator, the life quality index, and to illustrate the procedure in a variety of practical settings.

2.0 Principles for Managing Risks to the Public

Principles and a general framework of reasoning for managing risk in the public interest have developed gradually, from origins in the Age of Enlightenment, associated with 18th century empiricist thinkers (Bentham, Bayes, Lapalace, Locke and Adam Smith), and quantitative decision theory (von Neumann,

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[6] see Doll and Peto (1981).

Keynes, and Raiffa). The broadest goal in managing risk is to serve the public interest. In this Section we expand on the fundamental principles enunciated by the Joint Committee on Health and Safety of the Royal Society of Canada and the Canadian Academy of Engineering (JCHS, 1993). Nathwani (1995), Lind (1995) and Robertson (1995) have provided alternative statements of much the same basis for rational and defensible decision-making. In managing risk to the public, the need to serve the public interest comes first. We state the fundamentals in the form of four principles of accountability, maximum net benefit, compensation and life measure as follows:

(i) ***The Accountability Principle:*** Decisions for the public in regard to health and safety must be open, quantified, defensible, consistent and apply across the complete range of hazards to life.

A unified rationale is essential if we are to have a working basis for practical professional action in society's interest when risks to life, health or property are important. There is a need for a single, clear process for managing risks affecting the public. Once known and accepted, this rationale removes day-to-day decisions about risk from the political arena. The requirement for a proper procedure serves as the foundation of a professional ethic for public risk management analogous to the Hippocratic oath for physicians. The requirement may be viewed as a clear statement of what the public has a right to expect and support for those who have to make difficult decisions.

(ii) ***The Principle of Maximum Net Benefit*** : Risks shall be managed to maximize the total expected net benefit to society.

The principle that the net benefit is to be maximized across society as a whole is argued to be a rational guide to assessing the effectiveness of efforts directed at reducing risk with the goal of improving health and safety. Knowledge is never complete but decisions, on behalf of the public, must be made, nevertheless. Risk management must explicitly and consistently confront uncertainty. A guide under such circumstances is to pursue a course of action that maximizes life expectancy, with due consideration given to the healthfulness and the quality of life.

A simple and meaningful test of the effectiveness of a risk management allocation is: how much life saving does it buy, and could the same resource, if directed elsewhere, result in better gain for society as a whole? All activities directed at managing risk in the public interest ought to be subjected to this test.

An activity constitutes a net benefit to the public if it results in a net increase in life expectancy. A quality adjustment is to be included if data are available and such refinement suits the purpose at hand. The activity constitutes a net benefit to a given set of individuals if their share in the benefit is worth their share in the cost. To provide a quantitative measure for assessing effectiveness of public decision-making, we propose the use of an appropriate compound social indicator such as the life quality index.

The principle of maximum net benefit has certain limitations. It treats all persons in a group equally and is ill-suited for situations where inequality of the burden of risk or benefits is paramount. In general, the public management of risk balances risks to people at a low level, statistically in the prder of 1 in a thousan to 1 in a million. Identifiable individuals are not known, a priori. When this assumption of a general imposition of risk breaks down, affected individuals must be treated separately. On no account may we knowingly "sacrifice" identifiable individuals to the "greater good of the group." For such situations, constraints on imposition of risk must be clear and demonstrable. For the more general case, we recognize there is always an unequal distribution of benefits and risks. The benefits and costs of a risk-mitigating intervention are often unevenly distributed over many "publics" and over time. Compensation is necessary and considered adequate if it satisfies,

(iii) ***The Kaldor-Hicks Compensation Principle:*** 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.

If the losers are in fact compensated fully, they are by definition transformed into non-losers and the policy is Pareto optimal, i.e. optimal for all or at least neutral. The compensating measures may include protective barriers, compensation in kind or in money (for example, expropriation of land for a highway or a public infrastructure), or removal - the choice made by the affected individual being given primary weight. The measures needed to protect individuals from large detriments can be regarded as part of the cost of the project or activity.

Progress in achieving a better balance between risk reduction expenditures and the health benefits to be derived from such expenditures ought not to be frustrated by individuals demanding a "risk-free" environment. Some disbenefits may be unjust or unfair, but so small that they can reasonably be neglected. The phrase "de minimis non curat lex" - the law does not concern itself with trifles - in Roman Law recognises that some issues may be unjust but below legal concern. "De minimis" principles or limits have been prescribed in several areas of risk management formalizing limits of risk below regulatory concern.

(iv) ***The Life Measure Principle***: The measure of health and safety benefit is the expectancy of life in good health.

The goal of risk reduction efforts should be to maximize the net benefit to society in terms of the length of life in good health for all members at all ages. The effect of an activity on life expectancy is proposed as the aggregate measure of that activity's net safety impact. Life expectancy is a universal measure valid for comparisons both within and among countries. Whenever appropriate, the concept can be adjusted to include health expectancy and other factors that affect the quality of life. Such concepts have been formulated in the past and are generally referred to as the quality-adjusted life expectancy (QALE) or disability-adjusted life expectancy (DALE).

3.0 Social Indicators

Social indicators are statistics that quantify some aspect of the quality of life in a society or group of individuals. Social indicators are "social statistics which represent significant information about the quality of life, and can be accumulated into a time series." The Gross Domestic Product (GDP) per person and the life expectancy (LE) are well known examples of social indicators. They have been in use for half a century to express the wealth and health of a nation in numbers, and they are reliably measured. The life quality index is the compound social indicator we propose for:

(a) assessing the rationale and effectiveness of public decisions affecting the management of risk to life, health and safety; and

(b) reflecting how well a nation, in its overall management of risk, meets the broad goals stated.

The concept of what constitutes a good quality of life has been debated widely since it concerns human values and subjective responses. Although we do not lay claim to an ultimate measure of the good life for all, the LQI embodies two key aspects of our well-being and desires. In addition, it is a practical and useful tool for making decisions. There is an instructive analogy in the simple phenomenon of room temperature. If the thermometer reads 20 degrees Celsius, some will find it cold, others warm. Some will argue that temperature varies with location and orientation within the room, and that the thermometer reading is meaningless, humidity is important and so on. But in spite of its many limitations, the thermometer reading is nevertheless useful because it is objective, reliable, relevant and has validity. The thermometer says something about the state of the room air; what it says can be trusted, and can be used as a rough predictor of comfort for most people on the average, and the resolution of measurement is appropriate for the choice at hand (deciding whether to turn up the heat, to open the window, turn on the air conditioner, or do nothing). All indicators are imperfect but may nevertheless be useful.

Our approach relies on two of the major indicators identified in the UN and OECD program on the development of social indicators: Life expectancy as a measure of safety and real GDP per person as a measure of the quality of life are proposed as the appropriate indicators. These necessary quantitative social indicators are available for supporting decision-making in matters of public safety, despite the fact that uncertainties and subjectivity of values will always be present.

To be able to judge whether a health or safety provision is truly in the public interest requires an assessment of all the risks and the benefits. The safety benefit is the gain in life expectancy, or life extension expected upon implementation. The associated costs must also be evaluated and drawn into account as impacts on the real gross domestic product per person (RGDP). Ideally, with time and through public discourse, awareness of the costs of extending the expectancy and quality of life, or any other social indicator that is used to express "value" will increase. Informed debate and societal consensus would then form the basis for improvements to risk management practices and instruction to the professionals who recommend actions to decision-makers on health and safety.

