Affordable Safety By Choice:

The Life Quality Method

– Summary –

J.S. Nathwani, N.C. Lind, M.D. Pandey

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INSTITUTE FOR RISK RESEARCH

University of Waterloo
Waterloo, Ontario, Canada

titute for Risk Research
iversity of Waterloo
terloo, Ontario, Canada
L 3G1
: (519) 888-4567, ext. 3355
:: (519) 725-4834

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FOREWORD

This summary highlights the content of the book entitled: "Affordable Safety By Choice: The Life Quality Method," by J.S. Nathwani, N.C. Lind and M.D. Pandey. It has been prepared by the Institute for Risk Research, University of Waterloo, Waterloo, Canada for wider dissemination to a diverse audience.

The book will be of interest to decision-makers responsible for the development and implementation of safety policies and strategies in government, industry and academic institutions. The proposed methods and the analytical tools we have developed will be of interest to risk assessment specialists, scientists, engineers, public health officials, regulators and practitioners who provide support to decision-makers.

J.S. Nathwani
N.C. Lind
M.D. Pandey

July 1, 1997

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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.

Waterloo, Ontario, Canada, July 1, 1997.

J.S. Nathwani
N.C. Lind
M.D. Pandey

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?[1]" It is foolish to seek maximum benefit without considering the risks involved, but it is just as foolish to pursue minimum risk without regards for the cost. It is madness to ask for zero risk. *Risk management is a balancing act.*

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.

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

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1 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."

away from today's arbitrary, chaotic, and uncoordinated risk management practices.

The difficulty in making decisions, whenever safety is viewed by the public to be an important issue, 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[2] 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. Underlying many of the intense controversies surrounding the acceptability of risks are also 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.

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 the creation of wealth entail risks, risks that almost always can be reduced by proper engineering - but at some cost that reduces the efficiency of production of that wealth. For decision-makers - whether regulators, public health officials, scientists, engineers or managers - striking a balance between the benefits and risks is, at root, a professional obligation. We have

2 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).

proposed[3] 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 *from the risk of operation*.

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: how much 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.

The following Sections 4 to 7 will be of interest primarily to practitioners involved in risk assessment studies, analysts and scientific and technical experts who provide support to decision-makers. In Section 4 we first 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 the application of the LQI criterion 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. In Section 7 we address the important but often vexing aspects of "Uncertainty in Decision-Making." We review the available methods and their application to different situations.

3 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).

1. Managing Health and Safety Rationally

It is necessary to understand risk if we are to make intelligent decisions about it. 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, welfare and well-being. 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 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 analysed 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 to improve on our often "meagre and unsatisfactory" understanding of the processes we manage, and certainly not to replace judgement in management. We seek to be quantitative to aid the judgement of a decision-maker faced with complex issues, to foster consistency among risk management decisions, and to support accountability.

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?

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.[4] 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 rare but dramatic events, partly because of the dreadful nature of involuntary exposures to risk and partly because 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.

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4 see Doll and Peto (1981).

2. 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, 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 maximise the total expected net benefit to society.

The principle that the net benefit is to be maximised 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 maximises 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.

Of course, all instruments have their limitations. Those, such as the principle of maximum net benefit, that treat all persons in a group equally are ill-suited to focus on inequality, which must be addressed by other means. There should be *constraints on the imposition of risks.* The public management of risk balances low-level risks to people generally, not to known and identifiable individuals or groups. 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." In a society there is always an *unequal distribution of benefits and risks.* 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 many *"publics"* and over time that compensation is necessary. Compensation is 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 maximise 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 proper 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. 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, for thousands of years since it concerns human values and subjective responses. We cannot claim to have the ultimate measure of the good life for all. However, 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. It 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

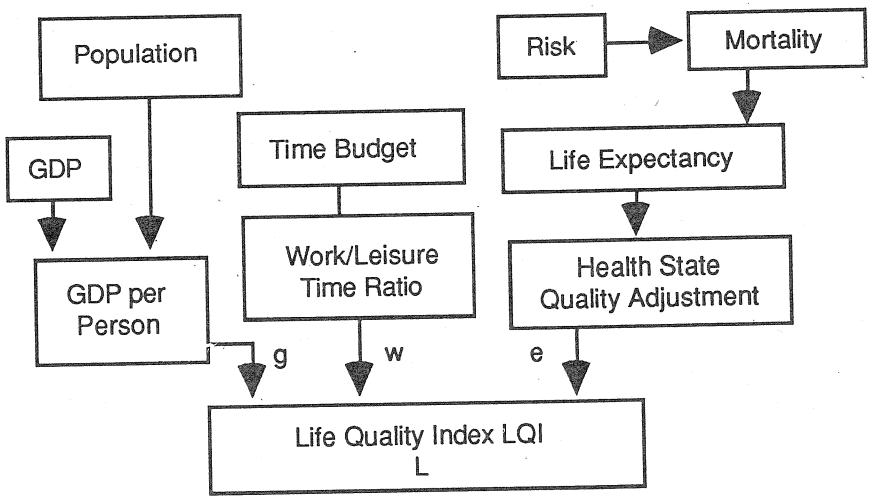
management practices and instruction to the professionals who recommend actions to decision-makers on health and safety.

