

LQI Bibliography and Abstracts

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Abstract

The literature about the Life Quality Index and its application in risk assessment and mitigation is in the hundreds of articles and growing. To help the researcher get an overview, this paper provides a draft bibliography with some abstracts. With the help of authors, it is hoped that this compilation can form the basis for a more definitive and complete collection of references.

If you are aware of a publication or abstract that should be included, please e-mail the information to Mrs Iris Strickler: iwstrickler@uwaterloo.ca.

1. Introduction

Since 1991 the Life Quality Index literature has been growing at a rate of about a dozen papers per year, comprising in 2012 over 200 articles. It is difficult for anyone to get an overview of what has been written – and what has not. During the same time the process of studying the research literature has become revolutionised by the advent of efficient search engines. Information is now easier to access, but in such an *embarras de richesse* that it has become harder to know where you should invest your research time.

This bibliography has been collected to help the researcher get a perspective and find a way to the relevant information. It is organised alphabetically by first author, and some readily available abstracts have been provided. This bibliography is incomplete – and will remain so, of course. But it is hoped that the authors of work involving the LQI, present or future, will help to make the information correct and more complete. The intention is that a final bibliography with abstracts can then be posted before the end of 2013.

2. Acknowledgments

We are very grateful to the authors and especially to Ms. Helen Yuheng, Mrs. Iris Strickler, Mr. Aaron Patel and Ms. Rita Huang for their substantial help.

3. The Bibliography and Abstracts

1. *Ammann WJ. (2006). Risk Concept, Integral Risk Management and Risk Governance. Risk 21 - Coping with Risks Due to Natural Hazards in the 21st Century. 3-25.*

To be able to take effective and efficient decisions leading to transparent and comparable results between different risk situations, a consistent and systematic risk management process has to be followed (in this context called “integral risk management”). The risk concept, as it is presented hereafter, is a systematic framework for the risk analysis and risk assessment procedures leading finally to the integral planning of measures. The paper discusses the systematic implementation of a conceptual approach to risk governance as a whole and to an integral risk management of natural hazards in particular. It describes, how to implement a consistent risk concept as a basic need for an integral risk management, specifies the single steps of risk identification, risk analysis, risk assessment and the evaluation of necessary risk reduction and mitigation measures, summarizes the resulting needs for an efficient risk dialogue among stakeholders and public and makes first proposals for a systematic and periodic risk controlling.

2. **Aven T., Ersdal G. (2008).** Risk Informed Decision-Making and its Ethical Basis. Reliability Engineering & System Safety. Vol 93, Issue 2. pp 197-205.
3. **Aven T., Renn O. (2010).** Risk Management and Governance: Concepts, Guidelines, and Applications. Springer. Vol 16 of Risk, Governance, and Society.
4. **Bardo WS. (2010).** The Limits to Risk Aversion: New Results from Safety Analysis. Measurement + Control, 43/5, June, 141.

Risk is an area where both Government and private industry have struggled. A public-sector example from the recent past was the response by Governments of both hues to the BSE outbreak in the late 1990s and early 2000s, where billions of pounds were spent when the problem was all but over, saving only a few human lives at most. Meanwhile in the private and public sectors, huge amounts of money were spent in the late 1990s on the so-called Millennium Bug, supposedly set to cause chaos in computer systems across all sectors of the economy, although in reality its effect turned out to be minimal. These cases shared the feature that it was possible to predict in advance the likely scale of consequences, and this information had reached the public domain at the time as a result of the efforts of a number of scientists and engineers. Nevertheless decision-makers in Government, industry and commerce showed themselves to be unable to cope with small amounts of uncertainty. Instead, citing the scientifically dubious precautionary principle, they spent billions of pounds of taxpayers’ and shareholders’ money on fabulously expensive countermeasures against the two scares in spite of the availability of more sensible options.

The problem has been that, until very recently, it has not been possible to say definitively how much should be spent on safeguards. But new findings from safety analysis mean that answers are at last becoming available. Drawing on concepts from both economics and actuarial science, they should allow objective and rational advice to be given to those with a duty to decide on the protection systems needed to avert the crash of a jet airliner, for example, or to prevent a chemical plant releasing large quantities of toxic gas into the environment.

This is a special issue on Risk Papers presented at the Briefing Seminar held on 26 November 2009. It was organised jointly with and hosted by the Royal Academy of Engineering, with co-sponsorship from the Hazards Forum. This gave an opportunity to show-case some of the new results. The material has now been written up as the set of papers contained in this issue of the Institute’s Journal.

The first paper by Professor Philip Thomas, Roger Jones and James Kearns describes the two trade-offs inherent in the J-value method of safety assessment. They ask us to think about safety in a more precise way, suggesting that improving life expectancy provides a firmer foundation for a “calculus of safety” than the concept of saving a life, which contains the logical flaw that no-one’s life can be saved for ever. They then draw attention to the link between risk management and economics, showing how the trade-offs involved in labour negotiations may be analysed to find the important risk-aversion parameter. This parameter will govern the terms of exchange during the “safety bargain”, which is the second trade-off. It is pointed out that the J-value offers a fully objective way of deciding how much should be spent on a safety system of a given capability.

Zoltan Butt, Professors Steven Haberman and Richard Verrall and Dr Victoria Wass explain how actuarial science is now able to give very much more realistic predictions for how much working life will be lost by someone who experiences a severe injury or a long-term illness. Their recent work provides the foundation of the 6th Ogden Tables, which are used by the courts in judging compensation awards. They point out that, while in the past, UK courts assumed that a maximum of 2 years working time was lost, a closer analysis of the labour statistics shows that the average person unfortunate to fall into this category forgoes nearer 9 years of working time.

While the J-value may provide an objective method of assessing how much should be spent on pure safety, we know that large industrial accidents can bring additional costs running into hundreds of millions or even billions of pounds. How do you bring these into the assessment process, in addition to loss of life? This is the challenge addressed by Professor Thomas and Mr Jones in the 3rd paper, who show how utility theory can be used to provide a solution once again. Denoting the additional costs as “environmental”, they explain that the decision-maker in a large organisation will tend to sanction more money for environmental protection when his risk-aversion increases, but that his level of motivation to do so will fall away at the same time, as measured by the new parameter, the “reluctance to invest”. At some stage, the decision-maker’s risk-aversion may reach the “point of indiscriminate decision”, when the absolute value of the reluctance to invest will have grown so small that the decision-maker will feel unable to distinguish between a safety system and a danger system. This situation is suggested to be akin to panic in everyday life, and provides an objective limit that defines the maximum, rational expenditure on environmental protection. This expenditure may be significantly more than strict proportionality would require, thus providing support for the notions of disproportion or even gross disproportion employed by UK regulators. It is already possible to use the J-value technique to find the maximum cost justified by the protection system’s reduction of human harm, and now it is further possible to find the maximum cost justifiable in terms of the system’s environmental performance. It is thus a simple matter to add the two costs together and divide the result into the actual cost of the protection scheme to find the Total Judgement Value. This JT-value will have similar properties to the J-value, and is claimed to provide a fully objective criterion for deciding on how much to spend on a protection system designed to protect against environmental costs as well as human harm.

In the final paper, Professor Thomas, Dr William Boyle and Mr Kearns develop the notion of a quantum of wealth applicable across the developed world. Strict comparability for the parameter, reluctance to invest, would suggest that a single currency should be used to value assets prior to applying the Atkinson Utility function preparatory to finding the JT-value. The authors present evidence that the effective quantum of wealth may lie in the range £1 - £5, but

show that only minor differences in JT are likely for large organisations if, for example, all assets are valued in US dollars rather than GB pounds.

Risk is an important topic of public concern where it is desirable to make the Institute's expertise open to a wide community, in line with our Royal Charter and as encouraged by the Charities Commission. Bearing this in mind, we are hoping to join with the two other bodies involved in the successful 2009 Briefing Seminar to hold a similar event in this coming year. Comments on the practical application of three 2010 papers in Measurement + Control by Thomas, Boyle and Kearns.

5. **Bayraktarli Y.Y. & Faber, M.H. (2011).** Bayesian probabilistic network approach for managing earthquake risks of cities, *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 5:1, 2-24.

This paper considers the application of Bayesian probabilistic networks (BPNs) to large-scale risk based decision making in regard to earthquake risks. A recently developed risk management framework is outlined which utilises Bayesian probabilistic modelling, generic indicator based risk models and geographical information systems. The proposed framework comprises several modules: A module on the probabilistic description of potential future earthquake shaking intensity, a module on the probabilistic assessment of spatial variability of soil liquefaction, a module on damage assessment of buildings and a fourth module on the consequences of an earthquake. Each of these modules is integrated into a BPN. Special attention is given to aggregated risk, i.e. the risk contribution from assets at multiple locations in a city subjected to the same earthquake. The application of the methodology is illustrated on an example considering a portfolio of reinforced concrete structures in a city located close to the western part of the North Anatolian Fault in Turkey.

6. **Bayraktarli, Y.Y, Faber, M.H. (2007).** Value of information analysis in earthquake risk management. *Applications of Statistics and Probability in Civil Engineering*.

The present paper considers the problem of quantification the value of additional information in the context of earthquake risk management. Substantial uncertainties are generally associated with the fragility curves and which in turn affects the uncertainty associated with loss estimation in earthquake risk management. In the present paper uncertainties are quantified in dependency of the level of detail – or scale – which is applied as basis for the assessment of the fragility curves. As it is obvious that a higher resolution assessment will reduce uncertainty and thereby provide more certain information but also higher expenses, the problem of optimal collection of information is addressed. Based on the pre-posterior decision theory and the concept of value of information an optimization problem is formulated in regard to information collection where the objective function considers the overall costs associated with risk management of portfolios of structures subject to earthquake hazards. The application of the methodology is illustrated through an example where a newly developed risk assessment framework is applied to identify optimal risk management decisions for a portfolio of generic reinforced concrete structures located on a site close to the western part of the North Anatolian Fault in Turkey. The risk assessment framework is based on an integration of Bayesian probabilistic networks in a GIS data management structure which greatly facilitates efficient assessment of risks and optimal risk management actions for larger number of structures.

7. **Bayraktarli, Y.Y, Ulfkjaer, Jens-Peder, Yazgen, Ufuk; Faber, M.H. (2005).** On the Application of Bayesian Probabilistic Networks for Earthquake Risk Management. International Conference on Structural Safety and Reliability.

The present paper considers the application of Bayesian Probabilistic Networks (BPN's) in risk management for portfolios of structures subject to earthquake hazards. The BPN's facilitate that risks are assessed in a generic framework using indicators to relate the generic representation to the specific condition prevailing a given site, soil conditions, structure class, occupancy, etc. Initially a summary of previous work in the area of earthquake risk management is provided. Thereafter the general problem framework for management of earthquake risks is introduced for three different decision situations; before, during and after an earthquake. Following this, a basic introduction on BPN's is provided and it is outlined how the concept of indicators provides an efficient means of representing risks generically and for updating generic models in accordance with site specific information. A generic structural modelling framework is described which facilitates the automatic generation of input files for non-linear structural response analysis using the open source finite element software OpenSees. This framework makes it possible in a straight forward manner to analyse and generate vulnerability curves for several structure classes with a minimum use of man-hours. The application of the methodology is illustrated considering the decision problem of whether or not to retrofit a specific class of structures. The structures within the considered class represent low-rise, bare frame reinforced concrete structures located on a site close to the western part of the North Anatolian Fault in Turkey. The example describes how vulnerability curves are produced for both original and retrofitted structures and based on a simplified consequence model illustrates how the BPN's can be used to support decision making.

8. **Bhattacharya, B., Chajes, M. (2004).** BRIDGE AND TUNNEL SECURITY: EXPLORING THE SOCIOECONOMIC IMPLICATIONS OF TERRORISM.

With the terrorist events of September 11, 2001 the security of the nation's bridges and tunnels became a priority for the United States government. This report focuses on exploring the socioeconomic implications due to a terrorist attack on a bridge or tunnel. An algorithm was developed to calculate the socioeconomic costs associated with a terrorist attack on a structure. It is based upon a report authored by the special Blue Ribbon Panel on Bridge and Tunnel Security and research related to insurance, natural disasters and Life Quality. Example socioeconomic costs have been calculated for the Golden Gate Bridge and Delaware Memorial Bridge for a range of severities in damage. These costs are important because they aid in prioritization or ranking of important structures and assist in selecting rational mitigation measures. The total costs due to closure of one lane and damage of the Delaware Memorial Bridge, from one day to one year, ranges from approximately \$8.8 million to \$2.2 billion. Some socioeconomic implications with relation to the San Francisco Bay Area are discussed considering collapse of the Golden Gate Bridge. The algorithm can be used to guide future research and data collection methods associated with the risks of terrorism.

9. **Brethwiler, Eugen; Adey, Bryan. (2005).** Improving the consideration of life-cycle costs in bridge decision-making in Switzerland. Structure & Infrastructure Engineering: Maintenance, Management, Life-Cycle.

10. **Casciati S. (2011).** Reliability assessment via differential evolution. Applications of Statistics and Probability in Civil Engineering.

11. *Cha, E.J., Ellingwood, B.R. (2011)*. Decision-Making for Civil Infrastructure exposed to low probability, high-consequence hazards: The role of Risk-Aversion. Applications of Statistics and Probability in Civil Engineering. London,

Quantifying risk to civil infrastructure requires two components: probability of a potentially damaging event and the corresponding consequence of the damage, measured in financial or human terms. Although the limit state probability (or reliability index) itself has provided a sufficient measure of risk in the development of first-generation probability-based limit states design codes [Ellingwood, 2000; Ellingwood and Wen, 2005], a more complete consideration of the consequences of failure will need to be included to advance the new paradigm of performance-based engineering and risk-informed evaluation and decision regarding civil facilities. Various decision models, such as cost-benefit analysis, expected utility theory, cumulative prospect theory, life quality index-based analysis, and capability-based analysis, have been developed and implemented in various contexts during the past two decades to incorporate both probability and consequence in decision-making [Tversky and Kahneman, 1992; Nathwani, Lind, and Pandey, 1997; Goda and Hong, 2008; Murphy and Gardoni, 2007]. The application of such models to decision-making involving low-probability, high consequence events affecting civil infrastructure requires a fundamental understanding of risk acceptance and how it affects individual and group choices. Risk acceptance attitudes determine the willingness of individuals, groups and institutions to assume or transfer (socialize) risk, and affect the manner in which stakeholders value the limit state probability as well as the consequence of failure. Risk-aversion is an important aspect of risk acceptance [Keeney and Raiffa, 1976]; risk-averse decision-makers tend to overestimate possible losses and limit state probabilities, especially for low-probability, high-consequence events, and thus resist choosing a decision alternative which a traditional quantitative risk assessment (e.g., minimum expected cost analysis) suggests is near-optimal. A substantial amount of evidence suggests that individuals, in particular, do not evaluate the probabilities and consequences of rare events rationally in actual decision processes. Moreover, the level of irrationality increases as the consequences of the event increase or become less certain at the same time that the probability of occurrence of the event decreases. Similar irrational patterns can be observed in decision-making of groups or institutions when the probable maximum losses exceed capital resources. Risk aversion is a major contributor to irrational behavior in decision-making; its roots and how it affects the irrationality in decision processes are not fully understood, especially in the context of dealing with low-probability, high consequence events affecting civil infrastructure.

This paper explores the nature of risk aversion embedded in decisions regarding safety of civil infrastructure subjected to low-probability, high consequence natural hazards such as earthquakes, hurricanes, or flooding using analytical and statistical approaches. Insights are achieved by examining the nature of risk aversion and how it is understood in the insurance industry and, from this examination, drawing inferences that are applicable to civil infrastructure decision-making regarding rare events. In the insurance industry, the concept of a volatility multiplying factor, defined as the ratio of insurance premiums to claims, has been introduced to price risks [Walker, 2008]. The volatility multiplying factor is determined based on dynamic financial analysis considering average annual losses, targeted average annual return on initial capital, and probability of insolvency, and increases as the magnitude of covered losses increases or the coefficient of variation of annual losses increases. The volatility factor reflects the willingness of the insurance company to tolerate the underwritten risks or, in other words, how risk-averse the insurance company is in underwriting risks from

damages from natural hazards and other catastrophic events, such as earthquakes or hurricanes, or flooding. Since corporate risk aversion is embedded in the volatility multiplying factor, the nature of risk-aversion (at least as viewed by a corporate entity) can be inferred from it and can be utilized to guide the development of possible value systems for other large civil infrastructure-related decisions. The process is illustrated with the structural design of a 9-story steel moment-resisting frame building, allowing the role of risk aversion to be examined in the context of a practical structural engineering problem involving risk-informed decision-making.

12. **Collins D. (2009).** Health Protection at the World Trade Organization: The *J*-Value as a Universal Standard for Reasonableness of Regulatory Precautions. *Journal of World Trade*, ISSN 1011-6702, 43:5, 1071-1091.

Article XXb of the General Agreement on Tariffs and Trade (GATT) and the Sanitary and Phytosanitary (SPS) Agreement prohibit health safety measures that are unreasonable restrictions on trade, which World Trade Organization (WTO) case law has shown to mean not based upon sound scientific principles or international consensus. However, the existing difficulty in ensuring uniformity in these criteria as implemented by the WTO Dispute Settlement Body (DSB) necessitates resort to a universal scale for assessing the legitimacy of health and safety precautions by reference to an objective cost-benefit analysis. This paper attempts to apply the *J*-Value scale, developed in the United Kingdom, to gauge expenditures in industrial risk prevention, to evaluate the reasonableness of WTO Member State product safety regulations in a readily quantifiable, judicially instructive manner. The *J*-Value can be implemented by WTO panels *ex post* and government regulators *ex ante* in order to assess whether or not a specific measure aimed at ensuring human health and safety is actually an unnecessary barrier to international trade. In keeping with WTO principles, key features of the *J*-Value formula allow for different tolerances towards health risks depending on the view of the Member States that implement them, based on factors such as life expectancy and Gross Domestic Product (GDP).

13. **Curbach, M. (2004).** Risikountersuchung am Beispiel historischer Brücken unter Schiffsanprall. [= Risk Analysis for historical Bridges under Ship Impact] *Beton-und Stahlbetonbau*. 99, 12. 956-966.

The definition of safety of existing structures is first transferred into the definition of risk. Subsequently several parameters to describe risks are introduced. The application of these parameters is then shown for two old bridges over navigable rivers under the event of a ship impact.

14. **Dasgupta, J. (2003).** Quality management of formal safety assessment (FSA) process. SNAME 2003 Annual Meeting. Vol 111. pp. 331-352.

15. **De Sanctis, G., Fischer, K., Fontana, M., Faber, M.H. (2011).** A Probabilistic Framework for Generic Fire Risk Assessment and Risk-Based Decision Making in Buildings. *Applications of Statistics and Probability in Civil Engineering*.