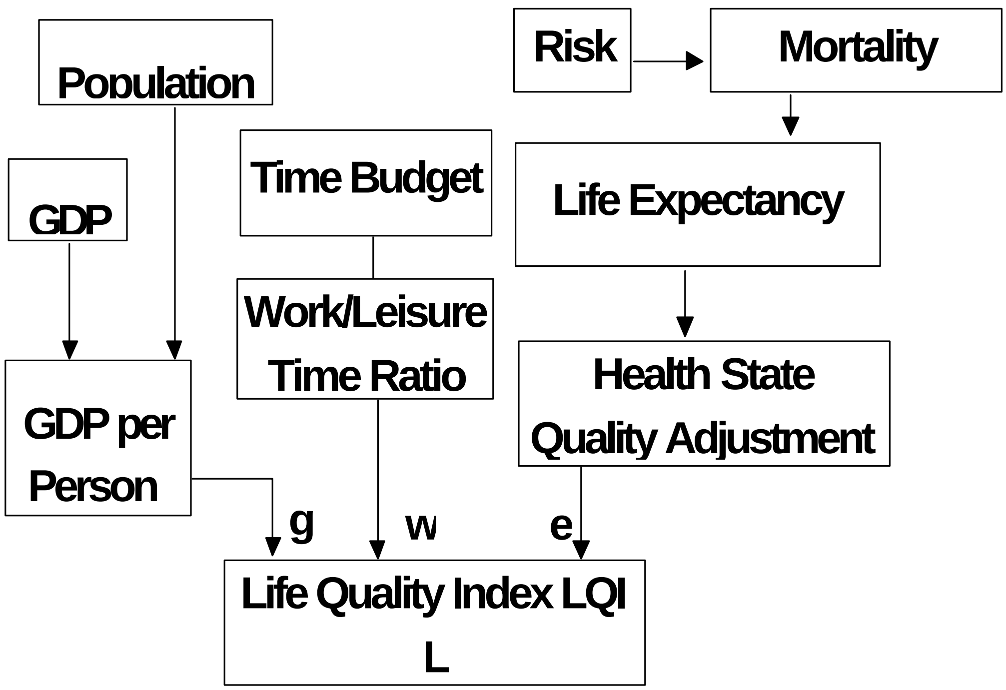
4. 0 Life Quality Index (LQI)

The life quality index is derived to reflect the expected length of "good' life, in particular the enhancement of the quality of life by good health and wealth.

The use of quality-adjusted life years (QALY) as a measure of substantial value to society has been advocated by many researchers of public policy, health and safety[7]. The life quality index may be thought of as refinement of monetary measures commonly used in cost-benefit analysis.

The chart shows the three components of the life quality index that are related to important human concerns: the creation of wealth, the duration of life and the time available to enjoy life in good health. The amount of life available to enjoy wealth acts as a multiplying factor upon the value of that wealth. Conversely, the amount of money one has to enjoy that lifetime available also acts as a multiplier.

[7] see Zeckhauser and Shepard (1976), Vaupel (1976, 1981), Graham and Vaupel (1981), Colvez et al. (1987), Lind et al. (1991), JCHS (1993).



Components of the Life Quality Index

The expression for the Life-Quality Index is:

$L = g^w e^{(1-w)}$ [1]

The wealth produced, *g*, is raised to the power of the time spent producing it *w*, while life expectancy, *e*, is raised to the remaining time (not spent in producing wealth).

The life quality index is derived as a weighted product of GDP per person, *g*, and life expectancy, *e*, with the weighting exponents *w* and *(1-w)* reflecting the fraction of time people allocate to economic and non-economic activity. The parameter w is based on time budget studies available for many countries. We have also employed a further refinement of health-related quality adjustment for life, while considering the factor g^w as a wealth-related quality adjustment.

The net benefit of a project or other changes in risks and costs is measured, according to the LQI, by the resultant increases in wealth and life expectancy, weighted by w and 1-w respectively. Risks influence the LQI via the age- and sex-specific mortality, calculated by changes in an actuarial life table. If a risk is known only in aggregate term for a population as a whole, its impact on the mortality may be assumed uniformly proportional and to give impacts on the life expectancy.

5.0 Judging Risk with the Life Quality Index

When there is a choice to be made we need to judge the risks. There are two kinds of situations. The choice could be to take the risk and proceed with an activity or a project that will yield expected benefits but involves risk. Conversely, the choice may be to reduce a risk by taking an opportunity to improve health or safety, but at a cost. We treat the two cases in the same way.

We note that the options may also involve significant environmental and social impacts. Where it is possible to quantify such effects in monetary terms, the treatment of environmental and social impacts can be handled explicitly in the analysis. When these impacts are difficult to draw into account. The environmental and social impacts can be considered separately.

We present a framework for judging risk at the national level based on the Life Quality Index (LQI). The objective is to promote better allocation of scarce resources, both by reducing wasteful efforts on inefficient risk-reduction and by supporting the implementation of efficient ones.

With the value of *w* for OECD countries taken as 1/8 (see Nathwani et al, 1997, section 4.4) Figure 5.1 shows a contour plot of the LQI function *L(g,e)*. To make the plot dimensionless, *g* and *e* were each divided by a reference value, g_o and e_0 respectively. The values of g_0 and e_0 can be selected to suit the context. Figure 5.2 shows for example the LQI for a few countries.

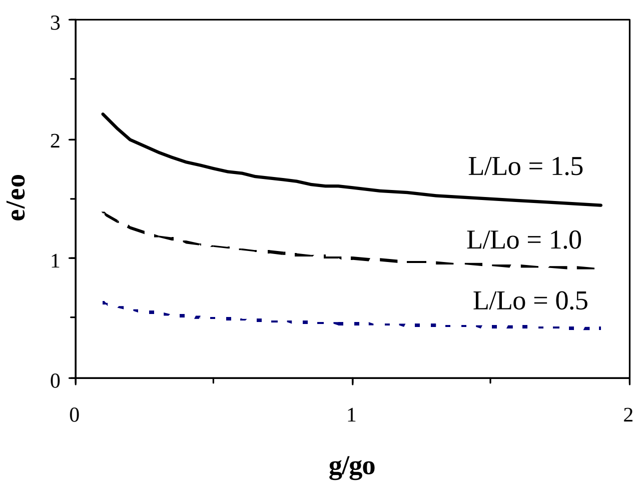


Figure 5.1: Contours of the Life Quality Index

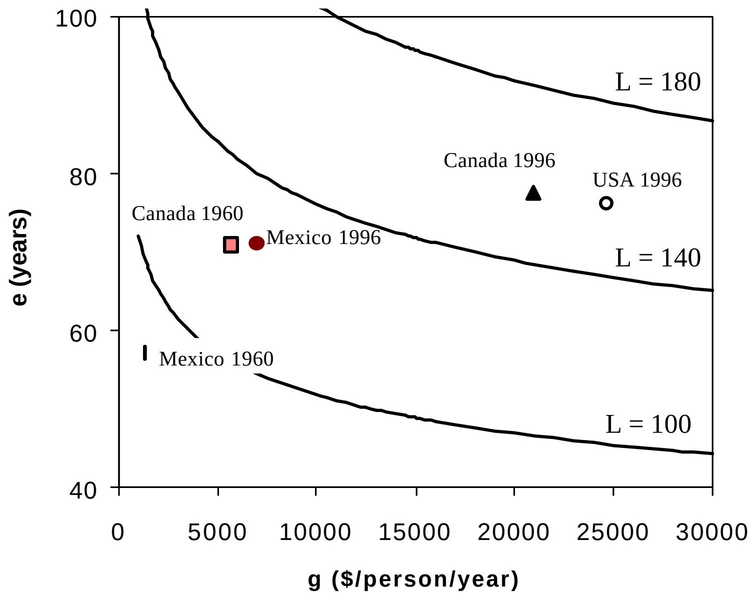


Figure 5.2 LQI for a few selected countries

It is often convenient to use a logarithmic plot as in Figure 5.3. Curves of constant LQI are then straight lines with slope -1/K=-w/(1-w)= -1/7.