4. 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[5]. 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.



Components of the Life Quality Index

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

The expression for the Life-Quality Index is:

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

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 $(1\text{-}w)$ 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 $1\text{-}w$ 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. 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 whether to take a risk, to 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. These impacts are as yet only partly quantifiable and often difficult to draw into account. The environmental and social impacts can be considered separately. 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.

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

$$\frac{dL}{L} = w\frac{dg}{g} + (1-w)\frac{de}{e}. \qquad [2]$$

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,

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

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.

6. Case Studies and Worked Examples

We illustrate use of the four principles for managing risk and apply the life quality index through worked examples. The case studies are based on data available in the literature. The examples are:

(1) *Health, Safety and Environment (HSE) standards and regulations:*

- 44 U.S. Regulations (Morrall, 1986; Viscusi, 1992);
- The Benzene standard;
- Environmental regulations to control releases of dioxin;
- Transportation safety standards.

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.

(2) *Risks associated with three major electricity generating options:*

- hydraulic;
- nuclear;
- coal.

The constraints and the power of using the LQI as a tool to evaluate options for generating electricity are illustrated. We show how the LQI may be used by a decision-maker in determining whether an option is of net benefit to society. Also, where data are available the LQI can draw into account social and environmental externalities.

The sensitivities to errors or different values of specific parameters can be studied and the conclusions tested for robustness. It is clear that extreme scenarios involving high costs or high levels of risk readily fail the test of acceptability implicit in the LQI criterion of maximizing the net benefit to society.

(3) *Risk of specific hazards*:

- ionizing radiation exposures;
- allocation of health care resources;
- LQI measure for nuclear fuel waste disposal;
- fair compensation for hazardous occupations;
- LQI measures for nuclear safety design features.

(4) *Voluntary Risks*:

- LQI measures of cigarette smoking.

7. Uncertainty

All activities, present and future, involve an element of uncertainty. The past is certain, but our knowledge about it is incomplete and uncertain. We can only judge the future in the light of the past, so this contributes to our uncertainty about the future. In some problems related to social and economic impact the uncertainty is major and unavoidable. The risk to human life arising from unanticipated failures is an important example. If only we knew in advance when and where an earthquake or an accident would occur, then the risk would be different and risk management would be simple. Uncertainty is not incidental to risk management: it is central to the problem of how we decide what is important and what resources we should commit to an issue.

Risk has two aspects: the consequences and the probabilities with which they may occur. There can be uncertainty over (a) the valuation of the consequences and (b) the distribution of the probabilities over the spectrum of consequences. Uncertainty over the values to be placed on consequences is often minor (as when they are either death or continuation of life). Yet, some risks (e.g. risk to distant future generations, risk to the environmental quality, or possible species extinction) are difficult to evaluate and thus require informed judgement. The main difficulty is to aggregate the various components (life, health, money, environment, . . .) into a

single quantity. The components are incommensurate, as different as chalk and oranges. The LQI criterion, in effect, imports into risk assessment the relative valuation of wealth, health, and duration of life that is implicit in people's time budget allocations, thus eliminating the uncertainty over the relative value of your life and your wealth.

Several methods are available to deal with uncertainty (Finkel, 1990; Granger, 1988); all have different rationales. The way it is done may be decisive for the outcome of an analysis. It is desirable to classify uncertainty according to the tools by which it can be drawn into account. Thus, we distinguish among four *sources* of uncertainty,

(i) *vagueness or lack of definition,*
(ii) *conflict,*
(iii) *natural event-to-event variation or fluctuation (statistical or aleatory uncertainty),* and
(iv) *lack of knowledge or ignorance (model uncertainty or epistemic uncertainty).*

All four sources are present in any practical decision problem, but one or a few often dominate so that the others may be neglected. We illustrate by examples how uncertainty can be taken into account in risk management:

- parameter uncertainty- example: passenger safety in cars;
- cost benefit analysis of marketing a hazardous product;
- hazardous waste disposal;
- model uncertainty- example: nuclear waste disposal.