The present paper describes a methodology for generic fire risk assessment in buildings for decision making purposes and optimization. Generic risk assessment facilitates quantification of the expected values of consequences due to fire events in dependence of risk indicators and

fire safety measures. Both may be associated with uncertainties due to lack of knowledge and randomness. A probabilistic model allows to consider these uncertainties consistently. Bayesian Probabilistic Networks are a strong tool to build such models. Moreover, it is possible to model complex time related events, affecting the fire development.

16. *Dewidar, K., Hassan, A., Kenawy, I., Magdy, N.* Upgrading informal settlements in Egypt towards a sustainable urban development.

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is about ensuring a better quality of life for everyone, now and for generations to come. This requires meeting four key objectives that are the social progress which recognize the need of everyone; the effective protection of the environment; the prudent use of the natural resources and the maintenance of high and stable levels of economic growth and employments. Informal settlements are areas where groups of housing units have been constructed on land that the occupants have no legal claim to, or occupy illegally; an unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing). In developing countries, cities are experiencing a real demographic explosion. This paper will deal with the problem of the informal settlement phenomenon in Egypt and the means of its upgrading by adopting the concept of sustainable urban development. It applies SWOT-AHP method to analyze stakeholders' perception of quality of life and their relationship to sustainable development. Results revealed significant agreement between stakeholders' groups of perception of strengths, threats and opportunities.

17. *Diamantidis D.*, Risk Acceptance Criteria,
http://www.jcss.byg.dtu.dk/Publications/Risk_Assessment_in_Engineering.aspx.

18. *Ditlevsen O. (2003)*. Decision Modeling and Acceptance Criteria. *Structure Safety*. 25, 2. 165-191.

This paper is partly tutorial by presenting well known classical decision theory in a slightly untraditional form, but it does also present thinking and results that have not been published in the engineering literature before. The paper introduces the mathematical modeling basis for rational formulation of decision criteria and public acceptance criteria connected to risk analysis of technical operations that may endanger human life and property. Public restrictions on the decisions concerning the design, construction and managing of the technical operation have in the past been imposed on the basis of the frequency and severity of experienced adverse events. No clear rationale to decide how restrictive the public should be in setting a boundary for allowable risk seems to have been applied. To clarify this problem, focus is on the difficulty of simultaneously having two decision makers, the owner that tries to optimize the net gain of the operation, and the public that has somewhat different preferences than the owner, but also strong interests in the success of the owner. The principles of rational decision are needed for appreciation of the problem. Recognizing that there is an insurance compensation value of a human life and a public money equivalent of a human life, where the last value usually is considerably larger than the first value, it is possible from the decision analysis to determine an upper limit that the public should impose on the ratio of the owner's expected loss rate to the expected gain rate. The public money equivalent of a human life is assessed by use of a recently in (Nathwani JS, Lind NC, Pandey MD. Affordable safety by choice: the life quality method. Waterloo, Ontario, Canada: Institute for risk Research, University of Waterloo, 1997) suggested Life Quality Index (LQI)

that combines wealth in terms of Gross Domestic Product per person, life expectancy at birth, and yearly work time into a single number. The philosophy behind the published evaluations is that the prevention of a loss of a life is counteracted by a cost such that the LQI remains unchanged (Skjong R, Ronold K. Societal indicators and risk acceptance. In: 17th International Conference on Offshore Mechanics and Arctic Engineering, number OMAE98-1488. ASME; 1998; Rackwitz R. Optimization and risk acceptability based on the Life Quality Index. Structural Safety 2002;24:297–331.).

19. **Ditlevsen, Ove. (2004).** Life Quality Index Revisited. Structural Safety. Vol 26, Issue 4. pp 443-451.

The derivation of the life quality index (LQI) is revisited for a revision. This revision takes into account the unpaid but necessary work time needed to stay alive in clean and healthy conditions to be fit for effective wealth producing work and to enjoyable free time. Dimension analysis consistency problems with the standard power function expression of the LQI are pointed out. It is emphasized that the combination coefficient in the convex differential combination between the relative differential of the gross domestic product per capita and the relative differential of the expected life at birth should not vary between countries. Finally the distributional assumptions are relaxed as compared to the assumptions made in an earlier work by the author. These assumptions concern the calculation of the life expectancy change due to the removal of an accident source. Moreover a simple public acceptance criterion is compared to the LQI criterion.

20. **Ditlevsen, O. (2008).** Model of Observed Stochastic Balance between Work and Free Time Supporting the LQTAI Definition. Structural Safety. Vol 30, Issue 5, pp 436-446.

A balance differential equation between free time and money-producing work time on the national economy level is formulated in a previous paper in terms of two dimensionless quantities, the fraction of work time and the total productivity factor defined as the ratio of the Gross Domestic Product to the total salary paid in return for work. Among the solutions there is one relation that compares surprisingly well with the relevant sequences of Danish data spanning from 1948 to 2003, and also with similar data from several other countries except for slightly different model parameter values. Statistical analysis reveals a data structure that allows the formulation of a simple stochastic model for the development of the data sequences with the year. Simulations with the stochastic model show sample curve behavior of the same fluctuating appearance as the factual data. This indicates that there are no other significant systematically balance influencing parameters on the macro economical level than those considered in the definition in the previous paper of the Life Quality Time Allocation Index.

21. **Ditlevsen, O., Friis-Hansen, Peter. (2003).** Nature Preservation Acceptance Model Applied to Tanker Oil Spill Simulations. Structural Safety. Vol 25, Issue 1. pp 1-34.

This paper emphasizes the adverse event categorization principle in risk acceptance analysis, and suggests the use of a standard type risk profile of lognormal type for each category of adverse events. The risk profile for a specified category of adverse events and corresponding to a given operation time is defined as the complementary probability distribution function for the accumulated loss during the operation time. The suggestion of the lognormal standard risk profile is based on the following modeling: The sequence of rare adverse events in time is mathematically modeled as a homogeneous Poisson process. It is shown that there is a specific mathematical form of the risk profiles which is robust with respect to variation of

distributional assumptions for the losses associated to the single adverse events. The effect of capitalization of the future losses to present time is that the risk profile asymptotically approaches a limit risk profile as the operation time increases. This asymptotic profile is well approximated by the lognormal profile as is the profile for shorter operation time if the single losses are assumed to have lognormal distribution. The risk profile modeling is exemplified by a study of oil spills due to simulated tanker collisions in the Danish straits. It is found that the distribution of the oil spill volume per spill is well represented by an exponential distribution both in Oresund and in Great Belt. When applied in the Poisson model, a risk profile reasonably close to the standard lognormal profile is obtained. Moreover, based on data pairs (volume, cost) for worldwide oil spills it is inferred that the conditional distribution of the costs given the spill volume is well modeled by a lognormal distribution. By unconditioning by the exponential distribution of the single oil spill, a risk profile for the costs is obtained that is indistinguishable from the standard lognormal risk profile. Finally the question of formulating a public risk acceptance criterion is addressed following Ditlevsen, and it is argued that a Nature Preservation Willingness Index can be defined in a similar way as the so-called Life Quality Index defined by Nathwani et al. [Nathwani JS, Lind NC, Pandey MD. Affordable safety by choice: the life quality method. Institute for Risk Research, University of Waterloo; Waterloo (Ontario, Canada): 1997], and can be used to quantify the risk acceptance criterion for the pollution of the environment. This NPWI acceptance criterion is applied to the oil spill example.

22. *Ditlevsen, O. (2004)*. A Stochastic Model for balance between work time and free time as observed in Denmark. Preliminary Reference: Reprint No. OD.

23. *Ditlevsen O., Friis-Hansen P. (2005)*. Life quality time allocation index – an equilibrium economy consistent version of the current life quality index, *Structural Safety* 27, 3, July 262-275.

The definition the life quality index for a country as originally suggested by Nathwani, Lind and Pandey is based on the gross domestic product (GDP), the expected life in good health at birth, and the fraction of life time the anonymous citizen of the country is occupied with money making work. The LQI is invented to serve as a mean to evaluate how much money that reasonably can be allocated to safety improving investments by simply requiring constancy of the LQI. By choosing that the importance of increments in the two first variables should be measured relative to the current values of the variables themselves, the relative increment of the LQI becomes defined as a convex combination of the two relative increments. The combination parameter is obtained by an optimality argument about the anonymous citizen's distribution of his or her time between free time and work time. In the original definition this equilibrium economy principle is applied under the assumption that the GDP is directly proportional to the work time fraction. This direct proportionality has been relaxed by the first author in two earlier papers with an essential effect on the combination parameter. The present paper presents a further development casting the definition into dimensionless quantities that make the index get a pure unit of time and not the somewhat obscure unit as a power product of a money unit and a time unit. To avoid confusion, this new variant of the LQI is called the life quality time allocation index (LQTAI). Moreover, the Danish data from the period from 1948 to 2003 show good agreement with the relation between the productivity and the work time as obtained from the optimality argument. The data fitting leads to an estimate of the combination coefficient of $c = 0.092$ together with a reduction factor of $r = 0.92$ to be applied to the total life expectation at birth to obtain the

expected life in good health. Among other infinitely many choices of (c, r) there are $(0.085, 1.0)$ and $(0.1, 0.85)$.

24. **Ditlevsen, O., Friis-Hansen, P. (2007).** Cost and Benefit including value of life, limb, and environmental damage measured in time units. Special Workshop on Risk Acceptance and Risk Communication.

Key elements of the authors' work on money equivalent time allocation to costs and benefits in risk analysis are put together as an entity. This includes the data supported dimensionless analysis of an equilibrium relation between total population work time and gross domestic product leading to the definition of the life quality time allocation index (LQTAI). A postulate of invariance of the LQTAI allocates societal value in terms of time to avoid life shortening fatalities as well as serious injuries that shorten the life in good health. The observed large difference between the actual costs used by the owner for economically optimizing an activity motivates a simple risk accept criterion suited to be imposed on the owner by the public. The paper ends with an example concerning allocation of economical means for mitigation of loss of life and limb on a ferry in fire.

25. **Ditlevsen, O., Friis-Hansen, P. (2009).** Cost and benefit including value of life, health and environmental damage measured in time units. Structural Safety. Vol. 31, Issue 2. pp. 136-142.

Key elements of the authors' work on money equivalent time allocation to costs and benefits in risk analysis are put together as an entity. This includes the data supported dimensionless analysis of an equilibrium relation between total population work time and gross domestic product leading to the definition of the life quality time allocation index (LQTAI). A postulate of invariance of the LQTAI allocates societal value in terms of time to avoid life shortening fatalities as well as serious injuries that shorten the life in good health. The observed large difference between the actual costs used by the owner for economically optimizing an activity motivates a simple risk accept criterion suited to be imposed on the owner by the public. The paper ends with an example concerning allocation of economical means for mitigation of loss of life and limb on a ferry in fire.

26. **Ditlevsen O. & Friis-Hansen P. (2006).** Discussion to: M.D. Pandey, J.S. Nathwani, N.C. Lind: The derivation and calibration of the life-quality index (LQI) from economic principles, Structural Safety, 28, (2006), 341-360

The life-quality index (LQI) is a versatile tool to support the effective implementation of programs and practices for managing risk to life safety. The LQI allows a transparent and consistent basis for determination of the net benefit arising from projects, programs, standards and policies undertaken at some cost to improve safety or enhance the quality of life. The paper shows that the LQI model is in harmony with well-established principles of economics, utility theory and recent developments to quantify the progress of nations through indicators of human development. The initial calibration of the LQI was based on a simplifying assumption of a linear relation between the GDP and work time. In this paper, we modify the calibration using empirical data for GDP and work time and link the LQI model to well-established economic principles and theory of production. The proposed improvements to the model eliminate a systematic bias associated with estimation of societal willingness to pay for safety. In addition, it provides a rigorous basis for program evaluation to assist decision-makers in directing expenditures where they may most effective.

27. *Ditlevsen O. & Friis-Hansen P. (2007)*. Life Quality Index - An Empirical or a Normative Concept? *International Journal of Risk Assessment and Management*. Vol 7, Number 6-7. pp 896-921.

The Life Quality Index introduced by Nathwani, Lind and Pandey is a social indicator that by invariance serves the purpose of allocating a balanced and ethically reasonable part of the Gross Domestic Product of a country to life saving initiatives. In the attempts to understand the reasoning behind the construction of the LQI one may ask whether the LQI is built on empirical evidence of social behavior that implies the modeled balance between the free time and the work time. Even if so, one may ask whether the invariance principle is a fact of social life or a normative principle of ethical social behavior. By using a dimensionless representation of the work time value production and the free time and an optimal balancing of the two against each other, it is demonstrated that there is a specific mathematical formula that connects work time and value productivity. Moreover, comparisons of the theory and available OECD-data show that the theory quite well represents the data for several countries. From the logical analysis of the theory it can be concluded that the empirical evidence cannot support the invariance principle of the LQI for money allocation as an empirically verified rule, but only as a normative rule of practice. Discrepancies between the logics of the derivations of existing variants of the LQI are made clear. It appears that these discrepancies are mostly epistemological in nature and of less importance for the practical applications.

28. *Doorn, N. Hansson, S.O. (2010)*. Should Probabilistic Design Replace Safety Factors? *Philosophy & Technology*. Vol. 24, Number 2. pp. 151-168.

Safety is a concern in almost all branches of engineering. Whereas safety was traditionally introduced by applying safety factors or margins to the calculated maximum load, this approach is increasingly replaced with probabilistic risk assessment (PRA) as a tool for dimensioning safety measures. In this paper, the two approaches are compared in terms of what they aim at and what they can, in fact, achieve. The outcome of this comparison suggests that the two approaches should be seen as complementary rather than mutually exclusive. PRA is particularly useful for priority setting and for the effect evaluation of safety measures; however, in most applications, uncertainties prevent PRA from providing an objective probability of failure or value of damage. Safety factors are indispensable for dealing with dangers that cannot be assigned meaningful probabilities.

29. *Ersdal, Gerhard. (2005)*. Assessment of Existing Offshore Structures for Life Extension. University of Stavanger. Norway.

The subject of this thesis is evaluation of possible life extension of existing offshore jacket structures. This thesis is a contribution to the further development of the theoretical background for the procedures and standards in life extension of offshore installations. The relevant standards for life extension of existing offshore jacket structures are reviewed, with focus on ultimate limit state analysis and fatigue analysis. In general, it can be said that the existing standards and procedures recommend assessment of existing structures for life extension based on: 1) Linear analysis and component checks, 2) Non-linear system strength analysis and component checks, and 3) Structural reliability analysis for the ultimate limit state check and: 1) SN fatigue analysis, 2) Fracture mechanics crack growth analysis, and 3) Structural reliability analysis for the fatigue limit state.

This thesis proposes that a risk evaluation of an ageing structure is needed as a part of the assessment. Such a risk evaluation should include identification of hazards and failure modes, and possibly include an identification of the preventive measures (barriers) for reducing the likelihood of these hazards and failure modes. A review of hazards and failure modes for an ageing offshore jacket structure are presented, and preventive actions to limit the hazards have been investigated using a barrier analysis approach. It is concluded that a review of hazards and failure modes should be included as a part of an assessment for life extension, as installation specific hazards and failure modes may be present.

Further work on system strength parameters for an offshore jacket structure is also included. It is chosen to represent the system strength with the reserve strength ratio indicator, and a reasonable criterion for this parameter is established. Similarly, it is chosen to represent the damage strength with the damaged strength ratio and a recommendation with respect to this parameter is also given. The robustness towards wave-in-deck loading is represented by introducing a reserve freeboard ratio. A criterion for this reserve freeboard ratio has also been suggested. The combined hazard of wave-in-deck loading and the system strength is found to be very important and combined criteria is found necessary. The use of probabilistic methods in assessment for life extension is also evaluated. In this thesis it is focused on a predictive Bayesian approach for probabilistic assessment. Within this approach the assigned probabilities are a measure of the uncertainty about the structure, and not an element of the structure itself. Decision methods based on the probabilistic analysis should take into account this understanding of the probability. A coherent methodology for decision making based on the predictive Bayesian approach is found, and presented in this thesis. The focus is by this shifted towards minimising the risks with the model used for the probabilistic analysis, instead of meeting a criterion for failure probability.

Finally, the degradation of an offshore jacket structure has been simulated through the life of the structure. Development in the failure probability has been studied with respect to different inspection and repair scenarios. Effects like subsidence and load redistribution after a component has failed are accounted for. From a purely structural point of view, life extension seems to be possible for an offshore jacket structure providing that sufficient inspection and repair is performed, the structure has sufficient strength and the freeboard is sufficient. Possible hazards like corrosion and pile related failures have not been included in this study, and the conclusion is based on these limitations.

30. **Faber, H., Maes, M. (2008).** Issues in societal optimal engineering decision making. Structure & Infrastructure Engineering: Maintenance, Management, Life-Cycle. Vol. 4, Number 5. pp. 335-351.

Optimal decision making in the context of engineering is addressed from the perspective of society, with the aim of optimal decision making being understood as to provide an informed basis for the identification of sustainable societal developments. The paper begins with a discussion of the issues that are presently of main concern in engineering decision making from a societal perspective. Following this, a suggestion is outlined for the hierarchical representation of the typical societal organizational instruments for ensuring such optimal decision making. This representation defines the boundary conditions for the optimization of engineering decision making. Thereafter, based on Bayesian decision theory, the main constituents of decision making are highlighted, and the various problems in the representation and treatment of these in the context of decision making are discussed in light of the most recent developments of research in these areas. This includes the representation of

society in decision making, decision making subject to uncertainty and lack of knowledge, treatment of risk perception, reconciliation of expert opinions, consistent risk assessment, and aspects of socio-economically sustainability.

31. **Faber, M.H., Maes, M.A., Baker, J.W., Vrouwenvelder, T, Takada, T. (2007).** Principles of Risk Assessment of Engineered Systems. Application of Statistics and Probability in Civil Engineering.

The present paper summarizes recent work performed within the Joint Committee on Structural Safety (JCSS) on the development of general principles for risk assessment for engineered facilities. The JCSS principles are forming a part of the background for a new ISO Guideline on Risk Assessment presently in development. The approach presented utilizes to a high degree the hierarchical characteristics of typical engineered systems and introduces a quantitative definition of system characteristics such as exposure, vulnerability and robustness. The approach suggested puts special emphasis on the assessment of so-called indirect consequences associated with loss of system functionality and directly related to lack of robustness. The paper describes the general principles proposed by the JCSS and outlines how these may be applied and implemented in practical risk assessment and risk management contexts.

32. **Faber, M.H.** Critical Issues in the Management of Catastrophic and Global Risks

33. **Faber, M.H. (2008).** Risk Assessment in Engineering: Principles, System Representation and Risk Criteria. JCSS.

34. **Faber, M.H. (2002).** Risk-Based Inspection: The Framework. Structural Engineering International. Vol 12, Number 3. pp 186-195.