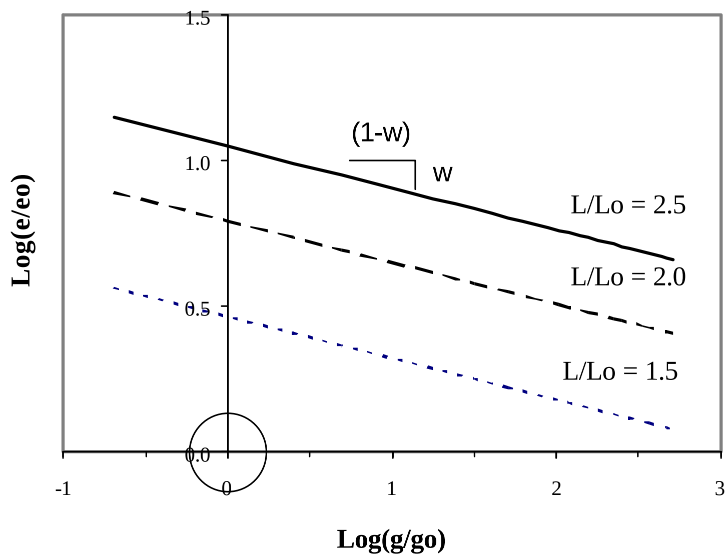


Figure 5.3 Plot of Log (g/g_0) vs. Log (e/e_0)

The Criterion of Acceptability.

Any project, program or regulation that materially affects the public by modifying risk through expenditure will have an impact on the relevant indicators. Thus, we derive acceptability for the life quality index by the requirement that its increment, expressed as function of the variables affected, is positive.

A small change in the LQI due to an activity, a project, or a change in policy or regulation can be assessed as

$$dL/L = w\,(dg/g) + (1-w)(de/e) \qquad [2]$$

In Equation [2], dg may represent the monetary cost of implementing a regulation (dg negative) or the monetary benefits that arise from a project or an undertaking (dg positive), whereas de is the change in life expectancy due to a change in the level of risk to the population, namely an increase in risk or a decrease in risk directly associated with the project, regulation or activity. The net benefit criterion requires that dL be positive or,

$$dg/g + K\,de/e > 0 \qquad [3]$$

Note that the net benefit criterion is a function of dg and de, which represent changes in expected cost and risk to life. The best option among several options is the one from which any change will reduce the LQI. This is in contrast to the ALARP criterion (making risk "As Low As Reasonably Practicable") which calls for a comparison of risk to some standard of practicality. It is also in contrast to absolute probabilistic risk criteria such as "the probability of death shall not exceed 1/1,000,000 per year for the person most at risk."

For application of the net benefit criterion, we have developed several equivalent models for cost-benefit analysis, all derived from expression [3]. The models include:

(i) comparison in terms of relative gains;
(ii) conversion of benefits to life years gained;
(iii) the economic equivalent of gains or losses of life expectancy;
(iv) a life quality index diagram;
(v) treatment of time series of benefits, costs and life expectancy.

5.2 Models for Cost-Benefit Analysis

Five different working models for cost-benefit analysis can be derived from equation [2]. They are equivalent, different only in form.

Model 1. Comparison of Relative Gains. The common conceptual model is shown in Figure 5.4**.** The term *dg/g* can be viewed as the relative economic benefit gained (or lost, if negative). Similarly, the term *Kde/e* represents the relative benefit to life expectancy. With K=7, Expression [2] says that there is a gain (resp. loss) in LQI if the economic benefit (loss), as a percentage of the GDP per person, is at least seven times greater than the percent loss (gain) in life expectancy. Thus, a life-saving intervention is justified according to the LQI criterion if the cost, in proportion to the GDP per person, does not exceed seven times the life-saving benefit, in proportion to the life expectancy:

$$\frac{1}{K}\frac{dg}{g} + de \geq 0$$

Model 2. Conversion to Life Years Gained. Expression [2] can be rearranged as

$$[3] \qquad \frac{e}{K}\frac{dg}{g} + de \quad \geq 0$$

where the first term is the economic gain expressed as an *equivalent gain of life expectancy*, and *de* is the gain in life expectancy.

Model 3. The Economic Equivalent of Life Expectancy. To perform cost-benefit analysis in fiscal units ($ values), Expression [2] is rearranged as

$$[4] \qquad dg + Kg\ \frac{de}{e}\ \geq 0$$

where *dg* is the project cost, and *K g de/e* is the life expectancy benefit expressed as a monetary equivalent.

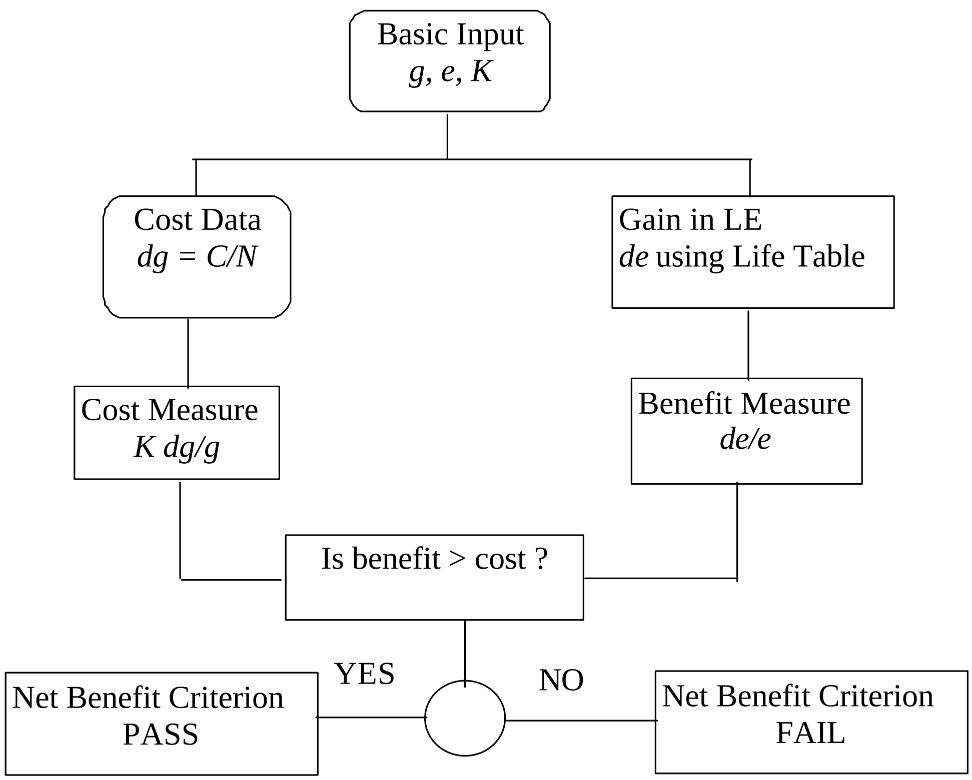


Figure 5.4 Conceptual Model for Cost Benefit Analysis. The benefits in this figure are in the form of Model 1.

Model 4. The Life Quality Index Diagram. Figure 5.5 shows enlarged the neighbourhood of the origin in Figure 5.3. The origin in Figure 5.5 represents *status quo*, the *null option*, or the *reference case*. Above the line dL = 0, lies the region of positive net benefit.

Equation [2] indicates the minimum acceptable improvement in life expectancy corresponding to an expenditure of public resources if *dg* is negative. Alternatively, [2] gives the gain in wealth necessary to compensate for an increased risk (*de* negative). Every undertaking can be represented by a radius vector *(dg/g, de/e)* in this diagram. In particular the diagram illustrates a case U that is expected to increase both *g* and *e*, evidently increasing the LQI and therefore indicated as beneficial. Any undertaking that plots in the first quadrant (region 1) in the LQI diagram of Figure 5.5 is indicated as beneficial by the LQI criterion. Conversely, any change from the origin into the third quadrant is detrimental according to the LQI criterion.