8. 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 likely to be 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.

GENERAL CRITERION OF ACCEPTABILITY

Any project, program or regulation that materially affects the public by changing risk through expenditure will have an impact on the life quality index. Acceptability is derived from the LQI by the requirement that its increment, expressed as a function of the variables affected, is positive.

The criterion indicates the minimum acceptable improvement in life expectancy corresponding to an expenditure of public resources, or the gain in wealth necessary to compensate for an increased risk.

1. **The Life Quality Index** combines two widely available and accurate social indicators. The LQI is expressed as follows:

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

2. **Justification of Practice**

The general criterion of acceptability of risk is derived from estimating the small changes in the LQI due to a project, policy or regulation:

$$\frac{dL}{L} = w\,\frac{dg}{g} + (1-w)\,\frac{de}{e}.$$

where

dg = monetary cost of implementing (-dg) or monetary benefit that arises from project (+δg);
de = change in life expectancy due to change in risk level.

3. **The Net Benefit Criterion** is met if **dL** is positive:

$$w\,\frac{dg}{g} + (1-w)\,\frac{de}{e} > 0$$

The criterion (see Section 5.1 and 5.2) indicates the minimum acceptable improvement in life expectancy corresponding to an

expenditure of public resources, or the gain in wealth necessary to compensate for an increased risk.

Any alternative can be represented graphically by a radius vector (dg/g, de/e) in the LQI diagram. Status quo is represented by the origin (Figure 8.1). The relative increase in quality-adjusted life expectancy, de/e, is plotted against the gain in proportion to the GDP, de/e. A line with a negative slope 1:7 (the proportion of working time to leisure time) divides the diagram into two half planes. Any undertaking that plots in the top half regions 2A, 1 or 4A above the line is indicated as beneficial by the LQI criterion. Undertakings that are expected to increase the LQI, falling above the line, meet the criterion of net benefit to society and would generally be accepted. Such undertakings could, of course, be rejected on other grounds, while undertakings that fall below the line dL = 0 could, nevertheless, be judged acceptable or tolerable on other grounds. The LQI diagram provides a transparent summary of the accounting in support of decisions in risk management.

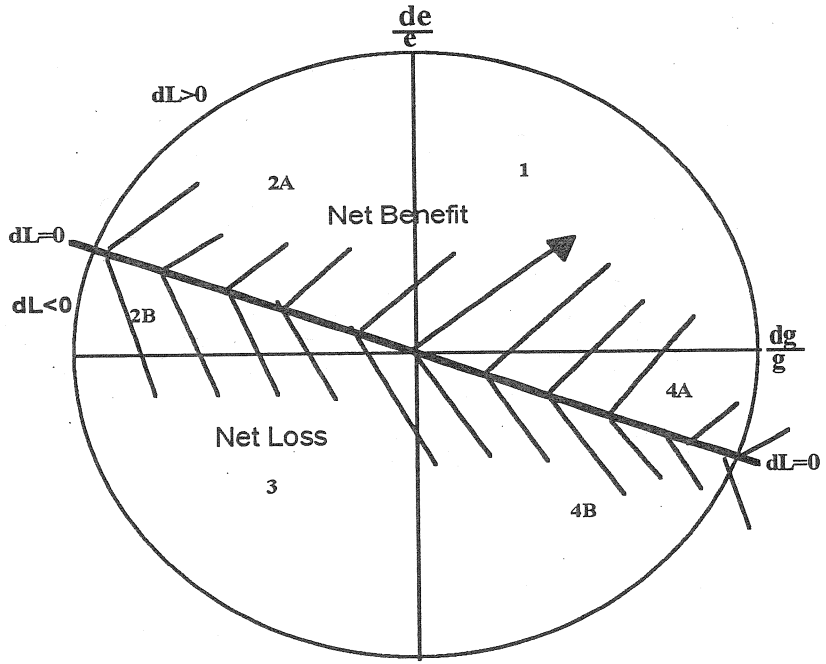


Figure 8.1: Impact on LQI of a relative change in life expectancy de/e vs. a relative change in GDP per person, dg/g.

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 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. Uncertainty is a dominant factor in all risk assessment. We have shown how uncertainty can and should be taken into account.

5. 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 you can determine what level of risk is tolerable, you must 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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* Jatin Nathwani, member of the Institute for Risk Research, is the editor of *Risk Abstracts*, a quarterly journal of abstracts, reviews and references published by Cambridge Scientific Abstracts.