The interest in Risk-Based Inspection (RBI) planning and risk management for deteriorating structures, technical installations and production facilities has been steadily increasing over the last decade. The first initiatives and developments of risk based approaches to inspection and maintenance planning were directed toward inspection planning for welded connections subject to fatigue in fixed steel offshore structures. Later the same methodology was adapted to other structures such as tankers, Floating, Production, Storage and Off-loading facilities (FPSO's) and semi-sub's and recently also onshore structures such as bridges and deterioration mechanisms such as corrosion of concrete structures were considered. Throughout the developments, structural reliability methods have played an important role.

Considering the strong interest in the field of reliability and risk-based inspection planning and the many new developments in the different industries it was decided to bring together the different parties involved in the field in order to achieve an overview of the present state of the art, strong points and shortcomings in practical applications and the major challenges lying ahead. In order to accommodate such an interdisciplinary exchange of ideas a workshop took place in Zurich, Switzerland in December 2000 in a collaboration between the Federal Institute of Technology, Switzerland, the Technical University of Aalborg, Denmark and Bureau Veritas, France. It was decided to revise and extend a selection of the papers presented at the workshop for the benefit of the larger and more broadly represented reader group of SEI and these papers are included in this issue.

It is hoped you will find the reports of interest and that they may encourage further studies of the subject.

35. **Faber, M.H. (2006).** Risk and Safety in Civil, Surveying and Environmental Engineering. Switzerland. Lecture Notes, ETH Zürich
36. **Faber, M.H., Fang, D. (2006).** Construction Safety & Health in the Framework of Civil Engineering Risk Assessment. Proceedings of CIB W99 International Conference on Global Unity for Safety & Health in Construction

The present paper sets out with the aim to investigate and utilize the possibilities for synergetic effects between the research areas of construction safety and recent developments in engineering risk assessments. Construction projects constitute in terms of systemic characteristics one of the most complex types of activities being dealt with in engineering. In addition, the construction industry is one of the most dangerous industries at present with a very high rate of fatalities and injuries among construction workers. In order to be able to assess and manage the risks in such projects and to ensure an appropriate level of life safety in particular all aspects of the interrelations between regulations, organizations, individuals, technical systems and equipment must be accounted for. In the present paper based on the papers submitted to the present conference first an outline of the present state of the research field of construction safety is provided. This outline is made in accordance with a categorization of the papers following a generic framework for risk assessment in engineering presently under development in the Joint Committee on Structural Safety (JCSS). Following this outline selected parts of the JCSS risk assessment framework is presented in more detail. This framework in particular addresses the modeling of complex engineered systems by introduction of a multi-level representation of the system characteristics; exposure, vulnerability and robustness. Furthermore, the framework provides ample guidance for assessing optimality, risk criteria and life saving efficiency, to be applied in the process of risk based decision making. For the assessment of societal acceptable life safety in a normative perspective a newly developed concept (the Life Quality Index) is outlined. Finally, an assessment is made in regard to which constituents of the JCSS risk assessment framework are actually covered by the present state of the research in the field of construction safety and health and based on this assessment recommendations are made in regard to future directions of research.

37. **Faber, M.H., Kroon, I.B., Kragh, Eva, Bayly, David, Decosemaeker, Patrick. (2002).** Risk Assessment of Decommissioning Options Using Bayesian Networks. J. Offshore Mech. Arct. Eng. Vol 124, Issue 4. pp 231-239.

For complex and costly decommissioning activities, it is beneficial, if not necessary, that all relevant risks are identified and assessed on an overall basis, treatment and assessing all risk within the same theoretical framework. Only then may the different options be consistently compared and the risks associated with decommissioning demonstrated and documents to the different parties of interest. The present paper suggests an approach for assessing the risks associated with the decommissioning of offshore facilities. The approach takes basis in a discrete point in time representation of the considered decommissioning options where important phases of the options are represented in terms of event scenarios. Using the possibilities of Bayesian Probabilistic Networks (BPN) the failure probabilities and risk events involved in the modeling of an option may then be analyzed for each phase and added up time-wise over the entire decommissioning process. The principles of BPN's are shortly described and the proposed approach is illustrated by an example linking the operational and structural risks in connection with a re-float decommissioning option for a concrete offshore platform. It is shown how the sensitivity may be evaluated on the basis of the BPN's, thus

providing a valuable framework to first improve the risk model in terms of the representation of important scenarios., then for deciding where to apply additional safety measures most effectively, and last but not least to demonstrated and document the contributions to the mission failure probability.

38. **Faber, M.H., Kubler, Oliver, Fontana, Mario, Knobloch, Markus. (2004).** Failure Consequences and Reliability Acceptance Criteria for Exceptional Building

The present paper summarizes recent work performed within the Joint Committee on Structural Safety (JCSS) on the development of general principles for risk assessment for engineered facilities. The JCSS principles are forming a part of the background for a new ISO Guideline on Risk Assessment presently in development. The approach presented utilizes to a high degree the hierarchical characteristics of typical engineered systems and introduces a quantitative definition of system characteristics such as exposure, vulnerability and robustness. The approach suggested puts special emphasis on the assessment of so-called indirect consequences associated with loss of system functionality and directly related to lack of robustness. The paper describes the general principles proposed by the JCSS and outlines how these may be applied and implemented in practical risk assessment and risk management contexts.

39. **Faber, M.H., Maes, M.A., (2006).** On Applied Engineering Decision Making for Society. Advances in Reliability and Optimization Structural Systems. London, UK. pp 17-30.

Engineering decision making is considered from the perspective of providing an informed basis for the identification of optimal societal developments. Based on Bayesian decision theory, the essential constituents of decision making are outlined and discussed in this context. Specific consideration is given to critical aspects of decision analysis such as the treatment of risk perception, system representation, epistemic uncertainties and consequence modeling. A new generic and indicator based risk assessment framework is suggested which appears to be generally applicable for societal decision making. Finally optimal decision making is addressed from a sustainability perspective and it is illustrated how preferences in regard to intergenerational equity may be formulated such as to facilitate identification of socio-economical optimal decisions.

40. **Faber, M.H., Narasimhan, H. (2010).** Multi-Hazard Risk Assessment Methodology. Urban Habitat Constructions under Catastrophic Event. pp. 435-442.

The development and management of societal infrastructure is a central task for the continued success of society. The decision processes involved in this task concern all aspects of managing and performing the planning, investigations, designing, manufacturing, execution, operations, maintenance and decommissioning of objects of societal infrastructure, such as traffic infra-structure, housing, power generation, power distribution systems and water distribution systems. During the planning and execution of engineering facilities and activities, the management of risks should ideally be based on a holistic perspective considering all possible events which may lead to and/or influence consequences of any sort. In reality such a seamless assessment and management of risks is difficult to realize due to the way in which engineering facilities and activities are planned and organized.

The basic premises required for the utilization of risk assessment to establish rational decisions for the benefit of society and other stakeholders and consistent with societal

preferences are described here. This can be used by decision makers and professionals responsible for or involved in establishing engineering decision support. The broad objective from a societal perspective by such activities is to improve the quality of life of the individuals of society both for the present and the future generations.

41. **Faber, M.H., Thöns, S., Narasimhan, H., Schubert, M. (2010).** Risikobasierter Ansatz zur Bewertung der Robustheit von Bauwerken. Stahlbau. Vol. 79, Issue 8. pp. 547-555.

Risk based approach for the assessment of the robustness of structures. - The present paper serves as an overview of recent developments by the author on the assessment and quantification of robustness of structures; the paper aims in this sense not to present any new results but collects approaches and results from previous publications. A general decision theoretical approach to the assessment and management of structural robustness is outlined. Structural robustness is introduced as a quality of the system comprising the structure; a quality which can be assessed by means of risk assessments. To facilitate an appropriate risk assessment for structural systems a scenario based model approach is outlined which differentiates consequences into two different types: direct (related to damages to individual components) and indirect (related to collapse failures). The definition of the “structural system” thus plays an important role in the risk assessment and it is discussed how the robustness assessed according to different definitions of the structural system will lead to different results and insights of relevance for the lifecycle management of the structural integrity. Furthermore, the important aspects of standardization of robustness assessments as well as requirements to robustness are discussed and suggestions for the treatment of these are proposed. Based on the presented approach to the assessment of structural robustness it is outlined how decisions on design, condition assessment, inspection and maintenance as well as monitoring activities for structures can be optimized for the purpose of managing structural risks over all phases of the life-cycle of structures

42. **Faber, M.H., Rackwitz, R. (2004).** Sustainable decision making in civil engineering. Structural Engineering International. Vol 14, Issue 3. pp 237-242.

43. **Faber, M.H., Stewart, M.G. (2003).** Risk Assessment for Civil Engineering Facilities: Critical Overview and Discussion. Reliability Engineering & System Safety. Vol 80, Issue 2. pp 173-184.

The present paper should be seen as a basis for discussion of important aspects of risk analysis and assessment, as well as attempting to describe risk assessment in accordance with the present state of the art. Risk assessment is thus presented in an overview form from the viewpoint of being a means for decision-making and thus within the formal framework of decision theory. First the motivation for risk analysis is given and the theoretical basis together with the practical aspects, methodologies and techniques for the implementation of risk assessment in civil engineering applications are explained and discussed. The paper furthermore addresses the problems associated with risk acceptance criteria, risk aversion and value of human life and attempts to provide suggestions for the rational treatment of these aspects. Finally a number of problem areas are highlighted and the needs for further education, research and dissemination are stressed.

44. **Faber, M.H., Straub, Daniel, Goyet, Jean. (2003).** Unified Approach to Risk-Based Inspection Planning for Offshore Production Facilities. J.offshore Mech. Arct. Eng. Vol 125, Issue 2. pp 126-133.

Based on new methodological developments in the area of risk-based inspection planning (RBI) for structural components subject to fatigue degradation, the present paper presents a unified approach to risk-based inspection planning for offshore facilities comprising components and systems of both the structural and process type. Suggestions are given for the formulation of acceptance criteria on component level based on overall facility acceptance criteria in terms of risk to personnel, environmental risks and economical risks. The methodology facilitates a generic modeling of fatigue and corrosion degradation for both structural and process type components. Furthermore, special considerations are given to the important aspect of updating of inspection plans when degradation has been observed. The different aspects of RBI for steel components subject to fatigue and corrosion degradation are illustrated on an example considering RBI for the components of a tripod well-head platform.

45. *Faber, M.H., Vrouwenvelder, A., Sorensen, J.D. (2011)*. Robustness of Structures -- A report on a Joint European Project.

46. *Faizian, M., Schalcher, H.R., Faber, M.H., (2005)*. Consequence Assessment in Earthquake Risk Management Using Damage Indicators. 9th International Conference.

The present paper reports on the methodical developments in regard to the modeling and assessment of consequences due to earthquakes within a multidisciplinary research project presently performed at the Swiss Federal Institute of Technology. The research project aims to develop a generic decision theoretical framework for the consistent quantitative and rational management of earthquake risks in three situations, namely prior to, during and after an earthquake. First the general framework for the earthquake risk management project is outlined. Thereafter the specific issues relating to the modeling of consequences of earthquakes are addressed including a review of existing methodologies and results of research projects reported in the literature. Finally an example of a draft Bayesian Probabilistic Net model considered in the project for consequence analysis is presented and it is explained how the net may be utilized for assessing the consequences of relevance prior, during and after an earthquake.

47. *Faschingbauer, G., Diamantidis, D., Scherer, R.J. (2004)*. Optimization of Safety Measures against Earthquakes based on Risk Acceptance Criteria. 13th World Conference on Earthquake Engineering. Paper

Recent developments in the field of risk acceptance criteria for structures are implemented in this contribution to derive cost-optimal safety measures against earthquakes in seismic regions. The methodology consists of four steps: a) Probabilistic representation of earthquake intensity: the random peak ground acceleration for a specific region or country is probabilistically evaluated as a function of its influencing parameters, i.e. source geometry, magnitude model (including uncertainty of the upper bound magnitude), occurrence rate, error term. b) Probabilistic assessment of the correlation between earthquake intensity and structural damage (vulnerability): results from recent earthquakes are included to present the damage probability matrix for several building classes; the associated model uncertainties are taken into account. c) Formulation of risk acceptance criteria based on the Life Quality Index LQI Approach: by using this approach an optimum acceptable cost per averted fatality (ICAF) can be derived for a specific country. d) Optimization of safety measures based on the aforementioned risk acceptance criteria: safety measures against earthquake such as preventive design (safety factors) or mitigation measures (rescue measures) can be optimized

by comparing the relative measure costs to the aforementioned ICAF and by considering their risk reducing effectiveness (based on experience and risk analysis background). The applicability of the proposed procedure dealing with optimisation of safety measures against earthquake is presented herein and illustrated in an example. Conclusions for further developments are drawn.

48. **Fischer, K., Virquez-Rodriguez, E., Sanchez-Silva, M., Faber, M.H. (2011).** Defining Guidelines for the Application of the Marginal Life Saving Costs Principle for Risk Regulation. Applications of Statistics and Probability in Civil Engineering

An optimal allocation of societal resources for life saving activities is guaranteed by deriving acceptance criteria for risk to life from efficiency considerations based on the marginal life saving costs principle. The Life Quality Index (LQI) can be used to quantify the societal willingness to pay for a marginal increase in life safety. The LQI net benefit criterion is the state-of-the-art method to establish quantitative risk acceptance criteria, being applicable to all areas where resources for life saving activities have to be allocated.

Yet for the application of the LQI principle to real-world regulatory decisions, clear guidelines are missing on how the assessment of conformity with societal preferences has to be performed. Problems arise especially when costs and benefits of a safety relevant decision accrue at different points in time and need to be discounted before comparison. Also in many cases the time horizon of the decision is not clearly defined. In the present paper we focus on the choice of time horizon for acceptance criteria. The aim of the discussion is to specify clear guidelines for a consistent application of the LQI net benefit criterion for regulatory purposes.

49. **Garcia-Perez, J. (2011).** Optimal Values of Seismic Design Coefficients Considering Variations of Indirect Economic Losses. Safety and Security Engineering IV. pp. 91-100
50. **Graubner, C., Brehm, E., Glowienka, S. (2008).** Economic Potentials of Probabilistic Optimization Methods. Beton-und Stahlbetonbau. Vol. 103, Issue Supplement 1. pp. 43-49.
51. **Gret-Regamey, A. Walz, A., Bebi, P. (2008).** Valuing Ecosystem Services for Sustainable Landscape Planning in Alpine Regions. Mountain Research and Development. Vol 28, Issue 2. pp 156-165.
52. **Guan, X., Xiong, X., You, J., Huang, D. (2009).** Reliability of Structural Purpose based on GDP. Journal of Natural Disasters. Vol. 3. pp. 87-94.
53. **Hansen, P.F., Bronsart, R., Cho, K.N., Hung, C.F., Leira, B., Mateus, A., Sielski, R., Spencer, J., Ulfvarson, A., Witz, J., Yoneya, T., Zhang, S. (2003).** Design Principles and Criteria. Proceedings
54. **Haukaas, T. (2004).** Developments in Finite Elements Reliability Analysis of Structural Systems. Reliability and Optimization of Structural Systems. London, UK. pp 181-187.

Finite element reliability methods have the potential of integrating advanced reliability methods into everyday engineering practice. This development is supported by the current extensive use of the finite element method and the introduction of "performance-based engineering." In this paper, long-term visions for the use of finite element reliability analysis

are discussed, recent developments and current capabilities are reviewed, and initial attempts are made to address outstanding issues. In particular, attention is given to the model and analysis errors, the uncertainty in the selection of failure criteria, and the coupling of experimental testing and numerical analysis. An objective of this paper is to stimulate the discussion of the long-term visions and the direction of future research.

55. *Hasofer, M. & Thomas, I*, Cost Benefit Analysis of a Fire Safety System Based on the Life Quality Index, International Association for Fire Safety Science, Fire Safety Science 9: 969-980.

Carrying out a cost benefit analysis requires, on the one hand, estimation of costs for the installation, running and maintenance of the system under consideration. On the other hand, it also requires estimation of the net reduction (in dollars) in property damage, as well as the effect on occupant injuries and fatalities.

Costing of injuries does not raise ethical problems, but there is no universally accepted answer to the question “What is the value of human life?” Beever and Britton carried out a cost benefit analysis of various fire safety measures in one and two family dwellings in Australia but carried out analysis of the financial aspects separately from consideration of life safety. Thus it was not possible to uniquely rank the various options considered.

In this paper their analysis is updated by integrating the financial aspects with the life safety aspects using a new approach, called the Life Quality Index (LQI) method, that has been developed by the Institute for Risk Research of the University of Waterloo, Canada. The life quality index can be calculated for many countries from widely available and reliable statistical data. It has been successfully used in environmental science and nuclear and structural engineering.

When applied, as an example of the use of the method, to a cost benefit analysis of the use of sprinklers in one and two family dwellings in Australia using the Beever and Britton data, the LQI methodology yields a financial measure of the benefit expected if sprinklers were installed in one and two family dwellings. The analysis shows a very low benefit to cost ratio and it is thus concluded that installation of sprinklers in these dwellings is not cost effective.

56. *Hoel, M., Sterner, T. (2006)*. Discounting and Relative Prices: Assessing Future Environmental Damages. Resources for the Future

Environmentalists are often upset at the effect of discounting costs of future environmental damage, e.g., due to climate change. An often-overlooked message is that we should discount costs but also take into account the increase in the relative price of the ecosystem service endangered. The effect of discounting would thus be counteracted, and if the rate of price rise of the item was fast enough, the effect might even be reversed. The scarcity that leads to rising relative prices for the environmental good will also have direct effects on the discount rate itself. The magnitude of these effects depends on properties of the economy’s technology and on social preferences. We develop a simple model of the economy that illustrates how changes in crucial technology and preference parameters may affect both the discount rate and the rate of change of values of environmental goods. The combined effect of discounting and the change of values of environmental goods is more likely to be low—or even negative—the lower the growth rate of environmental quality (or the larger its decline rate), and the lower the elasticity of substitution between environmental quality and produced goods.

57. **Imhof, D., Middleton, C.R. (2003).** Life Quality Method versus Cost-Benefit Analysis for short-Span Slab Bridges. *Applications of Statistics and Probability in Civil Engineering*. pp.681-68

Structural reliability analysis has been proposed for the assessment of existing structures by various researchers. A theoretical value for the probability of failure can be calculated using commercial software packages. However there is still no generally agreed acceptance criterion. A recently developed method based on the Life Quality Index has been suggested to determine the required safety level. In this paper determination of the acceptable failure probability using the Life Quality Method is compared to that using Cost-Benefit Analysis. Three short-span bridges were assessed using both criteria to find the minimum acceptable design parameters and thus the minimum acceptable failure probability. The sensitivity of the results to variations in parameters such as remaining service life, discount rate, corrosion rate and user costs due to traffic disruption was studied.