The interest is mainly with undertakings that involve an exchange of wealth and life expectancy, plotting in the second or fourth quadrants. Proposed safety regulations and health interventions plot in the second quadrant. If they fall in slice 2A (Figure 5.5), they are indicated as a net gain in LQI. If they fall in slice 2B, the net benefit, according to the LQI criterion, is negative. Similarly, when a proposed deregulation or industrial project plots in the fourth quadrant, the LQI would indicate that it serves the public interest only if it falls in sliver 4A. Undertakings that are expected to increase the LQI, falling above the line dL = 0 could, of course, be rejected on other grounds while undertakings that fall below the line could nevertheless be judged acceptable or tolerable on other grounds.

Model 5. Marginal Benefit/Cost Ratio Introducing the *characteristic* C, a function of country and year, given by

[4] $C = C(g,e,K) = e/Kg$,

and writing $dg = -dC$ allows equation [2] to be rewritten as

[5] $de/dC > C$

This equation states that the gain in life expectancy *de* per unit cost dC (unit years/$) shall exceed the characteristic value C.

Characteristic C (Equation [6]) for Several Countries

Canada	0.00053	Haiti	0.0077
USA	0.00044	Somalia	0.0056
Japan	0.00055	Sudan	0.0095
Netherlands	0.00064	Sierra Leone	0.0065
Norway	0.00054	Niger	0.0084

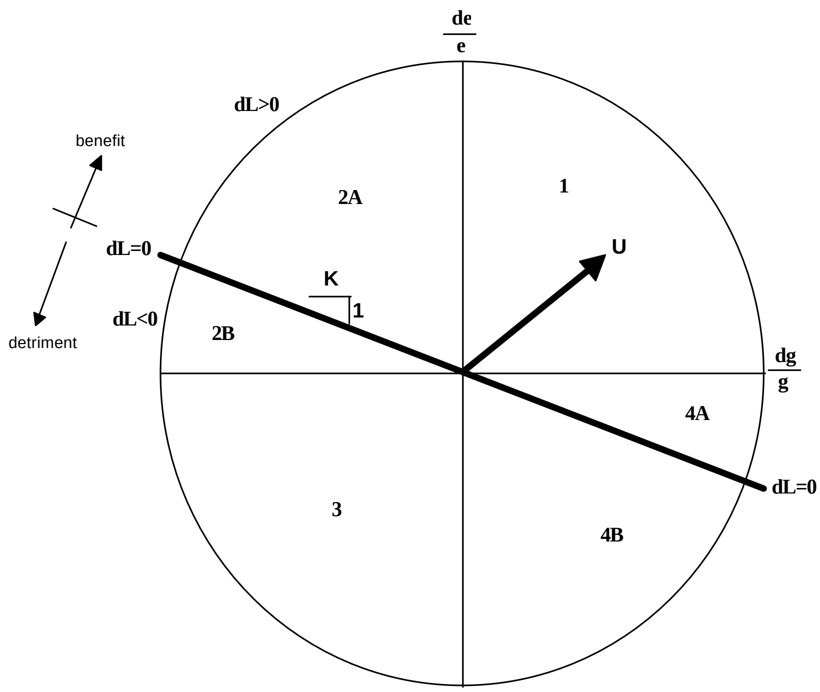


Figure 5.5 The LQI Diagram

6.0 Case Studies and Worked Examples

We illustrate use of life quality index through worked examples. We show how the life quality index can serve as a screening tool for evaluation of risk control strategies to test the effectiveness of regulations designed to reduce risks to life, health and the environment. The availability of data and the quality of data are key requirements; however, good preliminary estimates would be sufficient to establish whether the criterion of net benefit to society would be met by the regulatory initiative at the screening stage.

The important inputs required are:

(i) an estimate of the population at risk if no actions were taken;

(ii) the total costs (including compliance costs) associated with the regulatory initiative intended to protect the public;

(iii) the benefits of the regulation, namely, the estimated level of risk reduction, the potential lives saved or the estimates of gain in life expectancy or improvements in the health status of the population.

6.1 Health, Safety and Environmental Risks: Analysis of the effectiveness of regulations with the LQI Criterion

The emphasis on reducing the risks to health, safety and the environment has resulted in the creation of a vast number of international bodies, panels, working groups, task forces and several national regulatory agencies that control and manage all manner of activities including development of safety standards. Several of these organizations are charged with the sole responsibility for ensuring compliance but often agencies also pursue other approaches that include market-based instruments such as "trading in pollution permits" to achieve optimal resource allocations. By and large, the dominant approach to managing risk is through legislation, otherwise known as the "command and control" strategy. The data and information required to judge the effectiveness of such a vast global effort are sparse. This is so because the mandates of these agencies are different and they focus on different risks. Nevertheless, some recent information is available to allow us to test the applicability of the Life Quality Index (LQI) in judging the effectiveness of these efforts.

Morrall (1986) collected data on 44 well-documented US federal health and safety regulation proposals. For the 44 rules for which reasonably comprehensive information was available, he examined the kinds of risks addressed and the benefits and costs of the proposed regulations. The rules were proposed by the Occupational Safety and Health Administration (OSHA), the Food and Drug Administration (FDA), the National Highway Traffic Safety Administration (NHTSA), the Consumer Product Safety Commission (CPSC), the Environmental Protection Agency (EPA), the Federal Aviation Administration (FAA), and the Federal Railroad Administration (FRA). The data were obtained from "impact statements" required by various Presidential executive orders. The initial risk of those exposed to the "hazard," the number of lives saved by the regulation, and the cost effectiveness of the regulation measured by cost per life "saved" were summarized. Morrall (1986) noted several important qualifications as follows:

(i) *Agencies' estimates*. The benefits (lives saved) and costs (dollars per life saved) are generally based on estimates provided by the agencies at the time the rules were implemented.

(ii) *Conversion of incidental costs and benefits*. Many regulations were projected to yield benefits in addition to saving lives, such as reducing non-fatal injuries and property damage. These additional benefits were accounted for by subtracting monetary benefits from the costs and converting non-lifesaving health benefits into an index equivalent to additional lives saved;

(iii) *Discounting*. To ensure consistency and adjust for temporal variations, a uniform discount rate of 10 percent per annum was used for both benefits and costs.

Viscusi (1992, pp.264) has updated this information for a narrower set of regulations (33 of the 44 evaluated by Morrall) proposed between 1980 and 1990 in the USA. The regulations address a wide range of risks, ranging from 0.001 to 1850 lives lost per year, i.e. by a factor of more than a million. The level of population risk by itself may not be sufficient guidance for judging the effectiveness of a safety rule or standard. For example, some small risk may affect large populations. Conversely, a small sub-set of the population (for example a community downwind from a hazardous facility) could be subject to a much higher level of risk. Also, an estimate of the number of lives saved, in itself, may not be sufficient because a regulation could result in large lifesaving gains but at a cost disproportionately higher than a regulation that saves relatively few lives (in absolute numbers).

In principle, the best measure of desirability is *net social benefit* that addresses the value of the number of

We have performed an analysis of the 33 regulations as described by Viscusi (1992) using the Life Quality Index. The results are summarized in Table 6.1.1. The gains in life expectancy calculations are assessed using the 1985 life table for both sexes (Keyfitz and Flieger 1990); this is sufficiently accurate given the small changes in the age distribution and death rates in the U.S. population over the period of 1980 to 1990. According to the Life Quality Index, the first ten regulations in Table 6.1.1 with cost per life saved under 1.5 million dollars (1990 U.S.) pass the test, since there is a positive net social benefit. From the life-quality criterion, a limiting value of the cost per life saved can be derived as approximately $1.6 million(1990 US$).

6.2 U.S. Benzene Standards

Background:

To illustrate the use of the Life Quality Index for evaluating the net social benefit of regulations, we describe the background to the development of the benzene standards in the U.S. Benzene is a clear, colourless liquid used extensively in the petrochemical and refining industries. Benzene evaporates rapidly, enters the body primarily through inhalation, diffuses rapidly through lungs and is readily absorbed. Epidemiological studies, animal bioassays and other studies implicated benzene in increased incidence of leukaemia, non-malignant blood disorders and effects on chromosomes and embryonic development. In the 1970s, an estimated 15 billion pounds of benzene were produced in the United States (Bartman 1980).

The Occupational Safety and Health Administration (OSHA) estimated that approximately 190,000 workers were exposed to benzene in the mid-1970s. The US Environmental Protection Agency (EPA) estimated that 110 million people were exposed to atmospheric benzene at concentration of a few parts per billion to 0.5 parts per million. Exposures to high concentrations (greater than 100 parts per million) had been accepted as leukaemia producing in humans on the basis of medical reports in occupational settings and epidemiological studies.

The history of setting a standard for benzene by OSHA during the 1970's and the court challenges are documented by Bartman (1980). The Fifth Circuit Court of Appeals ruled on the challenges to OSHA's 1 part per million (ppm) standard, setting aside the standard, citing:

"the absence of substantial evidence showing a reasonable relationship between measurable benefits sought and the significant cost of the regulation to the affected industries."

The Supreme Court heard argument in OSHA's appeal of the circuit court decision stating, *inter alia*, that the benzene standard was based on the best available scientific evidence, that due to the lack of data on a safe level of exposure to benzene and the policy assumption that there is no safe exposure level for a carcinogen, require that the standard be set at the lowest feasible level, namely 1 part per million. The agency also argued that the Act did not require that standards be based on cost-benefit analysis. The American Petroleum Institute argued that the studies did not show an excess risk of leukaemia at low concentrations of benzene and that OSHA had failed to show that the standard would produce material or appreciable benefits. The Supreme Court affirmed the circuit court's decision holding that

> *"OSHA had not shown that a significant health risk was associated with the existing 10 parts per million standard. Rather, OSHA had lowered the benzene standard on a series of inadequately tested assumptions about the risk at 10 parts per million and about a risk that might result from a 1 part per million standard. OSHA lacked statutory authority to regulate to a completely risk-free level; the agency had to demonstrate that appreciable benefits would result from reducing exposure and had made no attempt to show that chronic exposure to 10 ppm of benzene would result in a significant or material health impairment."*

Table 6.1.1 : Risk-Benefit Analysis of U.S. Regulations (Viscusi 1992)

[1] Regulation	[2] Year	[3] Population (million)	[4] RGDP/ capita *g ($/year)*	[5] Cost per capita *dg*	[6] Lives Saved */year*	[7] Benefit *de/e*	[8] Economic Cost *dg /(Kg)*	[9] Benefit to Cost Ratio
Approved Regulations								
1. Unvented space heathers	1980	228	17755	3.34E-02	63	5.44E-06	2.69E-07	20.2
2. Oil and gas well service	1983	235	17827	2.57E-02	50	4.31E-06	2.06E-07	21.0
3. Cabin fire protection	1985	239	19454	1.51E-02	15	1.29E-06	1.11E-07	11.7
4. Passive restraints/belts	1984	237	18925	2.83E+00	1850	1.60E-04	2.13E-05	7.5
5. Underground construction	1989	249	21477	1.18E-02	8.1	6.99E-07	7.84E-08	8.9
6. Alcohal and drug control	1985	239	19454	1.06E-02	4.2	3.62E-07	7.78E-08	4.7
7. Servicing wheel rims	1984	237	18925	5.85E-03	2.3	1.98E-07	4.42E-08	4.5
8. Seat cushion flammability	1984	237	18925	1.13E-01	37	3.19E-06	8.53E-07	3.7
9. Floor emergency lighting	1984	237	18925	1.78E-02	5	4.31E-07	1.34E-07	3.2
10. Crane susp. personal platform	1988	246	21103	2.94E-02	5	4.31E-07	1.99E-07	2.2
11. Concrete and masonry const.	1988	246	21103	4.46E-02	6.5	5.61E-07	3.02E-07	1.9
12. Hazard communication	1983	235	17827	1.85E+00	200	1.73E-05	1.48E-05	1.2
13. Benzene/fugutive emissions	1984	237	18925	4.42E-03	0.31	2.67E-08	3.34E-08	0.80
14. Grain dust	1987	244	20385	1.05E-01	4	3.45E-07	7.35E-07	0.47
15. Radionuclides/uranium mines	1984	237	18925	3.86E-02	1.1	9.49E-08	2.92E-07	0.33
16. Benzene	1987	244	20385	3.21E-01	3.8	3.28E-07	2.25E-06	0.15
17. Arsenic/glass plant	1986	242	19879	1.05E-02	0.11	9.49E-09	7.58E-08	0.13
18. Ethylene oxide	1984	237	18925	3.65E-01	2.8	2.42E-07	2.75E-06	0.09
19. Arsenic/copper smelter	1986	242	19879	7.67E-03	0.06	5.18E-09	5.51E-08	0.09
20. Uranium mill tailing, inactive	1983	235	17827	2.98E-01	2.1	1.81E-07	2.39E-06	0.08
21. Uranium mill tailing, active	1983	235	17827	5.72E-01	2.1	1.81E-07	4.58E-06	0.04
22. Asbestos	1986	242	19879	3.33E+01	74.7	6.45E-06	2.39E-04	0.03
23. Asbestos	1989	249	21477	5.05E+00	10	8.63E-07	3.36E-05	0.03
24. Land disposal	1988	246	21103	4.32E+01	2.52	2.17E-07	2.92E-04	0.0007
25. Formaldehyde	1987	244	20385	3.56E+00	0.01	8.63E-10	2.50E-05	3.46E-05
26. Arsenic/glass manufacturing	1986	242	19879	1.77E-01	0.25	2.16E-08	1.27E-06	0.02
27. Benzene storage	1984	237	18925	4.42E-02	0.043	3.71E-09	3.34E-07	0.01
28. Radionuclides/DOE facilities	1984	237	18925	1.07E-03	0.001	8.63E-11	8.07E-09	0.01
29. Radionuclides/elem. phosphorous	1984	237	18925	6.32E-02	0.046	3.97E-09	4.77E-07	0.0083
30. Benzene/ethyl benzenol styrene	1984	237	18925	1.48E-02	0.006	5.18E-10	1.11E-07	0.0046
31. Arsenic/low-arsenic copper	1986	242	19879	3.43E-01	0.09	7.77E-09	2.47E-06	0.0031
32. Benzene/maleic anhydride	1984	237	18925	1.21E-01	0.029	2.50E-09	9.14E-07	0.0027
33. EDB	1989	249	21477	1.51E-01	0.002	1.73E-10	1.01E-06	0.0002

The scientific basis for the U.S. Environmental Protection Agency's (EPA) regulation, exhaustively reviewed in its health effects document, comprised the same studies on which the OSHA benzene standard was based. The EPA recognised that this evidence primarily involved research into occupational exposures at levels higher than those found in the ambient air, but noted that:

> *"in view of the existing state of scientific knowledge, prudent public policy require that carcinogens be considered for regulatory purposes to pose some finite risk of cancer at any exposure level above zero."*

Although the Environmental Protection Agency used quantitative risk assessment in a general balancing of the risks and costs of options to arrive at its final standard, the qualitative evaluation of health effects of benzene largely determined its regulation. The subsequent history of the EPA standard indicates problems with the way in which the calculations were performed. It reveals that the quantitative risk assessment, under somewhat modified key assumptions underlying EPA's calculations, in fact would show no risk associated with atmospheric exposure to benzene. The assumptions were too heavily influenced by EPA's policy of conservative interpretation of risk.

The example below shows how the Life Quality Index can be used to judge effectiveness of a regulatory standard.