58. **IMO(2007) FORMAL SAFETY ASSESSMENT**, Consolidated text of the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process (MSC/Circ.1023-MEPC/Circ.392), MSC83/INF.2.

The references to LQI in these IMO FSA Guidelines are as follows. Definitions: LQI (Life Quality Index): The index for expressing the social, health, environment and economic dimensions of the quality of life at working conditions. The LQI can be used to comment on key issues that affect people and contribute to the public debate about how to improve the quality of life in our communities.

Page 54: 3.2 The proposed values for NCAF and GCAF in Table 2 have been derived by considering societal indicators (refer to document MSC 72/16, UNDP 1990, Lind 1996). They are provided for illustrative purposes only. The specific values selected as appropriate and used in an FSA study should be explicitly defined. These criteria given in Table 2 are not static, but should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on LQI (Nathwani et al. (1996), Skjong and Ronold (1998, 2002), Rackwitz (2002 a,b).

59. **Jiang, XL., Li, Y.B. (2009).** Research on Theory and Quantitative Risk Analysis of Dam Decision Model. *Marine Science Bulletin*. Vol.1. pp. 65-74.

60. **Jones, R. D., and Thomas, P. J. (2009).** Calculating the life extension achieved by reducing nuclear accident frequency. *Trans IChemE, Part B, Process Safety and Environmental Protection*, 87, 81 - 86.

Improvements in nuclear safety are often achieved through introducing a new safety measure that reduces the frequency of a hazardous accident rather than its consequences. To carry out a J-value analysis, it is necessary to calculate how a reduction in accident frequency extends the life expectancy of the potentially exposed group of people. The paper presents two methods for calculating the loss of life expectancy associated with accidents of a certain severity occurring with a defined frequency. The first begins by using an equivalent, prolonged radiation exposure to represent the effects of the accident occurring once per year over the given period of operation. The resultant loss of life expectancy is then scaled by multiplying by the frequency of occurrence. The second method calculates the loss of life expectancy brought about by a single accident occurring during the given period of operation

and scales this by multiplying by both the length of the operational period and the frequency of occurrence. Results derived using the first method show that there is a relatively small effect on loss of life expectancy per accident if several accidents are assumed to occur during a typical period of operation. This conclusion permits a simple assessment of the effect of possible, multiple accidents. The accuracy of the second method is found not to be compromised materially by ignoring the possibility of multiple accidents. The second method is shown to be slightly more conservative than the first, and also somewhat more accurate. Calculations of the loss of life expectancy may be carried out before and after the new safety improvement has been implemented, and the difference between the two results will be the life extension brought about by the new safety measure.

61. **Jones, R. D., Thomas, P. J., and Stupples, D. W.**, 2007a, "Numerical techniques for speeding up the calculation of the life extension brought about by removing a prolonged radiation exposure", *Process Safety and Environmental Protection*, 85 (B4) 269–276.

The judgement- or J-value, which enables the worth of any health or safety scheme to be measured on a common, objective scale, may be applied to a scheme to reduce or eliminate a prolonged radiation exposure provided the life extension achieved can be calculated. The calculation is necessarily complex because of the long and stochastic incubation periods associated with radiation-induced cancers. However, numerical techniques are presented here that speed up the calculation of the improved life expectancy by a factor of about one hundred. The J-value assessment of new safety systems on nuclear plant is thus made much quicker and easier. See Erratum following: *Process Safety and Environmental Protection*, 85 (B6) 599.

62. **Jones, R. D., Thomas, P. J., and Stupples, D. W.**, 2007b, "Erratum: Numerical techniques for speeding up the calculation of the life extension brought about by removing a prolonged radiation exposure", *Process Safety and Environmental Protection*, 85 (B6) 599.

63. **Jongejan, R.B., Helsloot, I. Beerens, R.J.J., Vrijling, J.K. (2011)**. How prepared is prepared enough? *Disaster*. 35, Issue 1. pp. 130-142.

64. **Jongejan RB. (2008)**. How Safe is Safe Enough? The Government's Response to Industrial and Flood Risks.

Disasters can never be completely ruled out. The Dutch national government has therefore committed itself to the concept of risk rather than the false promise of absolute safety. The objectives of this study were to evaluate current regulatory practices in the domains of industrial and flood safety in the Netherlands, and to formulate proposals for improvement. The outcomes of such an endeavour obviously depend heavily on the chosen yardstick to distinguish between superior and inferior policy alternatives. Throughout this thesis, social improvements have been defined in a way that is consistent with the approach followed in societal cost-benefit analyses.

The main conclusions and recommendations are listed below. Each chapter ends with a more detailed set of conclusions. It should constantly be kept in mind that all conclusions and policy recommendations rest on a consequentialist ethic, i.e. an ethic that considers only the outcomes of decision-making. Different approaches might yield vastly different results. But understanding where a cost-benefit framework does not get us is arguably just as important as

understanding where it does. Because the study of risk and regulation requires a strongly multidisciplinary effort, this dissertation draws upon both the social and natural sciences. It is exactly the attempt to bring together various disciplines that, I hope, will make this thesis an interesting and thought-provoking read.

1. Risk appraisal is a value-laden activity. No scientist can rightfully claim to possess superior knowledge about the risks that ought to be acceptable to all. But this need not lead to mindless relativism. Scientists can assist decision makers by clarifying problems, by pointing to key variables and by illuminating trade-offs. (chapter 1)
2. Risk regulation is a balancing act. Neither too much nor too little risk or regulation comes to the benefit of society. Risk should not be singled out as the only factor driving decisions. (chapter 2, chapter 8)
3. Under the consequentialist utilitarian ethic that underlies this thesis, a necessary condition for government intervention lies in the presence of market failures. These include negative externalities (third party risks), public goods (the provision of flood protection), and imperfect information. (chapter 2)
4. Although market failure is a necessary condition for government intervention, it is by no means a sufficient one. The drawbacks of an intervention could outweigh its gains. (chapter 2)
5. Liability rules, taxes, subsidies and other forms of government intervention should not be treated in isolation as their consequences might overlap. The stringency of new regulations should depend on the liability rules and regulations that have already been put in place. (chapter 3)
6. The polluter pays should not be used as a general principle underlying risk regulation. This is because it does not always lead to the most cost-effective measures being taken. (chapter 3)
7. The ALARA-principle (As Low As Reasonably Achievable) is often interpreted as a continuous effort to reduce risks. While this interpretation is broadly reasonable in case of technological progress and/or intensifying demands for a safe society, it would sometimes be reasonable to allow risks to increase. (chapter 3)
8. The advice to not construct flood defences because they worsen rather than reduce flood risks is, at least for large parts of the Netherlands, incorrect. Firstly, the argument presupposes morphological conditions that seem highly unrealistic. Secondly, a delta without dikes would unlikely provide protection against the low probability, extreme events that the Dutch flood defences have to withstand. Finally, regular flooding would unlikely have been compatible with past economic growth. (chapter 4)
9. The Dutch industrial and flood safety policies are both firmly risk-based. But while the FN-criteria that are used in the Dutch major hazards policy are averse to larger numbers of fatalities, a linear value function for fatalities is used in the cost benefit analyses for the Dutch flood defences. (chapter 5)
10. Decision makers should be aware that it will often be troublesome to compare the reported financial balances of different cost-benefit studies in the field of health, safety, and the environment as the assumptions underlying these cost-benefit analyses sometimes diverge widely. In practice, a relatively high reported net present value need not imply that the project actually outperforms other public investments as there might be considerable differences between underlying assumptions. (chapter 6)
11. Pressing for uniform societal risk criteria is to confuse equity and efficiency: societal risk criteria are related to efficiency rather than equity. Different societal risk criteria should ideally apply to cases in which the marginal costs of risk reduction differ considerably from the average case. (chapter 7)
12. Although it might sometimes be wholly reasonable to act prior to proof of harm, many interpretations of "the" precautionary principle imply a number of biases that cannot be defended on utilitarian grounds. Politicians and policymakers are therefore advised to refrain

from using the popular (yet ambiguous) precautionary principle as a guide for risk decision making. (chapter 8)

13. The safety chain (proaction, prevention, preparation, repression) is not as weak as its weakest link. It is at least as strong as the strongest link. This has important implications for the efficient allocation of resources: underperforming links need not always be strengthened. (chapter 9)

14. The definition of an optimal level of disaster preparedness should encompass a probabilistic element: the expected frequency with which response capacity is allowed to fall short. Regional differences in preparedness, and differences between the preparedness of different emergency services (police, fire brigades, medical aid) can be wholly justifiable on utilitarian grounds. (chapter 9)

15. Concentration, moral hazard on the part of the government, and risk perception are important obstacles to the insurability of large-scale floods in the Netherlands. An insurance arrangement in which the national government plays a dominant role would be a viable and efficient means to resolve the uninsurability of largescale floods in the Netherlands. (chapter 10)

16. The interplay between insurance and prevention should not be overlooked. When full insurance against the actuarially fair premium is unavailable, the cost of risk bearing will typically exceed expected loss. In that case, it would be incorrect to optimize failure rates on the basis of risk-neutral cost-benefit studies. The risk neutral cost-benefit analyses that are used to calculate economically optimal failure rates for the Dutch primary flood defences implicitly assume full and fairly priced insurance. The introduction of an insurance program thus cannot be used as an excuse for not meeting flood safety standards or as a justification for a lower standard of protection. (chapter 11)

65. *Jonkman, S.N., van Gelder P.H.A.J.M., Vrijling, J.K. (2003).* An Overview of Quantitative Risk Measures for Loss of Life and Economic Damage. *Journal of Hazardous Materials*. Vol 99, Issue 1. pp 1-30

A comprehensive overview of methods to quantify and limit risks arising from different sources is still missing in literature. Therefore, a study of risk literature was carried out by the authors. This article summarises about 25 quantitative risk measures. A risk measure is defined as a mathematical function of the probability of an event and the consequences of that event. The article focuses mainly on risk measures for loss of life (individual and societal risk) and economic risk, concentrating on risk measurement experiences in The Netherlands. Other types of consequences and some international practices are also considered. For every risk measure the most important characteristics are given: the mathematical formulation, the field of application and the standard set in this field. Some of the measures have been used in a case study to calculate the flood risks for an area in the Netherlands.

66. *Jonkman, S.N. (2007).* Loss of Life Estimation in Flood Risk Assessment Theory and Application. Delft University of Technology

67. *Kearns, J.O. (2009).* "The trade-offs embodied in J-value analysis", Universities' Nuclear Technology Forum, UNTF 2009, March 18 - 20 2009, Cambridge, UK.

68. *Kearns JO and Thomas PJ (2010).* Assigning tolerances to J-values used in safety analysis. 13th IMEKO TC1-TC7 Joint Symposium. IOP Publishing. *Journal of Physics: Conference Series* 238, 012045.

This paper describes the methodology employed in the estimation of the input parameters required for J-value analysis. The conceptual foundations and theory behind J-value analysis are first presented, and the relevant parameters are derived. Evaluations of the parameters are then shown and their implications discussed, including an estimate of the coefficient of relative risk aversion, risk-aversion for short. Uncertainties of the parameters are calculated. It is shown that the internal accuracy of the J-value is $\pm 4\%$, but that other external, case-dependant effects may reduce this accuracy. Some of these case-dependant sources of uncertainty are discussed and quantified.

69. **Kearns, J. O., Thomas, P. J., Taylor, R. H., Boyle, W. J. O., 2012**, "Comparative Risk Analysis of Electricity Generating Systems Using the J-Value Framework", *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, Vol. 226, No. 3, May, pages 414 – 426. doi:10.1177/0957650911424699

Decisions regarding the implementation of different forms of electricity generating systems necessarily require consideration of a large number of social, economic, environmental, and technical indicators. One such important indicator is the effect on health. This article presents a comparative risk analysis of mortality impacts arising from the generation of electricity by nuclear, coal, gas, onshore wind, and offshore wind UK power plants. The risk analysis was carried out using the J-value method, which provides a common, objective scale by which human harm can be valued. The analysis assessed human mortality impacts arising from the construction of future plants over the 60-year period from 2010 to 2070 for the entire fuel chain. Despite the considerable uncertainties in current estimates, the analysis provides evidence of the worth of the J-value methodology, particularly in relation to its ability to take explicit account of loss of life expectancy in evaluating delayed health effects. Risks are delineated according to two dimensions: whether the risk is occupational or public, and whether the risk is immediate or delayed. Impacts are also assessed for major accidents. The results indicate that nuclear generally has the lowest impacts, while gas, onshore wind and offshore wind have indicative impacts that are about an order of magnitude greater, although the estimates for both wind technologies carry considerable uncertainty. Coal power was found to present high impacts compared with the other technologies, mainly as a result of pollution emissions, even though the potential harm from some emissions has not been included because the effects are not fully understood. Total nuclear impacts were found to be sensitive to assumptions regarding the use of collective dose and the assumptions which are then used to calculate impacts. For the most pessimistic case, when world exposures are taken, total nuclear impacts increase by about an order of magnitude, which would render the risks from nuclear generation comparable with those from gas and wind generation.

70. **Kim, D., Kim, S. (2009)**. Multi Criteria Decision on Selecting Optimal Ship Accident Rate for Port Risk Mitigation. *The Asian Journal of Shipping and Logistics*. Vol.25, No. 1. pp. 139-164.

Large ports have potential catastrophic accidents by handling enormous amount of hazardous and dangerous materials which tend to increase the risk of port and the facilities in its vicinity. In the paper, we propose a mathematical method to identify the ship accident types affecting risk in port areas which propagate into death of people as a consequence of the accidents. We consider a multi criteria port risk problem and a goal programming modeling is constructed for calculating accident rates of each accident type. The obtained results can be employed by decision makers or port authorities in implementing the port risk mitigation measures or in

designing (planning) future port construction. For the study, we use the accident data for the 12 domestic ports over the last 5 years from 2002 to 2007.

71. **Kontovas, Christos A.;Psaraftis, Harilaos N.(2009).** Formal Safety Assessment: A Critical Review. Marine Technology. Vol 46, Number 1. pp 45-59.

Formal Safety Assessment (FSA) is the premier scientific method that is currently being used for the analysis of maritime safety and for the formulation of related regulatory policy. This paper conducts a critical review of the FSA methodology and proposes ways to improve it. All steps of the FSA approach are looked at, and possible pitfalls or other deficiencies are identified. Then proposals are made to alleviate such deficiencies, with a view to achieve a more transparent and objective approach. The results of this paper may be useful if a revision of the FSA guidelines is contemplated along these lines. Recent International Maritime Organizations (IMO) developments are also described.

72. **Kontovas, C.A., Psaraftis, H.N. (2006).** Formal Safety Assessment: A critical Review and Ways to Strengthen it and Make it More Transparent. Working Paper NTUA-MT-06-102.

Formal Safety Assessment (FSA) is the premier scientific method that is being currently used for the analysis of maritime safety and for the formulation of related regulatory policy. This paper conducts a critical review of the FSA methodology and proposes ways to improve it. All steps of the FSA approach are looked at and possible pitfalls or other deficiencies are identified. Then proposals are made to alleviate such deficiencies, with a view to achieve a more transparent and objective approach. The results of this paper may be useful if a revision of the FSA guidelines is contemplated along these lines.

73. **Kontovas, C.A., Psaraftis, H.N. (2008).** Marine Environment Risk Assessment: A Survey on the Disutility Cost of Oil Spills. Society of Naval Architects and Marine ... pp 1-13.

“Formal Safety Assessment” (FSA) was introduced as a tool to help in the evaluation of new regulations for maritime safety and the protection of the marine environment and is currently, the major risk assessment tool that is being used for policy-making. However, there is not much work done in FSA as regards the protection of the marine environment and especially the prevention of sea pollution. Taking into account that a major harm to the sea is the accidental spillage of oil and by acknowledging that there is no significant work on this matter, this paper attempts a literature review on the issue and comments on alternative approaches. To that effect, prior research on oil spill damage cost assessment is placed within context, and various alternative approaches are presented. This work is also viewed within the framework of recent IMO developments in this area.

74. **Kroon IB, Maes MA.** Theoretical Framework for Risk Assessment and Evaluation, http://www.jcss.byg.dtu.dk/Publications/Risk_Assessment_in_Engineering.aspx.

75. **Kubler, O. (2007).** Applied Decision-Making in Civil Engineering. Hochschulverlag, AG.

Civil engineering facilities constitute a crucial backbone of any society and represent a considerable part of its asset. These facilities allow us to undertake activities, such as the

production and transport of energy, they provide space for living or business activities or they allow for the transportation of persons and goods by private and public transportation.

Civil engineering is concerned with the optimal management of civil engineering facilities. This not only comprises the design and construction of such facilities. They also have to be operated, maintained, inspected and, if necessary, repaired and/ or decommissioned. Given a specific budget, civil engineers aim to maximize the utility of these facilities. Finally, this involves engineering decision-making throughout the life cycle of such facilities.

To start with, decision theory is reviewed regarding its applicability in civil engineering. For engineering decision-making, Bayesian decision theory combined with methods of structural reliability provides a consistent and applicable basis for the optimal management of civil engineering facilities. Besides probabilities, consequences need to be assessed for decision-making. A framework for their consistent consideration is introduced. It also accounts for socioeconomic consequences which often are referred to as indirect or follow-up consequences. As an example, consequences due to business interruption are reviewed. It is found that the consideration of follow-up consequences can be crucial for the identification of the optimal decision.

Several approaches aim to optimize the utility of civil engineering facilities. The most general approach maximizes the expected life cycle benefit. It is shown that the minimization of the expected life cycle costs is equivalent to this approach, if the expected revenue is independent of the decision/ design variable. Moreover, it is shown that within the life cycle modeling it is possible to consider whether failed structures are reconstructed or not. Also the effect of deterioration processes can be taken into account. This includes both, the effect of the deterioration process on inspection results and secondly on the residual structural resistance.

Acceptability of decision alternatives can be assessed on the basis of the life quality index (LQI). The LQI is a compound social indicator from which acceptance criteria in terms of life saving costs can be derived. The latter can be introduced into the above mentioned optimization problem. In the present work the LQI is reviewed on the basis of microeconomics consumption theory. On that basis, a simple framework is introduced, which allows to interpret a correlation that is observed between the life expectancy and the gross domestic product per capita, as the result of rational decision-making with regard to risk to life.

Finally, it is shown that the described decision framework provides a basis for the calibration of modern structural design codes. Moreover, principal studies show the applicability of decision

76. **Kubler, O., Faber, M.H. (2005).** LQI: On the correlation between life expectancy and the gross domestic product per capita. ICOSAR 2005. pp.3541-3545

The Life Quality Index (LQI) is a compound social index based on the life expectancy, the gross domestic product (GDP) per capita and the ratio of time spent at work. Analyzing empirical data, it is found that the life expectancy and the gross domestic product per capita are correlated. The present paper discusses the implications following this fact. Furthermore, the assumption that the ratio of elasticities of the LQI with respect to GDP and life expectancy is constant is investigated. This assumption is required for the LQI derivation. However,

based on this assumption a relation between the life expectancy and the GDP per capita can be formulated which is supported by empirical data. But the data also show that this relation can not be observed for societies subject to strong exogenous influences.

77. **Kubler, O., Faber, M.H. (2003).** Optimality and Acceptance Criteria in Offshore Design. *Journal of Offshore Mechanics and Arctic Engineering*. Vol 126, Issue 3. pp 258 - 265.

The optimal design of offshore structures is formulated as a decision theoretical problem. The objective is to maximize the expected net present value of the life cycle benefit. The general optimization problem is simplified by taking into account the cost impacts of a possible reconstruction of the structure. The analytical solution to this problem has been derived for the case, where failure events follow a stationary Poisson process. The life cycle benefit is formulated in terms of the production profile, the design and construction costs, failure costs and reconstruction costs. In order to assess the effect of potential loss of lives, the costs of fatalities are included applying the concept of the Implied Costs of Averting a Fatality ICAF. The suggested approach to optimal design, which can be applied for any type of offshore structure, is exemplified considering the special case of steel structures. Here, it is standard to represent the ultimate structural capacity in terms of the Reserve Strength Ratio RSR. For the purpose of illustration, the relation between material usage and RSR, which is valid for monopod structures, is applied. Optimal RSR's and corresponding annual failure rates are assessed for both manned and unmanned structures covering a wide range of different realistic ratios between the potential revenues and costs for construction, failure and reconstruction.

78. **Lentz, Albrecht, Rackwitz, Rudiger. (2004).** Loss-of-Life Modelling in Risk Acceptance Criteria. Munich, Germany. Proc. PSAM7/ESREL

When questioning whether the risk a structure poses to society is acceptable, socio-economic, demographic and hazard-related aspects have to be considered. The hazard aspect comprises two phenomena, one of which is the probability of a failure, well described by reliability theory. The second one is the expected loss of human life on occasion of such a failure. The current paper seeks to point out the common traits in existing loss-of-life estimation models dealing with – as it seems – entirely differently structured event types, such as dam failure, fire and earthquake-induced building collapse. A general conceptual and methodological basis is developed.

79. **Lentz, Albrecht. (2007).** Acceptability of Civil Engineering Decisions Involving Human Consequences. PhD thesis, Technische Universität München, Germany.

In most cases, heightened structural safety leads to higher costs and therefore to a reduction of average disposable income. At the same time, average life expectancy rises because of the ensuing lower failure rates. From income and life expectancy, it is possible to derive socioeconomic utility functions such as the life quality index. A safety-relevant decision is deemed acceptable if the utility function value rises or remains at least equal. The thesis extends this approach in order to cover not only mortality effects, but equally effects upon morbidity. Furthermore, the effect of delays (latency) is investigated. A generalised consequence model facilitates the determination of mortality and life expectancy from failure rates and toxic emission rates. Realistic case studies illustrate the application of the proposed methods.

80. **Lentz, A., Kroon, I.B.. (2011).** The function of Regulations and Incentives for Societal Safety. Applications of Statistics and Probability in Civil Engineering. London, UK. Pp 669-670.

Regulations and incentives are a way of influencing the safety-related decisions of individuals and enterprises. The aim is to make individuals and enterprises act in (better) accordance with the preferences of society. The paper uses utility theory in order to explain the function and effect of both regulations and incentives. Regulations force individuals and enterprises to adjust to the preference of society, whereas incentives manipulate the preferences instead.

81. **Lentz, A., Rackwitz, R. (2006).** Consequences and Acceptability of long-term exposure to toxic substances in air, water and Oil. Australian Journal of Civil Engineering. 4(1):35-45, 2007.

Socio-economics introduced risk acceptance criteria in order to assess the affordability of health related measures some decades ago. Later, engineering risk criteria were derived partly on this basis with the aim of determining an admissible and affordable safety level for facilities involving loss of human life in case of failure. The present paper shows how to apply the latter type of criterion to toxic long-term effects, while including aspects such as demography and discounting.

82. **Lentz, A. and Rackwitz, R. (2006).** Acceptable engineering decisions: Extending the scope of utility-based criteria from mortality to morbidity. Proc. ESREL '06, Taylor & Francis, London, 2006, p. 1203-1210

Existing utility-based criteria for acceptable decision-making mostly limit themselves to fatal consequences (mortality). The present paper seeks to extend the so-called willingness-to-pay (WTP) approach in order to cover non-fatal health consequences such as injury and disease (morbidity) as well. To this purpose, the different effects of morbidity changes upon lifetime utility are investigated. The result is compared to empirical findings from the literature and illustrated by a numerical example.

83. **Lentz, A. and Rackwitz, R. (2005).** New developments for socio-economically based risk acceptability criteria. Proc ESREL '05, Balkema, Leiden, Netherlands, pp.1245-1252

After briefly resuming the development of risk acceptability criteria up to now, the paper introduces some novelties. Among these there are a combination of different strategies of lifetime utility discounting into a joint model (Generation-adjusted Discounting) and an extended consequence model. Here, the scope is extended from single event-type failure to long-term exposure with noxious matter. The correct consideration of phenomena such as latency in the risk acceptability formulation is explained.

84. **Liang, H., Haukaas, T., Royset, J. (2007).** Reliability-based optimal design software for earthquake engineering applications. Canadian Journal of Civil Engineering. 34, 7, 856-869.

85. **Lind NC, J.S. Nathwani, E. Sidall (1991).** Management of Risks in the Public Interest, Canadian Journal of Civil Engineering, 18, 446-453, 1991.

There is no Canadian policy for the management of health and safety in the public interest. Both lives and resources are lost as a result. Limited life-saving resources ought to be spent efficiently in the public interest. If the life expectancy at birth is the measure of safety overall, then account must be given of the efficiency of any safety program, policy, project, or regulation in terms of the years of life in good health saved and the cost incurred. A comparison is made of 26 programs implemented in the United States, and it is shown that they collectively waste several thousand lives per year; 95 cents on the dollar is wasted. An absolute upper cost limit is established, which no life-saving program can exceed without consuming more human time than it returns. Some elements of a rational safety policy, and some concrete steps that ought to be taken now towards its implementation, are suggested. *Key words:* risk, management, public interest, health, safety, life, human development, index, efficiency, ethics, profession, accountability.

86. *Lind NC, J.S. Nathwani, E. Siddall*, Managing Risks in the Public Interest, Institute for Risk Research, University of Waterloo, Waterloo, Ontario IRR, 1st Published June 1991, 2nd Ed., 1993.

Treasury Board Secretariat Summary:

http://www.tbs-sct.gc.ca/pubs_pol/dcgpubs/riskmanagement/rm-rcbp02-eng.asp. This study takes the position that public resources have often been misallocated on safety issues in the past. The misallocation relates to the diminishing efficiency of risk reduction-- controlling the last 10 percent is much more expensive than the 90 percent portion. The authors suggest that the process by which safety decisions are made is faulty because a rational framework is lacking. The faulty safety management process has the very serious end result that both lives and resources are being wasted.

This study develops the theme that progress in the management of risk is possible if an open accounting is rendered of the risks and benefits. The study goes on to suggest that maximizing net benefits to society among reasonable alternatives should be a guiding principle and provides a framework for the implementation of this principle. Two combined indicators of the expectancy and quality of life are developed to give criteria for decision-making in public policy matters on life saving and safety.

The role of perceived risk is recognized in this study but not explored in detail as a causal factor in the misallocation of resources. The study simply takes the position that objectives and analytical approaches to the assessment of risk should be pursued because actions based upon perceived risk cannot be relied upon for good decisions in the public interest.

87. *Lind NC*. Three criteria of acceptable risk. *Structural Concrete*, 4, 1, 13-18, 2003.

Structural safety is a part of general safety in a society. Safety factors should conform to a general rationale for all life safety. Two rationales are presented here, using a principle of time economy and using social indicators. The common-sense *time principle* of risk management states that a 'life-saving' alternative, if it is truly to save lives, should return to the community more years of life in good health than the years of work consumed to pay for its cost. Alternatively, a risk acceptability criterion can be derived from a compound social indicator that reflects general benefit to society and that is a function of gross domestic product and life expectancy. To be acceptable, alternatives should increase the social

indicator. The two compound social indicators, the Life Quality Index and the Human Development Index, yield practically identical criteria for risk acceptance.

88. *Lind, N. 2002.* Social and economic criteria of acceptable risk, *Reliability Engineering and System Safety*, 78, 1, 21-26.

A simple normative theory is proposed for the responsible management of risks to the public. A 'lifesaving' alternative, if it is truly to save lives, should return to the community more years of life expectancy in good health than the years of work consumed to pay for its cost. This common sense time principle of risk management provides a criterion for acceptable risk that is applicable in connection with cost-utility analysis. The principle is a benchmark, providing a unified rationale for the assessment of risks in health care and technology. Integration of acceptable risk criteria with criteria for national performance can be achieved via applicable compound social indices such as the Life Quality Index or the Human Development Index.

89. *Lind, N. 2002.* Time effects in criteria for acceptable risk, *Reliability Engineering and System Safety*, 78, 1, 27-31.

The paper proposes new answers to some questions that occur frequently in practice, such as: "Should you discount future life risks and, if so, how?" or "How can the acceptance criteria be applied when the risks and costs are not simultaneous, or are time series rather than numbers?" The solutions apply to many safety regulations or projects, when only the environmental, social and cultural consequences are secondary for acceptance in comparison with the costs and the risk to life or health. It is shown how discounting need be applied to financial quantities only, entirely obviating the ethical difficulties that go with the concept of "the value of a human life".

90. *Lind, N. 2007.* Discounting risks in the far future, *Reliability Engineering & System Safety* 92, 10, October 2007, 1328–1332.

Risks to life and health in the future must be discounted in quantitative risk analysis. Yet, risks in the distant future become trivialized if any reasonable constant interest rate is used. Our responsibility toward future generations rules out such drastic discounting. A solution to this problem is proposed here, resting on the ethical principle that our duty with respect to saving lives is the same to all generations, whether in the near or far future. It is shown that when a choice between prospects involving different risks has a financing horizon T , then ordinary principles of discounting apply up to this time T , while no further discounting is justifiable after T . The principle implies that risk events beyond the financing horizon should be valued as if they occurred at the financing horizon.

91. *Lind, N. (2007).* Turning life into life expectancy: The efficiency of life-saving interventions, *International Journal of Risk Assessment and Risk Management* 7, 6/7, 884-894.

A life-saving intervention, if truly it is to save life, should yield more life expectancy in good health than the amount of work time it takes to pay for it. Together with available cost-effectiveness data, this 'Time Principle' permits a separation of the efficient from the inefficient options among all life-saving interventions. The majority of known options for intervention are efficient according to the Time Principle.

92. *Lind, N.C. (1992)*. A compound index of national development, *Social Indicators Research*, 28,325-342.

The Life Product Index (LPI) is a combination of life expectancy and gross domestic product. It is structured to the notion of 'quality-adjusted life' and calibrated to conform with the value of economic activity reflected in the national time budget. The LPI can serve as a guide in national policy planning. It can also be used as an indicator of sensible regulation of hazardous technology and as a guide in the assessment of individual projects. An LPI criterion for net benefit assessment of a project, policy or proposed regulation is derived from first principles. Application is illustrated by an example.

93. *Lind, N.C. (1995)*. Policy goals for health and safety, *Risk Analysis*, 15, No. 6, 639-644.

Health management and safety regulation are separate disciplines but share the aim to extend expectancy of life in good health. The need to improve cost-effectiveness calls for their coordinated management according to a unified rationale. Three guiding principles of accountability, demonstrable net benefit and a uniform measure of performance have been laid out in Canada by the Joint Committee on Health and Safety. They call for open accounting in terms of (health-related quality-adjusted) life expectancy. The principles are utilitarian in format but, it is argued, inequity is naturally diminished in the process of optimizing cost-effectiveness through maximum marginal returns. Comments are made on practical implementation. The need for public consent in practice calls for two additional principles reflecting fair procedure and sovereignty of the citizens. It is concluded that public health and safety measures should be surveyed, documented for cost-effectiveness and prioritized for improvement.

94. *Lind, N.C. (1996)*. Life quality measures of smoking, *Social Indicators Research*, 36, 1-12.

The cost of smoking has three principal dimensions: money, reduced life expectancy, and diminished health. Each component can be quantified; all have an influence on the quality and duration of life. The combined influence can be evaluated using an aggregated social indicator, such as the Life Quality Index. It can be expressed in various ways, e.g. as an equivalent move to a nation or to a time with a lower level of the LQI, as an equivalent economic loss, or as an equivalent loss of life expectancy. To illustrate, the analysis is applied to Danish data on smoking; the cost for a typical pack-a-day habit is equivalent to a 57% reduction in personal income, 8.6 years loss of life expectancy, or a 4% drop in the Life Quality Index. These measures underscore the seriousness of smoking as a health hazard.

95. *Lind, N.C. and Nathwani, J.S. (1992)*. Optimal safety levels via social indicators, *Transactions of the American Nuclear Society*, 65, 6/92, 521-522.

In the management of natural or technological hazards in a society, the objective should be to serve the public interest in a rational manner. Decisions with regard to risk levels for the public - if they are to be defensible and self-consistent - require an integrated system of values that covers the entire range of hazards under public regulation. The process for setting risk levels (or safety goals) should ideally involve a thorough consideration of cost and benefit of all kinds, supported by explicit quantified comparison on a widely acceptable scale. The purpose of the paper is to show how quantitative

criteria within the context of an appropriate framework can be used to guide risk management decisions. Social indicators are time series, statistics that reflect some aspect of the quality of life in a society or group of individuals. Development, validation, and use of social indicators is an important current research activity, as exemplified by journals such as *Social Indicators Research*. The basic objective is to provide quantitative measures for assessing the rationales and effectiveness of public decision-making. The concept is applicable to the nuclear industry.

96. *Lind N (2004)*. Values reflected in the human development index, *Social Indicators Research*, 66, 283-293.

The Human Development Index (HDI) implicitly defines “human development” and ranks countries accordingly. To elucidate the HDI’s meaning of “human development,” the paper examines the sensitivity of the HDI to changes in its components, namely social indicators of education, longevity and standard of living. The HDI is next compared with two alternatives, the Life Quality Index (LQI) and a Time Allocation Index (TAI) developed in this paper from the HDI’s components. Also considered is the likely uncertainty in the HDI and what it means for HDI rankings.

It is concluded that the HDI’s weighting of the gross domestic product is in good agreement with peoples’ preferences as revealed in the LQI and the TAI; further, that the HDI places many times greater weight on education than is indicated by peoples’ allocation of time in developed countries. Literacy is accorded very high weight in the HDI, but its measure is unreliable. The HDI ranking of highly developed nations is so close and so uncertain that it is meaningless.

97. *Lind, N.C. (2004)*. Criteria for Optimal Safety. Reliability and Optimization of Structural Systems. London, UK. pp 105-122.

Structural safety, to be optimal, should conform to a general rationale for all life safety and health in a society. Two rationales are suggested here, one using a principle of time allocation, the other using a social indicator. The Time Principle of risk management states in effect that a ‘life-saving’ alternative, if truly it is to save lives, should return to society more years of life in good health than the years of work consumed to pay for its cost. Alternatively, a risk optimality criterion can be derived from a compound social indicator that reflects general benefit to society and is a function of gross domestic product and life expectancy. To be preferable, an alternative should maximise the social indicator. The Life Quality Index yields the same optimality criterion as the Time Principle, defining “How safe is safe enough.” Although risk must be discounted like finances, it is suggested as an ethical principle that this discounting should not extend beyond the period of financing. It is concluded that the cost-utility of structural codes and standards (and other provisions for public health and safety) should conform to these criteria.

98. *Lind, N.C. (2005)*. The Welfare Economics of Structural Safety. Proc Simposio Luis Esteva. Mexico DF.

99. *Lind, N. (2006)*. Discounting risks in the far future, *Reliability Engineering & System Safety* (accepted 1 Sep 2006).

100. *Lind, N.C., Pandey, M.D. and Nathwani, J.S. (2007)*. Socially optimized engineered safety: The Life Quality Index. pp. 1-6. pp.1-5. Proc. 10th Int. Conf. Applications of Statistics and Probability in Civil Engineering, Kanda, Takada & Furuta (eds), Taylor & Francis Group, Tokyo, Japan, July 31-August 3.

The Life Quality Index (LQI) is a simple but versatile tool to support effective implementation of programs and practices to manage all risks to life and health. The LQI allows a rational and transparent basis to determine the net benefit arising from projects, programs, standards and policies undertaken to improve safety or enhance the quality of life. The LQI thus makes it possible to manage all such risks in a consistent, ethical manner in harmony with the principles of human welfare.

The LQI model is derived from established principles of welfare economics, decision theory and the progress of nations as quantified by indicators of human development. We use a new realistic relation between gross domestic product and work time. The model eliminates a systematic bias associated with estimation of the “societal willingness to pay for safety.” It is supported by solid data. It provides a rigorous basis to assist decision-makers in directing expenditures where they may do the most good, serving engineers’ professional obligation to “balance safety and economy.” The goal is to promote a fully transparent process, with risk communication integrated at each step, so as to ensure consistency in practice. A simple and intuitive time principle that supports the theory is shown to hold under very general conditions.

In application to engineered safety, a standard of practice for optimization is described. Engineered safety serves to ensure that the significant risks are identified and minimized to a reasonable level. Engineered safety sets safety margins so as to balance the cost effectiveness of risk control and the benefits of risk mitigation. For the net benefit to the owner or society at large to be positive, the management of risk requires that priorities be set because available resources are limited. Net benefit is measured by the increment to the LQI. This approach gives a more solid and rational basis for decision-making about engineering projects or standards when life safety is a concern.

The evaluation process, the data required to support the analysis, and the major components of the LQI model are illustrated by two examples. The examples in particular show the need for evaluation of the net present value of risk, for which a new model is compared with extant ones.

101. *Lind, N.C., Pandey, M.D. and Nathwani, J.S. (2008)*. Assessing and Affording the Control of Flood Risk. *Structural Safety*, 31, 143-147, 2008.

Flood is among the severest causes of natural or man-made catastrophes. With a growing world population the need to live in flood-prone areas has grown, and so has the risk to life and property. This paper proposes three alternatives to flood risk assessment that each may help provide for better (more rational and defensible) design of flood control structures (1) Time series data analysis by cross-entropy minimization; (2) deriving society’s capacity to control risks from welfare economics; and (3) discounting risks, but only up to the end of the financing period.