Method and Data Requirements for Use of the Life Quality Index

(a) Assessment of Economic Impact

The following information is required for assessing the impact of the risk mitigating activity:

1. the total cost, *C* of reducing the risk in order to meet a target safety requirement;
2. population, *N,* that bears the total cost, *C; (for a national standard to be applied universally, N is the total national population)*
3. cost per person, $dg = - C/N$;
4. real gross domestic product (RGDP) per person per year, *g*;
5. the proportion of time, *w,* spent in economic activities to create wealth $w = 0.125$, $K= (1-w)/w = 7$
6. the ratio *dg/Kg* that represents the economic impact expressed in terms of relative loss of life expectancy (see Section 5.2, Model 1).

(b) Assessment of Gain in Life Expectancy

1. life expectancy at birth, *e;*
2. increase in life expectancy, *de,* due to proposed reduction risk caused by a source of hazard;
3. the ratio, *de/e,* that represents the benefit generated by the risk reduction program.

(c) Calculation of Benefit-Cost Ratio

The ratio of gain to loss of life expectancy, estimated in previous steps, provides the equivalent of benefit-cost ratio. The benefit-cost ratio greater than unity indicates that the risk mitigating program under consideration generates net benefit to society.

Example : U.S. EPA's **Benzene/fugitive emissions (1984**) regulation tested against the LQI criterion of net benefit to society.

Input Data

(1) Lives saved by the regulation= 0.31 /year
(2) Cost per life saved = 3.38×10^6 \$ (1990 U.S.)/life
(3) U.S. Population in 1984 = 237 million (OECD 1992)
(4) Death rate in U.S. (1985), $M = 8.74 \times 10^{-3}$ (Keyfitz and Flieger 1990)
(5) Real Gross Domestic Product, g = 18,925 \$(1990 U.S.)/person

Costs
(6) Total cost of the regulation, $C = (1)\times(2) = 1.0478 \times 10^6$ \$ (1990 U.S.)
(7) Cost per capita $dg = - C/$ Population $= - 4.42 \times 10^{-3}$ \$ per person
(8) Economic cost of the regulation = $- dg/Kg = 3.34 \times 10^{-8}$

Benefits
(9) Decrease in the U.S. death rate $- dM = (1)/(3) = 1.3 \times 10^{-9}$ /year
(10) Net benefit- gain in life expectancy = $de/e = 19.2dM = 2.5 \times 10^{-8}$

<u>NOTE</u>: the gain in life expectancy was calculated by Equation [4.16].

Benefit to Cost Ratio:
(11) Benefit to cost ratio = (10)/(8) = 0.75

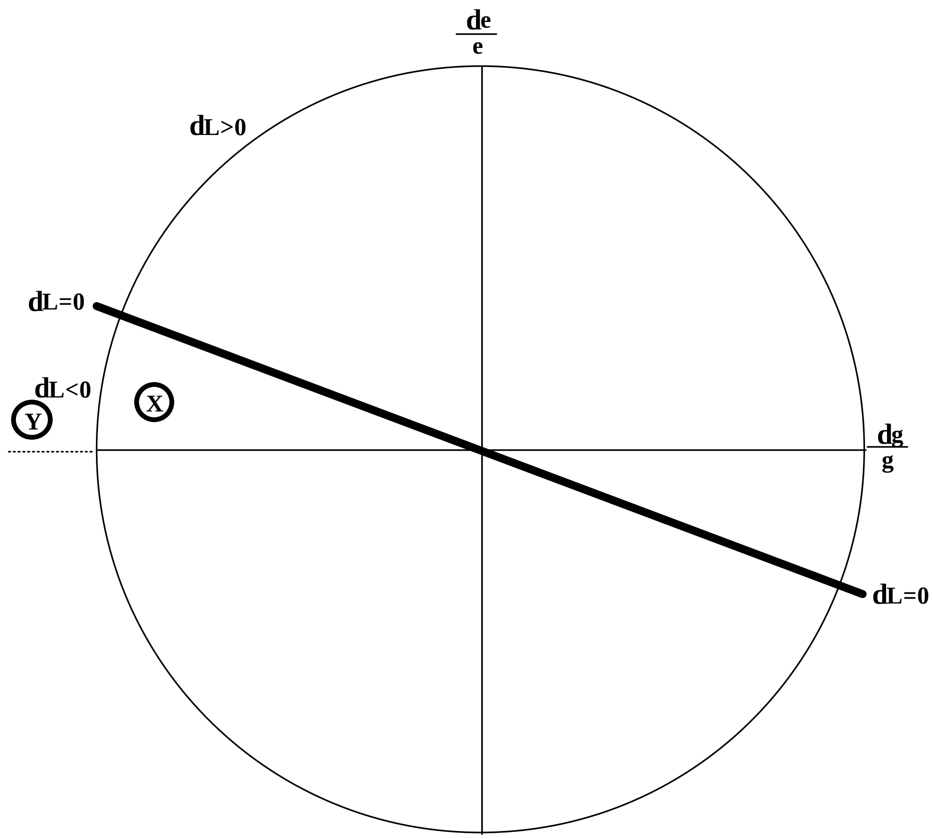
Example: U.S. EPA's ***Benzene storage (1984)*** regulation tested against the LQI criterion of net benefit to society.

Input Data
(1) Lives saved by the regulation = 0.043
(2) Cost per life saved = $243.7\ 10^6$ \$ (1990 U.S.)

All other input data are identical to (3) - (5) above. Proceeding as before gives:

Benefit to Cost Ratio:
(11) Benefit to cost ratio = (9)/(7) = 0.01

In this case, it is observed that the regulation is not effective by a very large margin and the net social benefit is too small to justify the regulation. The uncertainties in input variables would likely have no impact on the robustness of the conclusion.



X represents the Benzene Emissions Regulation
Y represents the Benzene Storage Regulation

Benzene Fugitive Emissions

6.3 Fair Compensation For Hazardous Occupations

There are hazardous occupations that, in spite of all safety measures taken, expose workers to high risks to life and health. As a rule, the more hazardous occupations are also better paid, reflecting compensation, as noted by Starr (1969). The increase in pay is determined by market forces (supply and demand for each occupation) or by negotiation between labour and employers.

Fair compensation for occupational risk is an important part of fairness in employment. Extensive accident statistics define occupational risk relatively accurately. Yet, it seems that perceived risks rather than occupational risk statistics determine the compensation. This is not surprising, as long as there is no rational way to translate a known risk into a fair compensation.

Occupational risk varies enormously. Table 6.3.1 shows accidental death risk statistics for selected occupations in the United Kingdom in the 1970s (Henderson 1987) and the 1990 (Pitblado 1996). The table shows occupational risk of death varying by more than 100 times the average (Henderson 1987). Besides, the occupational risk can vary greatly in a broad set of jobs within a general class. For example, “railway staff” could include ticket office clerks together with the brakemen that shunt freight cars, thus diluting and disguising the high risk of the most hazardous jobs. Third, accidental death rates fail to include loss of life in good health due to injury and occupationally generated disease such as “black lung.”

What amount of compensation, financial or other, would be adequate for a given occupational hazard? Because different people have different needs and tolerance for danger, for drudgery, and comfort it is not possible to give a simple answer. The marketplace value of compensation is also unreliable, because people’s judgement about risk is poor.

What, precisely, is “fair” compensation? An idea of fairness is reflected in the *Kaldor-Hicks Compensation Principle* (see Section 2.3.2). Compensation is one approach whereby the cost of detriment can be internalized as part of the cost of a project and affected individuals who bear the additional risk are compensated. The compensation, if it is viewed as fair by those affected, transforms the potential losers into non-losers thus making the policy for all at least neutral.

Table 6.3.1. Accidental Death Rates per Million at Work per year in U.K.