Cross-entropy minimization. The familiar “tail problem” of rare-event risk analysis is especially important in flood data analysis because the hydrological regime cannot be

assumed stable and known. Arbitrarily assuming a mathematical model will often add an appreciable amount of information in comparison with that of the sample data. Cross-entropy minimization can compare a broad spectrum of distribution types to determine the best fitting model F . This model does not, however, comply with the constraints that all n data points i should satisfy $G_i = i/(n+1)$. The method further defines the least-information distribution G that complies and minimizes the total information.

Society's capacity to commit resources to control risks is a well-defined quantity that for fatalities derives from the *time principle* that the reduction of a risk to life or health should cost no more, in terms of the time to produce the wealth equal to its cost, than the consequent expected increase in life expectancy. This time principle, in turn, follows from the requirement that the associated increment to the *Life Quality Index* (LQI) should not be negative. The LQI is a well-defined social indicator that can be derived from the classical theory of welfare economics.

Discounting risks is necessary, but if done at a constant rate, however small, it trivializes risks in the far future that flood control must be concerned with. There is an ethical requirement to value risks to present and future generations equally. This requirement, it is shown, places discounting in relation to the period of financing of any long term project: Risks beyond the this period should be discounted only up to the end of the financing period.

The impact of each of these three considerations is examined by several examples and some recommendations for analysis are made.

102. **Lind, N., Pandey, M., Nathwani, J. (2011).** Global Flood Risk Assessment of Major Port Cities. Applications of Statistics and Probability in Civil Engineering. London, UK. Pp 577-578.

We consider the problem of assessing the hazards, exposures and risks of flood with respect to lives and assets in major port cities world-wide. Port cities have large concentrations of people and assets. They are a vital part of the global economy. Flood hazard presents an important civil engineering challenge, both in terms of potential loss of life and assets. Flood is among the most consequential problems in public risk management policy. Several recent floods, as in New Orleans in 2005, have illustrated the vulnerability of wealthy and poor societies.

The analysis builds on the study by Nicholls et al. (2007) who gave a global overview of the coastal flood hazard for 136 port cities with a population over 1 million. They produced rankings by hazard and social-economic vulnerability to weather extremes. The 100-year flood area assets were estimated as a function of the population exposed. Long-life assets were taken as five times the population's share of the GDP, losses from flood events five times greater than the GDP of the affected population.

Across all 136 cities about 40 million people are subject to a 100-year coastal flood event. When assets are considered, the distribution is weighted towards developed countries. Our analysis considers 28 of the most seriously affected port cities, each being among the top 20 with respect to assets or population subject to flood or both. The 28 cities span a very wide range of social and economic development.

The Life Quality Index LQI, deriving from the economics of human welfare (Nathwani et al. 2009), allows a comparison of risks on the background of such diversity. The LQI aggregates the expectancy of healthy life e with the GDP per person g calculated at purchasing-power parity. The Societal Capacity to Commit Resources (SCCR = $5 g/e$ \$/year) to risk reduction, used here for simplicity to aggregate risks, is derived from the LQI.

The countries fall into two distinct groups: Bangladesh, China, Egypt, India, Ivory Coast, Vietnam and Thailand have normalized LQIs under 0.09. Canada, Germany, Japan, Netherlands, UK, and USA have LQIs greater than 0.9. The two groups differ markedly with respect to SCCR, flood protection and population loss rates. Yet, there is little group difference with respect to population, flood area population or asset loss rate.

The expected loss of life conditional upon flooding is the population in the area subject to flooding factored by the loss rate. Each fatality is taken to produce a loss of life years averaging one half of the life expectancy at birth. The total exposure is obtained by either expressing asset loss in terms of life loss equivalent or *vice versa*.

Exposure is not risk; the risk depends on the degree of flood protection and the emergency response capacity. Both must be carefully estimated by detailed analysis for each port city to determine the optimal level of flood protection. Such analysis is beyond the scope of this paper, but the available data provide a first assessment of the risk. The framework can readily serve with updated data for more accurate assessment and decision making.

Risk can be seen from the point of view of an individual exposed, or a member of the community, or the nation as a whole. All such viewpoints have their validity and application; there is no universal criterion to rank cities with respect to flood. The risk is assessed by six criteria: Annual expectation of (1) Fatalities, (2) Asset losses, (3) Annual expectation of life years lost (Figure 1), (4) Total of fatalities and asset losses in equivalent life years (Figure 2), (5) Same total per inhabitant in terms of purchasing-power, and (6) Same, as per cent of the GDP per person. We ranked the cities according to each criterion and determined the corresponding quartiles. Every criterion shows great diversity of risk. Guangzhou has the highest risk in terms of total life and asset losses, loss of life years per person, or loss per person as per cent of the GDP per person. Guangzhou is in the highest quartile also at high risk according to more than half of the criteria. China has by far the largest population exposed to the flood hazard. Among the 28 cities studied, the quartiles of lowest risk comprise some nine cities. Amsterdam, Fukuoka-Kitakyushu, Hamburg, London, Rotterdam and Tokyo all exhibit low risk according to each of the six criteria.

All data in this study are uncertain, more uncertain than usual in engineering risk analysis for particular locations. Any measure of uncertainty is itself uncertain. But it is useful to get a rough estimate of the uncertainty in the calculated risks, precisely because of the high uncertainty, to evaluate how robust the possible conclusions may be. The assigned coefficients of variation fall in two sets, with relatively low and high Coefficients Of Variation (COV). Since the latter set is large and dominant, the uncertainty in the former set is ignored if their COV is less than one third (17%) of the higher COVs. The reduced set of COVs used are then the same for all urban areas. To simplify the analysis further we assumed that the variables are approximately lognormally distributed, so that the aggregated risk variables will be approximately lognormal as well. The resulting COVs range for exposure variables from 54% to 59% and for risk variables from 74% to 77%. In spite of these wide error bands, the exposure and risk are concentrated on a few cities. The risk varies 300-fold

over the set of 28 cities, from very serious to quite insignificant. Most high-risk locations are in Asia. The risks are generally small in the developed countries.

Flood area assets and flood area population are not good indicators of exposures and risks. Nicholls et al., cautiously call their study a "ranking" rather than exposure analysis. For the exposure analysis we had to make further assumptions, estimating some design return periods. When the accuracy has to be adequate for risk-based decision making, return periods can only be determined by detailed analysis for each urban area individually. The same applies to the loss rates for population and assets. Such estimates, and hence more accurate assessments of exposures and risks, are technically feasible. The risks obtained here are thus preliminary. Our triage (rather than a ranking) gives an indication of the relative and absolute magnitudes of flood hazard measures, indicating where further study is most urgent. If more accurate data become available, a revised set of values is readily calculated by the formulas presented.

103. *Maes, M.A. (2003)*. On Applied Engineering Decision Making for Society. Advances in Reliability and Optimization. Taylor & Francis Group.

104. *Maes, MA, Pandey, MD and Nathwani, JS (2003)*. Harmonizing Structural Safety Levels with Life Quality Objectives. Canadian Journal of Civil Engineering, 30(3), 500-510.

Life-quality objectives are identified as an essential element in design decision making. Of particular concern is the question of optimal safety levels that are consistent with reasonable expectations of individuals in a present-day society. Using sound principles of decision analysis and utility theory, a lifetime utility function is developed. It is shown to be related to human consumption, life duration including the cumulative effects of mortality and discounting, and the relative amount of time spent on work versus leisure. Questions regarding the acceptability and affordability of changes in life quality can be addressed using the utility functions developed. As an application, design safety levels for the Confederation Bridge are examined and discussed. Life-quality objectives can also be included in a life-cycle cost optimization. This allows us to perform a level IV probabilistic design approach including costs and consequences without having to estimate the value of human life, but instead including the effect of consequences on changes in life quality of individuals at risk. This results in a useful tool to determine optimal limit state design safety levels, as is illustrated in a parametric analysis in the case of a single limit state.

105. *Manohar, C.S., Gupta, S.*, Modeling and evaluation of structural reliability: current status and future directions.

An overview of developments in selected areas in the field of structural reliability analysis is presented. The topics covered include probabilistic modeling of uncertainty that include discussions on non-Gaussian models, first and second order reliability methods, asymptotic analyses of the probability integral, simulation based techniques including variance reduction methods, system reliability analysis, time variant reliability analysis, probabilistic model reduction and importance measures, stochastic finite element method including discussions on simulation and discretization of Gaussian/non-Gaussian random fields, response surface methods, reliability analysis including structural nonlinearities, discussions on critical excitation models for uncertainty and robust reliability. The emphasis of the paper is on presenting a critical discussion on methods of reliability modeling and analysis and not so

much to explore specific application areas. A discussion on avenues for future research in the field concludes the paper.

106. **Miodrag, P. (2007).** Ocena integriteta betonskih konstrukcija na osnovu rizika. Integritet i vek konstrukcija. Vol. 7, No. 1. pp. 29-36.

107. **Narasimhan, H., Borg, R.P., Cacace, F., Zuccaro, G., Faber, M.H., De Gregorio, D., Faggiano, B., Formisano, A., Mazzolani, F.M.. (2010).** Modeling and Evaluation of Structural Reliability). A framework and Guidelines for Volcanic Risk Assessment. Urban

The risk management of natural hazards is a complex issue often due to very significant potential consequences and substantial uncertainties. A framework for risk based decision making in the field of engineering is first described in this paper. This framework is then applied for the risk assessment of volcanic hazards. Towards this end, aspects related to the modeling of the hazard process due to volcanoes are described. A system of classification of structures and identification of different building characteristics that could be used for volcanic vulnerability and risk assessment is then proposed. This is followed by a discussion on the fragility and vulnerability modeling of structures. Finally, general issues concerning the evaluation of risks and their treatment and communication are discussed.

108. **Narasimhan, H., Faber, M.H. (2009).** Categorisation and Assessment of Robustness Related Provisions in European Standards. Joint Workshop of COST Actions TU0601 and E55. pp. 147-164.

A fundamental aim of modern codes of practice is to provide a suitable basis for the design of structures that ensures adequate structural safety with efficient and cost effective material use. The requirements necessary to fulfill this aim can be viewed to comprise of i) a standard safety format that incorporates models of material and structural behaviour and appropriate factors of safety, and ii) provisions to ensure adequate robustness. However, the provisions under these two categories are presently not separated in a clear and consistent manner in modern codes or standards. In order to enhance the general strategy for ensuring safety and robustness in structures, an effective understanding and systematic categorisation of the existing robustness related provisions in codes of practice is first necessary.

Towards this end, a review of European standards dealing with the design, execution, material aspects and maintenance of concrete and steel structures has been carried out. The robustness related provisions in these standards are identified and categorised using five fields related to different aspects of risk management in structures: approach to risk treatment, nature of risk control, relationship with event/exposure, manner of reducing risk, and the phase of the life cycle of the structure at which the provision is applicable. This categorisation provides a systematic and differentiated picture of the treatment of the robustness in European standards and also serves as a viable platform for the future establishment of improved or optimal provisions for robustness in structures.

109. **Nathwani, J.S., E. Sidall and N.C. Lind, Energy for 300 Years: Benefits & Risks,** Institute for Risk Research, University of Waterloo, Waterloo, Ontario, IRR, June 1992

The activities of human groups should produce the greatest expected net benefit among realistic alternatives. Any activity results in some benefits and some detriments and these are intertwined; net benefit is the excess of the benefits over the detriments. Reduced safety is a detriment, among others; increased safety is a benefit, among others.

The net gain or loss of life expectancy is used as the measure of safety. In decision making, there can be no absolute certainties; however, the net benefit when estimated on reasonable expectations provides an effective criterion for judging alternative courses of action.

Life expectancy has increased in human societies as income and energy use have increased. It is a reasonable assumption that some fraction of the increase in life expectancy has resulted from the increase in energy use; estimation of this fraction permits the gain of life expectancy resulting from energy use to be calculated. The risks of various systems of energy supply are assessed and expressed as loss of life expectancy. Taking benefits and detriments of other kinds into account, the expected net benefit of each alternative is therefore assessed. Schemes which offer the greatest expected net benefit to society are proposed.

The future population of the world in three groups having high, medium and low incomes per person, and the demand for end use of energy in each group, are estimated from past and present trends. From these, the total world demand for end use of energy is estimated for the period up to 2300. Realistic alternative technologies and installations for meeting this demand are formulated. Most attention is devoted to the most important and promising alternatives. The total impact of each alternative (coal, oil, natural gas, hydro, nuclear, wind, solar, and conservation) is considered, and the important elements are assessed quantitatively. The expected net safety benefit of each is evaluated. This information is presented together with impacts which can only be expressed qualitatively.

Conclusions are:

- None of the major energy supply options present any important risk to human health and life. Not meeting the demand imposes the largest risk.
- Growth of population together with the desire to improve the social and economic well-being of people will result in a large gap between the supply and demand of oil and natural gas in a few decades.
- Major expansion of the world's coal supply would result in severe global warming. Positive steps to reduce the use of coal may thus become necessary in the longer term.
- Biomass, wind and solar are technically feasible but appear unattractive from environmental and economic considerations.
- Nuclear supply option confers the greatest expected net benefit.
- Free exploration of all energy options, if encouraged, would sustain the global needs over the very long term.

The overall conclusion is that the requirements for large scale production and use of energy, determined by growing populations of the world, can be managed and sustained over the long term. All energy generating options, if encouraged, can contribute to meeting the needs. The risks to human health and life associated with each of the major options for the supply of the needed energy are small in relation to the benefits that would accrue to the population.

110. *Nathwani J.S., N.C. Lind and E. Sidall*, Risk Benefit Balancing in Risk Management : Measures of Benefits and Detriments, in *The Analysis, Communication and Perception of Risk*, ed. John B. Garrick, *Advances in Risk Analysis Series*, New York: Plen.

111. *Nathwani, J.S. and Narveson, J., (1995)*. Three Principles for Managing Risk in the Public Interest, *International Journal of Risk Analysis*, vol. 15, No.6, pp 615-626.

We propose three principles and a general framework of reasoning for managing risk in the public interest. **Principle 1.** *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 sufficient and rational guide to assessing the effectiveness of efforts directed at reducing risk and thus improving health and safety. The net benefit of an activity is the excess of the totality of benefits over the totality of detriments. **Principle 2.** *The safety benefit to be promoted is life-expectancy*— The goal is to ensure that risk mitigation efforts maximize the net benefit to society in the specific terms of length of life for all individuals. The effect of an activity on life expectancy is proposed as the proper basic measure of its net safety impact. Life expectancy is a universal measure valid for comparisons both within and among countries and can be adjusted to include health expectancy and other factors such as income levels that affect the quality of life. The impact on life expectancy allows a dispassionate accounting of the good and the bad inherent in any proposal or activity that is in the public interest but has some impact on life and health. **Principle 3.** *Decisions for the public in regard to health and safety must be open and apply across the complete range of hazards to life and health*— Systematic efforts to evaluate *all* the important consequences, both direct and indirect, are required to improve the basis for risk management in society. Balancing of the detriments *and* the benefits of any given initiative is the key aspect of the undertaking. Safety may well be an important objective in society, but it is not the only one. Thus, allocation of society's resources devoted to safety must be openly and continually appraised in light of other competing social needs because there is a limit on the resources that can be expended to save lives. Maximization of healthful life for all is judged the proper basis for managing risk in the public interest, and that this is achieved when the net of the contribution to the total saving of life exceeds the loss of life.

112. *Nathwani, J.S. and N.C. Lind. (1992)*. Optimal Safety Levels via Social Indicators, Invited Paper, in *Risk Management- Expanding Horizons*, Proceedings of the American Nuclear Society, Boston, Mass., June 8-10, .See Transactions of the ANS, Ann.

In the management of natural or technological hazards in a society, the objective should be to serve the public interest in a rational manner. Decisions with regard to risk levels for the public - if they are to be defensible and self-consistent - require an integrated system of values that covers the entire range of hazards under public regulation. The process for setting risk levels (or safety goals) should ideally involve a thorough consideration of cost and benefit of all kinds, supported by explicit quantified comparison on a widely acceptable scale. The purpose of the paper is to show how quantitative criteria within the context of an appropriate framework can be used to guide risk management decisions. Social indicators are time series, statistics that reflect some aspect of the quality of life in a society or group of individuals. Development, validation, and use of social indicators is an important current research activity, as exemplified by journals such as *Social Indicators Research*. The basic objective is to provide quantitative measures for assessing the rationales and effectiveness of public decision-making. The concept is applicable to the nuclear industry.

113. *Nathwani, J.S. (2004)*. Strategic Principles for Managing Risk, Keynote Lecture, Proceedings of the 11th IFIP Conference Reliability and Optimization of Structural Systems, (eds.) Maes, M.A. and Huyse, L., pp. 13-22 .

The prospect of death and disease commands widespread attention resulting in much effort expended to reduce risk and promote safety. The principles described here are directed at decision-makers in government, industry and institutions responsible for the engineering and management of human safety.

The three principles are as follows:

- (i) Accountability - Decisions for the public in regard to health and safety must be open and apply across the entire range of hazards to life and health.
- (ii) Maximum Net Benefit - Risks shall be managed to maximise the total expected net benefit to society.
- (iii) Life Measure - The measure of health and safety benefit is the expectancy of life in good health.

There is sufficient evidence of erratic risk management resulting in large expenditures of resources that do not appreciably reduce risk. The challenge is to ensure consistency between different efforts to control risk through a rigorous assessment of the effectiveness of life-saving schemes. Maximising life expectancy in good health as the proposed indicator is considered to be a sufficient and rational guide for judging the effectiveness of interventions for improving health and safety. The principles provide a defensible philosophical basis and a robust framework of reasoning for the management of risk in society.

114. **Nathwani, J.S., Lind, N.C. and Pandey, M.D. (1997).** Affordable Safety by Choice: The Life Quality Method. Institute for Risk Research, University of Waterloo, Waterloo, Ontario, pp.230.

. . . We consider the problems of managing risks responsibly on behalf of others. 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 Jill 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 detracts from the objective and cannot be justified.

115. **Nathwani, J.S., Lind, N.C. and Pandey, M.D. (2008).** The LQI standard of practice: optimizing engineered safety with the Life Quality Index, *Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance*, vol. 4, Issue 5.

This paper describes a standard of practice for optimizing engineered safety. The objective in managing risk is to ensure that significant risks are identified and appropriate actions taken to minimize these risks to a reasonably low level. Engineered safety is always determined on the basis of a balance between the cost effectiveness of risk control and the benefits arising from

the mitigation of risk. For the net benefit to be positive, whether it accrues to the organization or to society at large, the management of risk entails a process of priority setting, as there are limits on available resources. The net benefit is measured by the consequent increment to the Life Quality Index (LQI). With this approach, enterprises, both public and private, have a more confident and rigorous basis for decision-making and planning engineering projects when life safety is a concern. The evaluation process, the requirements for data to support the analysis, and the major components of the LQI model are illustrated by specific examples. The goal is to promote a fully transparent process, with risk communication integrated at each step, to ensure consistency in practice.