	(a)	(b)
Manufacture of clothing and footwear	5	-
Manufacture of vehicles	15	-
Radiation working in radiation industry	18	-
Average, all occupations	23	18
Manufacture of timber, furniture, etc.	40	-
Manufacture of bricks, pottery, glass etc.	65	-
Chemical and allied industries	85	21
Agriculture	-	79
Shipbuilding and marine engineering	105	-
Construction Industries	150	97
Railway staff	180	130
Coal miners	210	200
Quarries	295	210
Non-coal miners	750	-
Offshore oil and gas	1650	1000[1]
Sea fishing (at sea only, -1970)	2800[2]	1200[1]

[1]3-year period January 1989-1991.
[2]at sea only, 1970

Column (a): (1974-78 except as noted; after
Column (b): April 1987-March 1991 except as noted; after Pitblado (1996)

The life quality index provides a relative valuation of pay against risk if it is applied to the statistics of groups of workers. In $L = g^w e^{1-w}$ let g denote the average pay of all workers in a society. The life quality index for the workers is compared to

[1] $L_* = g_*^w e_*^{1-w}$

for a subset of these workers whose average life expectancy e_* is different because of their occupational risk. Setting $L_* = L$ gives

[2] $g_*/g - 1 = (e/e_*)^{(1-w)/w} - 1.$

Equation [2] gives the relative increment in pay that is indicated as fair, according to the life quality index and the compensation principle.

For a concrete example we use the life table for Canada (1994). The life expectancy for males at birth is 74.55 years. Let the pay of a person be one unit: $g = 1$. With w = 1/8 this gives LQI = 43.49 units (Table 6.7.2, line 1). This applies for the average occupational risk. If the mortality is increased from age 20 to age 65 by the amounts shown in column (a) in Table 6.7.2, then the LQI is reduced as shown in column (e).

However, if g simultaneously is increased by the percentage in column (f), then LQI would remain at 43.49 units. The analysis suggests that if a group of workers' income after tax is increased by the percentage shown in column (f), then their disposable wealth is increased sufficiently to compensate for the reduced expected time to enjoy that wealth.

Another way to restore a life quality index that is lowered by occupational risk is to give days of vacation with full pay. Column (g) shows the number of days with full pay per year (over a 45 year period) needed for compensation.

The best way to look at these calculations is as a “benchmark” or “anchor” for the process of judging or negotiating compensation. Any three-variable social indicator can only give a simplified picture of the real world. Yet, as in the case of the life quality index, it can give an accurate, reproducible, objective, fair and dispassionate picture. Health, wealth and long life, the most important prerequisites for a good life for all, jointly control the life quality index, each in the proportion that is reflected in people’s allocation of their own time.

Attention should be given in application to accurate measurement of occupational risk. Unlike the data in Table 6.3.1, it includes illness and delayed disease. Expected future loss of health or life must be discounted explicitly. Inconsistency is avoided only if the discount rate is the same as for the financial; discount rate (minus inflation). It is also important to avoid dilution of risk due to lumping the hazardous jobs together with safe ones.

Table 6.3.2.

Compensation indicated by the LQI for males exposed to excess mortality from age 20 to age 65 (w = 0.125; life expectancy calculated from Canadian life tables 1990-92 (1994)).

Excess Mortality, 10^{-6}/year (a)	g $ (b)	e years (c)	LQI units (d)	-ΔLQI units (e)	Compensation: Pay Δg/g % (f)	Compensation: Days per year (g)
Δm= 0	1	74.55	43.49	0	-	-
100	1	74.40	43.41	0.07657	1.24	0.6
200	1	74.25	43.33	0.15317	2.50	1.2
500	1	73.80	43.10	0.38307	6.39	3.1
1000	1	73.04	42.71	0.77176	13.35	6.3
2000	1	71.57	41.96	1.52499	28.39	12
5000	1	67.35	39.79	3.69826	86.28	30

6.4 Controls on Land Use around Hazardous Installations- France

Accidents such as the 1984 disaster at Bhopal, India, have highlighted the risk to people living near hazardous industry. It is difficult to implement controls on land use near such installations because of conflicting interests between politicians, industry, landowners, the public and public authorities. In France the government, trying to ensure that land use takes account of the risks, has considered the social and economic ramifications of posing severe restrictions on land use near hazardous plant (Rocard and Smets 1992).

There are about 300 such installations in France. The neighboring land that should not be built upon totals 90 km^2. The total loss due to control, incurred by the owners of this land, was estimated at FF 3 billion using market values for the land, although owners likely would demand more for their land. The GNP for France is about FF 5500 billion (Rocard and Smets 1992).

Rocard and Smets (1992) analysed the statistics of severe accidents in France, Europe and the World. They concluded that the annual probability P of an accident with an off-site loss of life greater than x can be modelled by a Pareto distribution. When Pareto's law is satisfied, the aggregate gravity of accidents in successive classes of gravity is constant. For high values of x, P is an inverse function of x. Thus the expected total number of deaths in accidents involving 1 to 9 deaths is the same as the expected total number of deaths in accidents involving 10 to 99 deaths or 100 to 999 deaths, or 1000 to 9999 deaths. They considered an accident type involving 1000 deaths, 5000 severely disabled and 20,000 partially disabled (the 1984 Bhopal accident caused about 3000 deaths and 75,000 permanently disabled). They estimate the probability of such an accident at 0.3 accidents per 1000 years. The annual expected loss in such accidents is 0.3 deaths, 1.5 severely disabled and 6 partially disabled.

If we assign a quality-adjusted loss of life for the severely disabled at 1/2 life and 1/10 life for the partially disabled, then the annual expected loss in accidents with more than 1000 deaths is 0.3+1.5/2+6/60=1.15 deaths. Following the Pareto hypothesis, we assign similar expected losses to accidents involving 1 to 9, 10 to 99, and 100 to 999 deaths. The total expected off-site losses to life and health are therefore 4(1.15)= 4.6 lives per year.

Life expectancies in France and Canada are very similar. France has a population of about 50,000,000 so, as a good approximation, (see Nathwani et al, 1997)

de/e = -19.2(4.6/50,000,000) = -2 E-6.

The LQI criterion (Model 3, Equation [5.2.4]) could justify an annual compensation of

-K g de/e = -7(FF 5500 E9/year)(-2E-6) = FF 77 million/year.

The net present value of such compensation for an assumed average plant life of 30 years at 3 % pa (above inflation) is therefore

NPV(FF 7.7E7, 0.03, 30) = 26.5(FF 7.7E7) = FF 2.04 billion.

Compensation at the same rate in perpetuity has a net present value of (1+1/0.03)(FF 7.7E7) = FF 2.64 billion.

We conclude that the LQI criterion justifies a compensation that is comparable to (but 1/8 to 1/3 less than) the estimated FF 3 billion based on land values.

Death and injury are not the only losses that would be incurred in a severe accident. Other losses, partially intangible, cited by Rocard and Smets (1992), include:

- loss of plant and production,
- loss of public confidence,
- shutdown of similar plant elsewhere for checks,
- increased insurance premia,
- retrofitting to new and more stringent regulations, and
- changes in demand resulting from the accident.

Therefore (but without making use of a “value of life” or a social and political “aversion factor”) we concur with the conclusion of Rocard and Smets (1992) that “it makes sense to ban building on such land even if it means that the owners have to be compensated.”

7.0 Closure

In this book we attempt to place the management of public risks into the broader context of social policy in the service of the public good. We have presented a unified foundation for risk management strategy in the form of four principles. Together these principles reflect some necessary general attributes of the good life in a modern state: public accountability, maximum net benefit for all, compensation for those who lose when there is change, and long life in good health with maximum personal choice. These principles assure the public of a commitment to the open, self-consistent, just and economical management of communal risks.

Managing Risk Strategically- Decision-makers in the past have used a great variety of principles in their efforts to cope with hazards. Neither the problem nor its solutions are new. Indeed, living organisms have tested and successfully employed diverse immune reactions against micro-organisms and numerous other ingenious defense mechanisms (armour, mimicry, venom and so on) to control risk. Entire species also employ survival strategies; foremost among these is prolific breeding. Two early general strategies of defense, still used by even the most primitive life forms and yet indispensable in modern technology, are: exclusion (e.g. the cell wall or the fuse) and redundancy (defence in depth, or backup).

The philosophy of safety has apparently not received much coherent study until very recently. Several authors, among them professional philosophers, have studied risk, but the set of available strategies for coping with risk have not been systematically explored. Wildavsky (1988) asked one of the central questions whether it is better "to attempt to anticipate dangers before [accidents] occur or to inculcate a capacity to respond resiliently, i.e., to learn from experience to cope with untoward events?" and compiles massive evidence in support of resilience. Anticipation and resilience can be considered the broadest opposing strategic alternatives for attempting to secure safety. Each of these two extreme strategies has its advocates, although resilience is currently being overlooked by most regulators as a powerful strategy to manage hazards that are little known.

Of the many possible ways to pursue safety, three well-known strategies can be identified as elementary or basic:

… trial and error,
… safety first, and
… specialization.

An essential but often unrecognized element of technological risk management is trial and error. Until the beginning of this century, technological risk was to a large extent the risk of mechanical failure: collapse of structures, bursting of pressure vessels, bursting of dams and so on. In each case the issue was one of uncertain capacity, or uncertain demand, or both. By replication or by cautious modification of successful projects, and by repair or redesign of failures, many near-optimal, economically viable and tolerable safe designs have been obtained.

A sub-strategy to trial and error is the naive (but nevertheless wise) approach that initially focusses on benefits exclusively, hazards dealt with ad hoc as they arise. The introduction of the automobile might not have been possible if the numerous associated hazards had been given the prominence they now receive; traffic deaths and injuries and air pollution, for example. The burning of coal, the use of lead in vessels and ceramic glazes, the use of asbestos, the diagnostic use of X-rays are other examples. This reactive response is perhaps the most common strategy being used to deal with the risk from natural and technological hazards.

Another sub-strategy of trial and error, satisficing, was introduce by Simon (1979). It refers to the reduction of undesirable consequences to a level that is of no practical concern, instead of seeking the optimum balance between risk and benefits. Satisficing is a common, practical way to deal with minor hazardous aspects of design but it carries the risk of expending many resources on issues of little consequence.

Safety First is the commitment to eliminate risk at any cost, sometimes workable and best suited when economic constraints or competition are not governing. The term "best available technology" applies to such a strategy.

The development of professional expertise and responsibility is a strategy of a different type that rests on specialization. Surgeons, pharmacists, firefighters, engineers, pilots and air traffic controllers and other professional groups are entrusted to control specific risks by specialized knowledge, judgement and professional consensus. Society in effect employs the collective obligation that rests upon each profession to develop and maintain expertise, including the best practical control of risk, as a tool to achieve effective risk management.

While this listing of strategies is not exhaustive, it is indicative of how risk management decisions have been guided in the past. It is also sufficient to support the main contentions of this book that:

(i) the practices that have followed from past experiences are unsystematic, erratic and unquantitative;

(ii) there is no reason to believe that the result is optimum in the public interest, as there is no unity of approach, and there is no satisfactory rational underpinning; and

(iii) the methods are vulnerable to the known misjudgements and distortions arising from perceptions of risk.

Principles for Managing Risk to the Public- The need to develop defendable methods for managing risk is an ethical obligation. The broadest goal in risk management is to serve the public interest. Managing risk on behalf of the public involves, inter alia, practical economics, politics, science, engineering, values, and ethics. The duty is to harmonize the conflicting demands of safety and economy.

We take the view that life, is the true measure of all things,- indeed, the numeraire for risks of loss to life. We have developed a set of principles, described in Section 2, to help guide the decision-makers. Briefly,

(i) The Accountability Principle- is a requirement for a single, clear process for managing risks affecting the public. Once known and accepted, this rationale removes day-to-day decisions about risk from the political arena. The principle of accountability serves as the foundation of a professional ethic for public risk management.

(ii) The Principle of Maximum Net benefit- is a requirement to maximize the net benefit to society and this is argued to be a sufficient and rational guide to assessing the effectiveness of efforts directed at reducing risk with the goal of improving health and safety.

The benefits and costs of a risk-mitigating intervention, and the risks of other ventures that affect the public, are often so unevenly distributed over different publics and over time that compensation is necessary. Compensation that turns losers into non-losers is considered a sufficient rationale for social acceptability of an unfair distribution risk. Thus, according to

(iii) The Kaldor-Hicks Compensation Principle- requires that 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.

(iv) ***The Life Measure Principle-*** requires risk reduction efforts to be maximized in terms of the length of life in good health for all members at all ages.

The Life Quality Index (LQI) is proposed as a summary index of the net benefit. The life quality index is a social indicator derived to reflect the expected length of "good" life, in particular the enhancement of the quality of life by good health and wealth. The LQI is derived from two aggregated indicators: the life expectancy at birth and the real gross domestic product per person. The life quality index can be calculated for many countries from widely available and reliable statistical data. It can be used as an objective function in setting national goals for managing risk.

Life Quality Index to Judge Risk- An evaluation of whether a health or safety provision is truly in the public interest requires a review of all the risks and benefits associated with pursuit of an option. The safety benefit is the gain in life expectancy, or life extension expected upon implementation (including, where appropriate, refinements such as the quality-adjusted life expectancy in terms of health). The cost impacts must also be evaluated, measured as the impact on the real gross domestic product per person (RGDP) (with refinements that could include correction for purchasing power parity for international comparisons).

Net Benefit Criterion for Managing Risk- The proposition for risk management is simple: the objective is to maximize life expectancy subject to resource constraints. Reducing risk of death and disease translates into longer healthful lives. The length of life extension in good health for a population can be reliably measured as the impact on the gain in life expectancy (GLE). Resources and monies are required to achieve the gains, or increases, in life expectancy. If the resources are wisely spent, then the gains in life expectancy will be large, sufficiently large that there is a net increase in the Life Quality Index (LQI). In contrast, if inordinate sums are spent on activities that do not save lives or result in only meagre life extension then there is a net decrease in the LQI.

CONCLUSIONS

1. Coherent Framework - A coherent and unified rationale for managing risk in the public interest has been developed in the form of four principles of accountability, maximizing net benefit to society, compensation and life measure. Adherence to these principles will allow us to move away from erratic and costly risk management practices.

2. Development of Social Indicators - The life quality index we have developed combines two widely available and accurate social indicators. Such quantitative measures are necessary for accountability to support decision-making in matters of public safety.

3. Life Quality Index as a Tool for Managing Risk - We have shown, through case studies and worked examples, how the life quality index can be used to assist decision-makers and others in evaluating the effectiveness of regulations and activities aimed at reducing risk to life, health and the environment. The LQI is a versatile tool that can be used to assess a wide range of risk management problems. We have shown[8] by detailed examples how the LQI can be applied to study:

… the effectiveness of standards and regulations for health and safety;
… the relative benefits of electricity generating options;
… the risks of specific hazards, e.g. radiation exposures;
… voluntary risks, e.g. cigarette smoking;
… issues related to reallocation of health care resources;
… fair compensation for hazardous occupations;
… nuclear fuel waste disposal; and
… nuclear safety design features.

4. Better Allocation of Society's Resources - Our objective is to promote better allocation of scarce resources, both by reducing wasteful efforts on inefficient risk-reduction and by supporting the implementation of efficient ones. Before one can determine what level of risk is tolerable, there is a need to be clear about the fundamental issues involved in the balancing process: the costs, the benefits, the risk and the uncertainty. The life quality index is a sufficiently robust tool that can provide the necessary guidance to the decision-maker.

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[8] See Nathwani, Lind, Pandey, "Affordable Safety by Choice: The Life Quality Method," Institute for Risk Research, University of Waterloo, 1997.

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