116. *Nathwani, J.S., Pandey, M.D. and Lind, N.C. (2005)*. A standard for determination of optimal safety in engineering practice. Proc. IFIP Conference, pp.1-8. May 23-25, Aalborg, Denmark.

A "Draft" standard, based on an application of the Life Quality Index (LQI), is proposed for the determination of optimal safety levels in engineering practice. This paper provides a basis for the development of a uniform universal standard for the assessment and evaluation of safety practices. The specific focus herein is on structural safety. The requirements, the tools and the methods relevant for a decision-maker to make an informed judgment about allocating the correct level of expenditure that optimizes safety are described. The evaluation process, the requirements for relevant data to support the analysis, and the major components of the LQI model are illustrated by specific examples.

The objective of risk management is to ensure that significant risks are identified and appropriate actions are taken to minimize these risks to a reasonably low level. In general, such actions are determined on a balance of the cost of risk control strategies, their effectiveness and the benefits to the organization tasked with implementing a project. Management of risk thus entails priority setting due to limits on available resources. This standard is the first step in the evolution of engineering practices that explicitly provides a transparent basis for making consistent decisions.

117. *Nathwani, J.S. and Lind, N.C.*, Determination of Risk Tolerability from Social Indicators, in Proceedings of the European Safety and Reliability (ESREL) Conference 93, May 10th-12th, Munich, Germany., Elsevier Applied Science Publisher, 1994.
118. *Nathwani, J.S., Lind, N.C., E.Sidall*, Safety, Social Well-Being and Its Measurement, in Proceedings of 1st World Congress on Safety Science, Cologne, Germany, Sept 24-26, 1990, Living in Safety, ed. Albert Kuhlmann, Verlag TUV Rheinland GmbH,
119. *Nishijima, K., Faber, M.H. (2007)*. Societal optimal performance of infrastructure subject to natural hazards. International Forum on Engineering Decision Making.

The present paper proposes a methodology for assessing the effect of different design and maintenance policies for infrastructure on societal economic growth. The approach adopted takes basis in the general economic theories and economic models and provides an interface between economics and civil engineering with which the engineering knowledge can be reflected in the economic models. The proposed methodology can be utilized by societal decision makers to identify the optimal investments into infrastructure for ensuring sustainable societal development. An illustrative example is provided considering sustainable decision making in regard to design and maintenance of infrastructure subject to natural

hazards. Thereby the advantage of the proposed methodology is shown; it enables to analyze the economic growth and the economic stability corresponding to different design and maintenance policies for infrastructure.

120. *Nishijima, K., Maes, Marc., Goyet, J., Faber, M.H. (2009)*. Constrained optimization of component reliabilities in complex systems. *Structural Safety*. Vol 31, Issue 2. pp 168-178.

The present paper proposes an approach for identifying target reliabilities for components of complex engineered systems with given acceptance criteria for system performance. The target reliabilities for components must be consistent in the sense that the system performance resulting from the choice of the components' reliabilities satisfy the given acceptance criteria, and should be optimal in the sense that the expected utility associated with the system is maximized. To this end, the present paper first describes how complex engineered systems may be modelled hierarchically by use of Bayesian probabilistic networks and influence diagrams. They serve as functions relating the reliabilities of the individual components of the system to the overall system performance. Thereafter, a constrained optimization problem is formulated for the optimization of the component reliabilities. In this optimization problem the acceptance criteria for the system performance define the constraints, and the expected utility from the system is considered as the objective function. Two examples are shown: (1) optimization of design of bridges in a transportation network subjected to an earthquake, and (2) optimization of target reliabilities of welded joints in a ship hull structure subjected to fatigue deterioration in the context of maintenance planning.

121. *Nishijima, K., Maes, M.A., Goyet, J., Faber, M.H. (2009)*. Constrained optimization of component reliabilities in complex systems. *Structural Safety*. Vol. 31. pp. 168-178.

The present paper proposes an approach for identifying target reliabilities for components of complex engineered systems with given acceptance criteria for system performance. The target reliabilities for components must be consistent in the sense that the system performance resulting from the choice of the components' reliabilities satisfy the given acceptance criteria, and should be optimal in the sense that the expected utility associated with the system is maximized. To this end, the present paper first describes how complex engineered systems may be modelled hierarchically by use of Bayesian probabilistic networks and influence diagrams. They serve as functions relating the reliabilities of the individual components of the system to the overall system performance. Thereafter, a constrained optimization problem is formulated for the optimization of the component reliabilities. In this optimization problem the acceptance criteria for the system performance define the constraints, and the expected utility from the system is considered as the objective function. Two examples are shown: (1) optimization of design of bridges in a transportation network subjected to an earthquake, and (2) optimization of target reliabilities of welded joints in a ship hull structure subjected to fatigue deterioration in the context of maintenance planning.

122. *Nishijima, K., Maes, M., Goyet, J., Faber, M.H.. (2007)*. Optimal Reliability of Components of Complex Systems Using Hierarchical System Models. *Special Workshop on Risk Acceptance and Risk Communication*.

The present paper addresses the issue of optimization of reliability acceptance criteria for components of complex engineered systems with given criterion to acceptable system risk. To this end, the paper first describes how complex engineered systems may be modelled

hierarchically by use of Bayesian probabilistic networks. The Bayesian probabilistic network serves as a function relating the reliability acceptance criteria of the individual components of the system to the risk acceptance criteria for the system. Thereafter, a constrained optimization problem is formulated for the optimization of the component reliabilities. In this optimization problem the system risk acceptance criterion defines the constraint and the expected utility from the system, is considered as the objective function. A ship hull structure is taken as an example of a complex engineered system to illustrate how the proposed framework may be implemented into a software tool using commonly available techniques and algorithms.

123. *Nishijima, K., Straub, D., Faber, M.H. (2006)*. Sustainable Decisions for Life-Cycle Based Design and Maintenance. Australian Journal of Civil Engineering.

General aspects of sustainable decision making are investigated and a possible formulation of socio-economical sustainable decision making is illustrated on the problem of life-cycle based design and maintenance of civil engineering facilities. First an overview is given on the present understanding of sustainability indicators and on available theoretical and methodical frameworks for including such indicators in sustainable decision making. Thereafter basic principles of sustainable decision making are suggested by defining the “rules” for optimizing decisions that are made at present but may have consequences in the future. A decision-theoretical framework is then formulated which allows for modeling the interaction between intra-generational decision making and inter-generational decision making, utilizing the recently developed concept of agent based systems representation. The suggested framework is general but is here illustrated on the specific and simple decision problem related to life-cycle based design and maintenance of civil engineering facilities. For this problem, sustainable decisions are identified through minimization of the joint economical consequences for the present and future generations related to design and maintenance over the life cycle of such facilities. The suggested approach is demonstrated on a specific example considering the optimization of a concrete structure subject to chloride induced corrosion of the reinforcement.

124. *Paik, J.K., Brennan, F., Carlsen, C.A., Daley, C. Garbatov, Y., Ivanov, L., Rizzo, C.M., Simonsen, B.C., Yamamoto, N.Y., Zhuang, H.Z. (2006)*. Condition Assessment of Aged Ships. 16th INTERNATIONAL SHIP AND STRUCTURES CONGRESS

125. *Pandey, M.D, Nathwani, J.S. (2004)*. Discounting models and the Life-Quality Index for the Estimation of Societal Willingness-to-pay for Safety. Reliability and Optimization of Structural Systems. London, UK. pp 87-94.

The engineering and management of human safety is an important societal objective that includes extensive efforts by governments, both legislative and administrative, to enhance the health and safety of the public. Although the achievement of safety goals depend primarily on individuals and organizations responsible for safety, much support is drawn from expertise in diverse scientific and engineering disciplines. The activities range from structural safety (dams, tunnels, bridges to tall buildings) to safe operation of hazardous industrial installations (energy generation facilities, LNG terminals, petrochemical plants) to transportation systems (airline, rail, car safety) to technologies designed to minimize adverse impacts on the environment. All these activities are crucially concerned with risk: with the likelihood and the probable effects of various measures on life and health. We have developed a unified rationale and a clear basis for effective strategic management of risk across diverse sectors. Safety is an

important objective in society but it is not the only one. The allocation of society's resources devoted to safety must be continually appraised in light of competing needs, because there is a limit on the resources that can be expended to extend life. The paper presents the Life Quality Index (LQI) as a tool for the assessment of risk reduction initiatives that would support the public interest and enhance safety and quality of life. The paper provides an intuitive reformulation of the LQI as equivalent to a valid utility function that is consistent with the principles of rational decision analysis. The LQI is further refined to consider the issues of discounting of life years, competing background risks, and population age and mortality distribution. The LQI is applied to quantify the societal willingness-to-pay, which is an acceptable level of public expenditure in exchange for a reduction in the risk of death that results in improved life-quality.

126. **Pandey, M.D. and Nathwani, J.S. (1997).** Measurement of Socio-Economic Inequality using the Life-Quality Index. *J. Social Indicators Research*, 39 (2), 187-202.

As income inequality presents a narrow view of overall inequality prevailing in a society, the paper focuses on its much broader definition, referred to as socio-economic inequality, which considers the disparities in income as well as in mortality, and standard of living. The paper presents a new method for measuring the socio-economic inequality using a composite social indicator, Life-Quality Index, derived from two principal indicators of development, namely, the Real Gross Domestic Product per person and the life expectancy at birth. Income inequality and the associated life expectancy variations are integrated into a quality adjusted income (QAI), to account for the observed differentials in life-quality of various quintiles of the population. The Gini coefficient of the distribution of QAI is introduced as a measure of socio-economic inequality. The proposed approach is illustrated using data on life expectancy of five income quintiles in urban Canada. It is found that the magnitude of inequality in Canada is higher than that reflected by the traditional measure, the Gini coefficient of income.

127. **Pandey, M.D. and Nathwani, J.S. (2003).** A Conceptual Approach to the Estimation of Societal Willingness-to-Pay for Nuclear Safety Programs. *Int. J. Nuclear Engineering and Design*, 224(1).

The design, refurbishment and future decommissioning of nuclear reactors are crucially concerned with reducing the risk of radiation exposure that can result in adverse health effects and potential loss of life. To address this concern, large financial investments have been made to ensure safety of operating nuclear power plants worldwide. The efficacy of the expenditures incurred to provide safety must be judged against the safety benefit to be gained from such investments. We have developed an approach that provides a defensible basis for making that judgement. If the costs of risk reduction are disproportionate to the safety benefits derived, then the expenditures are not optimal; in essence the societal resources are being diverted away from other critical areas such as health care, education and social services that also enhance the quality of life. Thus, the allocation of society's resources devoted to nuclear safety must be continually appraised in light of competing needs, because there is a limit on the resources that any society can devote to extend life.

The purpose of the paper is to present a simple and methodical approach to assessing the benefits of nuclear safety programs and regulations. The paper presents the Life-Quality Index (LQI) as a tool for the assessment of risk reduction initiatives that would support the public interest and enhance both safety and the quality of life. The LQI is formulated as a utility function consistent with the principles of rational decision analysis. The LQI is applied to

quantify the societal willingness-to-pay (SWTP) for safety measures enacted to reduce of the risk of potential exposures to ionising radiation. The proposed approach provides essential support to help improve the cost–benefit analysis of engineering safety programs and safety regulations.

128. **Pandey, M.D. and Nathwani, J.S. (2003).** A Reinterpretation of Life-Quality Index for Cost-Benefit Analysis of Safety Programs. Proc. Int. Conf. Application of Statistics and Probability in Civil Engineering (ICASP 03), Der Kiureghian A., M.

The engineering and management of human safety is an important societal objective that includes extensive efforts by governments, both legislative and administrative, to enhance the health and safety of the public. Although the achievement of safety goals depends primarily on individuals and organizations responsible for safety, much support is drawn from expertise in diverse scientific and engineering disciplines. The activities range from structural safety to safe operation of hazardous industrial installations to transportation systems to technologies designed to minimize adverse impacts on the environment. All these activities are crucially concerned with risk: with the probability and the possible effects of various measures on life and health. We have developed a unified rationale and a clear basis for effective strategic management of risk across diverse sectors. The paper presents the Life Quality Index (LQI) as a tool for the assessment of risk reduction initiatives that would support the public interest and enhance safety and quality of life. The paper provides an intuitive reformulation of the LQI as equivalent to a valid multi-attribute utility function that is consistent with the principles of rational decision analysis. The LQI is further refined to consider the issues of discounting of life years, competing background risks, and population age and mortality distribution. The LQI is applied to quantify the societal willingness-to-pay, which is an acceptable level of public expenditure in exchange for a reduction in the risk of death that improves life-quality.

129. **Pandey, M.D. and Nathwani, J.S. (2003).** Canada Wide Standard for Particulate Matter and Ozone: Cost-Benefit Analysis using a Life-Quality Index. Int. J. Risk Analysis, 23(1), 55-67.

This paper considers the application of Bayesian probabilistic networks (BPNs) to large-scale risk based decision making in regard to earthquake risks. A recently developed risk management framework is outlined which utilises Bayesian probabilistic modelling, generic indicator based risk models and geographical information systems. The proposed framework comprises several modules: A module on the probabilistic description of potential future earthquake shaking intensity, a module on the probabilistic assessment of spatial variability of soil liquefaction, a module on damage assessment of buildings and a fourth module on the consequences of an earthquake. Each of these modules is integrated into a BPN. Special attention is given to aggregated risk, i.e. the risk contribution from assets at multiple locations in a city subjected to the same earthquake. The application of the methodology is illustrated on an example considering a portfolio of reinforced concrete structures in a city located close to the western part of the North Anatolian Fault in Turkey.

130. **Pandey, M.D. and Nathwani, J.S. (2003).** Life-Quality Index for the Estimation of Societal Willingness-to-Pay for Safety. J. Structural Safety, 26(2), 181-199.

The engineering and management of human safety is an important societal objective that includes extensive efforts by governments, both legislative and administrative, to enhance the health and safety of the public. Although the achievement of safety goals depend primarily on

individuals and organizations responsible for safety, much support is drawn from expertise in diverse scientific and engineering disciplines.

The activities range from structural safety (dams, tunnels, bridges to tall buildings) to safe operation of hazardous industrial installations (energy generation facilities, LNG terminals, petrochemical plants) to transportation systems (airline, rail, car safety) to technologies designed to minimize adverse impacts on the environment. All these activities are crucially concerned with risk: with the likelihood and the probable effects of various measures on life and health. We have developed a unified rationale and a clear basis for effective strategic management of risk across diverse sectors. Safety is an important objective in society but it is not the only one. The allocation of society's resources devoted to safety must be continually appraised in light of competing needs, because there is a limit on the resources that can be expended to extend life. The paper presents the Life Quality Index (LQI) as a tool for the assessment of risk reduction initiatives that would support the public interest and enhance safety and quality of life. The paper provides an intuitive reformulation of the LQI as equivalent to a valid utility function that is consistent with the principles of rational decision analysis. The LQI is further refined to consider the issues of discounting of life years, competing background risks, and population age and mortality distribution. The LQI is applied to quantify the societal willingness-to-pay, which is an acceptable level of public expenditure in exchange for a reduction in the risk of death that results in improved life-quality.

131. **Pandey, M.D. and Nathwani, J.S. (2004).** Discounting Models and the Life-Quality Index for the Estimation of Estimation of Societal Willingness-to-Pay for Safety. Proc. 11th IFIP Conference Reliability and Optimization of Structural Systems.

The allocation of society's resources devoted to safety must use continually appraised in light of competing needs, because there is a limit on the resources that can be expended to extend life. The Life-Quality Index (LQI) has been shown to be an effective tool for the assessment of risk reduction initiatives that would support the public interest and enhance safety and quality of life. The selection of discounting rate is a critical element of decision analysis, especially in the context of long-term risk abatement programs. A controversial feature of the classical exponential discounting is that it leads to drastically low net present value of the benefits of a long-term program. To overcome this limitation, the paper presents a time-variant hyperbolic discounting model, which incorporates a higher rate of discount in the short-term and a smaller rate in the long term. The approach is consistent with empirical evidence about the inter-temporal decisions of consumers: The LQI model is further refined with a time-variant discount rate model and applied to quantify the societal willingness-to-pay for safety.

132. **Pandey, M.D. and Nathwani, J.S. (2007).** Foundational Principles of Welfare Economics Underlying the Life Quality Index for Efficient Risk Management. Int. J. Risk Assessment and Management, Vol. 7, Nos. 6/7, 2007, 862-883.

The paper provides the philosophical foundation and clarifies the methodological assumptions that form the basis of the Life Quality Index (LQI) as an innovation to promote efficient risk management practices. The basic premise is that enhancement of life safety is a fundamental human value. The LQI draws into account key social indicators as identified in the UN Human Development Reports with significant emphasis on income and life expectancy. The paper shows that the LQI model is in harmony with well-established principles of welfare

economics as highlighted in the literature on economics and human development. Furthermore, the derivation of the LQI is shown to be consistent with the key operational requirements of utility theory and econometric modelling. The LQI has potential to be an effective and versatile tool to support social and economic cost-benefit analysis of engineering projects that have consequential impacts on individual welfare and the quality of life.

133. **Pandey, M.D. (2005).** A discussion of derivation and calibration of the Life-Quality Index. Proc. 9th Int. Conf. Structural Safety and Reliability, ICOSSAR, pp.1-8. June 22-25, 2005, Rome, Italy.

134. **Pandey, M.D., Nathwani, J.S. and Lind, N.C. (2006).** The Derivation and Calibration of the Life Quality Index (LQI) from Economic Principles. J. Structural Safety, 28 (4), 341-360.

The life-quality index (LQI) is a versatile tool to support the effective implementation of programs and practices for managing risk to life safety. The LQI allows a transparent and consistent basis for determination of the net benefit arising from projects, programs, standards and policies undertaken at some cost to improve safety or enhance the quality of life. The paper shows that the LQI model is in harmony with well-established principles of economics, utility theory and recent developments to quantify the progress of nations through indicators of human development. The initial calibration of the LQI was based on a simplifying assumption of a linear relation between the GDP and work time. In this paper, we modify the calibration using empirical data for GDP and work time and link the LQI model to well-established economic principles and theory of production. The proposed improvements to the model eliminate a systematic bias associated with estimation of societal willingness to pay for safety. In addition, it provides a rigorous basis for program evaluation to assist decision-makers in directing expenditures where they may most effective.

135. **Pandey, M.D., Van Noortwijk, J.M. and Klatter, H.E. (2006).** The Potential Applicability of the Life-Quality Index to Maintenance Optimisation Problems, pp. 1-8. Proc. IABMAS Conference, Lisbon Portugal.

136. **Pavisc, M. (2006).** Risk Based Integrity Assessment of Concrete Structures. FRACTURE OF NANO AND ENGINEERING MATERIALS AND STRUCTURES. pp. 1067-1068.

Damage process initiation and propagation in concrete structures is a time dependant phenomena, with the negative implication to the structure load bearing capacity, decreasing its overall resistance and as a final consequence, decreasing degree of structural safety and reliability. Previous, deterministic procedure of the assessment of concrete structures is extensive and conservative, leading to rather subjective engineer decision making, to the conclusions without right answer about the real degree of structural safety and to the implementation of non-optimal reparation procedures. In the paper, it is proposed the probabilistic approach which on the basis of previous analysis of structural critical elements and virtual structure failure mechanism, adopting corresponding limit state, determines the probability of reaching the limit state and based on the expected negative consequences, determines degree of risk which the structure is exposed to. As an example, the procedure is applied to the pre-stressed concrete highway bridge integrity assessment. The bridge was heavily damaged during NATO bombing of Yugoslavia and an urgent decision about the right

measures for the bridge reparation was quickly requested. Applying Monte Carlo method for the proposed limit state of the bridge structure, degree of risk is calculated and the right decision was made.

137. *Pliefke, T., Peil, U. (2008)*. On the Integration of Equality Considerations into the Life Quality Index Concept for Managing Disaster Risk. *Beton- und Stahlbetonbau*. Vol. 103, Issue Supplement 1. pp. 57-64

Decisions about investments in public disaster risk mitigation projects are to be made in presence of many other investments a society could possibly perform. In order to derive a statement about the advantageousness of a particular disaster risk reduction initiative in comparison to other potential investments, the cost of the intervention has to be put in relation to the expected benefits that go in line with it. The question if the benefits outweigh the cost entails a transformation of the primary non-monetary benefits due to disaster risk reduction into monetary units, where especially the valuation of reduced mortality risk can be conveniently assessed by applying the net benefit criterion derived from the life quality index (LQI). But as public risk reduction interventions usually involve a great variety of affected people, cost effectiveness is only one determinant in declaring a project as being socially beneficial. Only if the concept is widened to also account for the distributional consequences, i.e. the identification of winners and losers from the intervention, it can be guaranteed that a great number of individuals profit from the enhanced safety standards. This paper addresses this issue by extending the conventional net benefit criterion to also incorporating distributional effects in the decision process and demanding an equally distributed share of cost and benefits throughout society. Thus, in a welfare economic sense more comprehensive risk reduction acceptance criteria are derived.

138. *Pliefke, T., Peil, U. (2008)*. Die Bewertung gesellschaftlicher Risikoreduktionsmaßnahmen von Naturkatastrophen – Eine soziale Kosten Nutzen Analyse, Dissertation TU Braunschweig, <http://www.digibib.tu-bs.de/?docid=00033977>.

The cautious treatment of natural disaster risk constitutes a major challenge for governments of affected countries. In the evaluation of public risk reduction interventions it should always be warranted that the scarce invested means are allocated efficiently and thus possess the potential to increase social welfare. In the present thesis public risk reduction projects are considered as investments and are evaluated on basis of a social cost benefit analysis. In the first part of the thesis an innovative risk management framework is developed, that allows to systematically identify the social exposure to natural hazards and to quantify disaster risk probabilistically both before and after implementation of the risk reduction measure. The second focus of the thesis constitutes the economic evaluation of human safety. In particular, general cost benefit rules for pricing enhanced human safety on basis of the willingness to pay (WTP) concept are derived. Special emphasis is given on the Life Quality Index (LQI) concept, which has recently gained increasing attention as a risk management tool in civil engineering. For the latter a new time consistent derivation method is developed in a general equilibrium model that clearly reveals the economic reasoning behind the index. Based on this the conventional LQI based safety pricing rule is extended and improved in its calibration. In the last part of the thesis the concept of real options is firstly applied to the evaluation of public disaster risk reduction interventions and the traditional net present value criterion is replaced by more extensive decision rules in the presence of uncertainty. Eventually, a detailed case study for the seismic risk management of San Francisco based on the disaster

loss estimation program HAZUS demonstrates the practical applicability of the presented methodology.

139. **Progar, D. (2008).** Integrating Dutch Flood Policy Innovations into California Flood Policy. MS CE Plan II.
140. **Proske, D. (2008).** Quality of Life the Ultimate Risk Measure. CATALOGUE OF RISKS. pp. 379-460.
141. **Proske, D., van Gelder, P. Vrijling, H. (2008).** Some Remarks on Perceived Safety with Regards to the Optimal Safety of Structures. Beton-und Stahlbetonbau. Vol. 103, Issue Supplement 1. pp. 65-71.

The paper gives a critical view about the development and application of optimisation procedures for safety of structures. Optimisation techniques for safety of structures have experienced major progress over the last decade based on, for example, the introduction of quality of life parameters in engineering. Nevertheless still such models incorporate many major assumptions about the behaviour of human and societies. Some of the assumptions and limitations are mentioned in the paper in short. These assumptions heavily influence the outcome of such optimisation investigations and cannot be neglected in realistic scenarios. Therefore the authors advise against the application of such optimisation techniques under real world conditions. Finally examples are given to illustrate effects of individual and social behaviour under stressed situations, which are not considered in the optimisation techniques mentioned.

142. **Proske, D., van Gelder, P., Vrijling, H. (2007).** Perceived Safety with Regards to Optimal Safety of Structures. 5th International Probabilistic Workshop.
143. **Psarros, G., Skjong, R., Eide, M.S.. (2009).** The acceptability of maritime security risk. JOURNAL OF TRANSPORTATION SECURITY. Volume 2, Number 4, pp. 149-163.

The cost-effectiveness of security measures is of paramount importance to how society's resources are spent to protect against a range of possible future threats. Resources are limited and the challenge arises when deciding where to invest scarce resources in order to maximise benefits. In this respect, a criterion of averting a fatality is proposed for evaluating the effectiveness of maritime regulations concerning security issues. This criterion is derived in the same context as the one used when adopting safety regulations for the maritime industry. It is demonstrated that such kind of a decision criterion can be proposed with a value of \$6 million.

144. **Rabl, A., Nathwani, J., Pandey, M.D. and Hurley, F. (2003).** Tools and Strategies for Improving Policy Responses to the Risk of Air Pollution. Accepted for publication in Int. Conf. Strategies for Clean Air and Health. 5-7 November, Rome, I.

This paper offers a brief review of the need for cost-benefit analysis and the available policy instruments for assessing externality costs associated with air pollution. In order to prioritize different possible actions, one needs to know which source of pollution causes how much damage. This requires an impact pathway analysis, i.e. an analysis of the chain emission → dispersion → dose-response function → monetary valuation. The methodology for this is described and illustrated with the results of the ExternE (External Costs of Energy) project

series of the EC. The results include an exploration of the uncertainties. Two examples of an application to cost-benefit analysis are shown: in one case a proposed reduction of emission limits is justified, in the other not. The difference arises from differences in the technologies concerned by the proposed regulation. It is advisable to subject any proposed regulation to a cost-benefit analysis. Even if the uncertainties are large and a policy decision may have to take other considerations into account, a well-documented analysis clarifies the issues and provides a basis for rational discussion.

One of the main sources of uncertainty lies in the monetary valuation of premature mortality, the dominant contribution to the damage cost of air pollution. The widely used “value of statistical life” is not appropriate for air pollution, for several reasons. It is based on accidental deaths, very different from air pollution in nature and loss of life expectancy per death. The appropriate indicator of air pollution mortality is the reduction in life expectancy, necessitating a monetary value for a year of life lost due to pollution. Until recently there had been no studies of that and even now the available estimates are extremely uncertain. As an alternative an innovative policy tool, the Life Quality Index (LQI), for managing risk in the public interest is described. The LQI is a compound social indicator comprising societal wealth and life expectancy in good health. The use of LQI for valuation of mortality in the analysis of the efficacy of air pollution standards is presented and applied to the Canada-wide standards for particulate matter and ozone.

Regardless of monetary valuation, assessment of the potential health benefits of environmental policies has clearly shown the gain in life expectancy that could be achieved in Europe and North America if the concentration of PM10 is reduced by 50%: This translates into an increase in life expectancy for the population in the order of 4 to 5 months. This is a finding of enormous significance for improving public health.

145. *Rabl, A., Nathwani, J., Pandey, M.D. and Hurley, F. (2007). Improving Policy Responses to the Risk of Air Pollution. Journal of Toxicology and Environmental Health, Part A; 70 (3), 3.*

This paper offers a brief review of the need for cost-benefit analysis (CBA) and the available policy instruments for air pollution. To prioritize different possible actions, one needs to know which source of pollution causes how much damage. This requires an impact pathway analysis, that is, an analysis of the chain emission → dispersion → dose-response function → monetary valuation. The methodology for this is described and illustrated with the results of the ExternE (External Costs of Energy) project series of the European Commission. Two examples of an application to CBA are shown: one where a proposed reduction of emission limits is justified, and one where it is not. It is advisable to subject any proposed regulation to a CBA, including an analysis of the uncertainties. Even if the uncertainties are large and a policy decision may have to take other considerations into account, a well-documented CBA clarifies the issues and provides a basis for rational discussion. One of the main sources of uncertainty lies in the monetary valuation of premature mortality, the dominant contribution to the damage cost of air pollution. As an alternative, an innovative policy tool is described, the Life Quality Index (LQI), a compound indicator comprising societal wealth and life expectancy. It is applied to the Canada-wide standards for particulate matter and ozone. Regardless of monetary valuation, a 50% reduction of PMIO concentrations in Europe and North America has been shown to yield a population-average life expectancy increase on the order of 4 to 5 mo.

146. **Rackwitz, Rudiger. (2002).** Optimization and Risk Acceptability Based on the Life Quality Index. *Structural Safety*. Vol 24, Issue 2-4. pp 297-331.

Optimization techniques are essential ingredients of reliability-oriented optimal designs of technical facilities. Suitable objective functions are presented for different replacement strategies for structural facilities. Within FORM/SORM structural reliability analysis can be reduced to an optimization task and some simple algebra. However, instead of an optimization of cost on top of a optimization for the reliability task, a one-level optimization is proposed by adding the Kuhn–Tucker conditions of the locally stationary reliability problem to general cost-benefit optimization. For locally non-stationary failure phenomena a bilevel optimization must be used. A rational basis to account for the cost of saving lives based on the recently proposed Life Quality Index is presented. Several examples illustrate the methodology. # 2002. Published by Elsevier Science Ltd.

147. **Rackwitz, Rudiger, Streicher, Hermann.** Optimization and Target Reliabilities. *JCSS Workshop on Reliability Based Code Calibration*. Munich, Germany.

The engineering profession agrees that present design and quality assurance rules lead to sufficiently safe and economic structures although these rules have been developed widely by trial and error. If safety is quantified in probabilistic terms admissible risks are calibrated against present rules of practice. Unfortunately, large variations in admissible, calibrated risks are found and it is unclear whether the variations are the result of different risk acceptance attitudes or of economical considerations. Recently, two new concepts have led to new insights into the problem of risk acceptance and optimality. Formulating design as a decision problem under uncertainty where cost, benefits and expected failure consequences are included converted well-known reliability analysis into reliability-oriented optimization. If all failure consequences including losses of human life and limb are suitably introduced an optimal structure is also an admissible structure. The recently proposed life quality index (LQI) enables to quantify what is necessary and what is affordable for a society to invest into risk reduction. The life quality index is a function of the gross domestic product, the life expectancy at birth and the fraction of time necessary to raise the gross national product by work. It is applicable for the investments by the public into health care, into road traffic safety, into fire protection systems and, of course, to structural safety. Its differential form defines an acceptability criterion from a societal point of view in terms of relative changes in life expectancy and gross national product. Two types of optimizations can be performed, one in the public interest and the other in the owner's or operators' interest. Both will work with different benefit and interest rates but the optimization in the public's interest must include the cost for saving potentially endangered lives. The cost of risk reduction via a standard or regulation is all but easy to determine. It is necessary to quantify the effect of a risk reducing operation in terms of changes in life expectancy of a population. By some demographic considerations it is possible to derive a constant which relates changes in life expectancy to changes in mortality. The concept also allows us to define the upper and lower bound of the so-called ALARP region. The upper bound is derived from the differential LQI-criterion. The lower bound corresponds to the optimal solution. It can be shown that the upper bound almost always corresponds to economically suboptimal structures. Upper and lower bound, however, depend on the specific problem at hand, i.e. on the mechanical, on the stochastic context and on the specific cost efficiency of the safety related interventions.

148. **Rackwitz, Rudiger. (2001).** Optimizing Systematically Renewed Structures. *Reliability Engineering & System Safety*. Vol 73, Issue 3. pp 269-279.

149. **Rackwitz, Rudiger. (2003).** Risk Control and Optimization for Structural Facilities. IFIP Conference. pp 143-167
150. **Rackwitz, Rudiger. (2006).** The Effect of Discounting, Different Mortality Reduction Schemes and Predictive Cohort Life Tables on Risk Acceptability Criteria. Reliability Engineering & System Safety.

Technical facilities should be optimal with respect to benefits and cost. Optimization of technical facilities involving risks for human life and limb require an acceptability criterion and suitable discount rates both for the public and the operator depending on for whom the optimization is carried out. The life quality index is presented and embedded into modern socio-economic concepts. A general risk acceptability criterion is derived. The societal life saving cost to be used in optimization as life saving or compensation cost and the societal willingness-to-pay based on the societal value of a statistical life or on the societal life quality index are developed. Different mortality reduction schemes are studied. Also, predictive cohort life tables are derived and applied. Discount rates [γ] must be long-term averages in view of the time horizon of some 20 to more than 100 years for the facilities of interest and net of inflation and taxes. While the operator may use long-term averages from the financial market for his cost-benefit analysis the assessment of interest rates for investments of the public into risk reduction is more difficult. The classical Ramsey model decomposes the real interest rate (=output growth rate) into the rate of time preference of consumption and the rate of economical growth multiplied by the elasticity of marginal utility of consumption. It is proposed to use a relatively small interest rate of 3% implying a rate of time preference of consumption of about 1%. This appears intergenerationally acceptable from an ethical point of view. Risk-consequence curves are derived for an example.

151. **Rackwitz, Ruediger.(2004).** Optimal and Acceptable Technical Facilities Involving Risks. Risk Analysis. Vol 24, Issue 3. pp 675-695.
152. **Rackwitz, R. Joanni, A., Streicher, H. (2008).** Cost-Benefit Optimization and Risk Acceptability for Existing, Aging but Maintained Structures. Structural Safety. Vol 30, Issue 5. pp 375-393.
153. **Rackwitz, R. (1997).** Zuverlässigkeit und Lasten im konstruktiven Ingenieurbau. Skriptum TU München.
154. **Rackwitz, R. (2001).** Reliability Analysis - a review and Some Perspective. Structural Safety. Vol 23, Issue 4. Germany. pp 365-395.

Theory and methods of structural reliability are briefly summarized and reviewed, both in original and standard space. Some extreme examples demonstrate where and why these methods do not work. Importance sampling schemes for updating approximate probability estimates are described. Algorithmic problems are addressed. Some new fields of potential application are outlined. Most urgent is the development of suitable optimization procedures for structures. Finally, the question of acceptability is discussed and a concept for assessing acceptability limits is described.

155. **Rackwitz, R. (2002).** HOW SAFE IS SAFE ENOUGH? AN APPROACH BY OPTIMIZATION AND THE LIFE QUALITY INDEX. Proceedings of ASRANET Conference.
156. **Rackwitz, R. (2003).** Time Aspects in Applying the Life Quality Index to Structural Safety. Reliability and optimization of structural systems:proceedings of 10th IFIP WG7.5 Working Conference.pp. 2.
157. **Rackwitz, R. (2004).** Discounting for Optimal and Acceptable Technical Facilities Involving Risks. ICASP-9, July, 6-9, 2003, San Fransisco, CA Heron. Vol 49, No.2. pp 139-170.

Optimization of technical facilities involving risk for human life and limb require suitable discount rates both for the public and the operator depending for whom the optimization is carried out. Also, acceptability criteria based on the life quality index require a discount rate which is acceptable for the public. Discount rates must be long term averages in view of the time horizon of 20 to more than 100 years for the facilities of interest and net of inflation and taxes. Their effect on cost and benefits as well as on acceptance criteria is proportional to and, therefore quite remarkable. While the operator may use long term averages from the financial market for his cost-benefit analysis the assessment of interest rates for investments of the public into risk reduction is much more difficult. Most authors in economics propose values of 4 to 6%, even if applied to investments into long term ecological matters or public health care. The classical Ramsey model decomposes the output growth rate into the rate of time preference of consumption and the rate of economical growth multiplied by the elasticity of marginal utility of consumption. In the paper various implications of this model are discussed. It is found that the rate of time preference of consumption should be a little larger than the long term population growth rate if used for the determination of parameters in the acceptability criterion. The output growth rate on the other hand should be smaller than the sum of the population growth rate and the long term growth rate of a national economy which is around 2% for most industrial countries. Accordingly, the rate of time preference of consumption is close to zero, actually about 0.8%, which is also intergenerationally acceptable from an ethical point of view. It is also shown that given a certain output growth rate there is a corresponding maximum financial interest rate in order to maintain non-negativity of the objective function.

158. **Rackwitz R,** The Philosophy Behind the Life Quality Index and Empirical Verification,http://www.jcss.byg.dtu.dk/Publications/Risk_Assessment_in_Engineering.aspx.

The following memorandum collects and discusses most of the relevant material presently available for setting up rational risk acceptance criteria and risk reduction expenses. They are based on the so-called life quality index and utility considerations. The paper attempts to support all basic assumptions by empirical findings. Much of the material presented herein is not available elsewhere. The memorandum is meant to be the basis for practical decisions. Before starting we try to estimate the size of risk reductions we are going to discuss. Overall crude mortality (per year) is about 0.01 in industrial countries but only 3 in 10000 are not due to natural causes. If one subtracts from this number those deaths which are induced by voluntary risky activities (sports and some traffic accidents) and those which are unavoidable such as house accidents, climbing stairs, etc., then, the reduction of a mortality of about 0.0002 or less is the subject of our study. It may be a little larger because certain risks typical

for industrialized countries like air pollution are not separated out in the usual statistical records. Also, we estimate the result of a (crude) mortality reduction d_m /year in terms of increases in life expectancy d_e using a European life table. It is concluded that we are discussing small changes in mortality with changes in life expectancy between several days to a few years.

159. **Rackwitz, R. (2005).** Life quality index revisited, *Structural Safety*. Volume 26, Number 3. pp 276-278.
160. **Rackwitz, R. (2006).** Socio-economic Risk Acceptability Criteria. *Recent Developments in Reliability-based Civil Engineering*.
161. **Rackwitz, R. (2007).** Recent developments in risk acceptability for technical facilities. *International Journal of Risk Assessment and Management*. Vol. 7, Number 6-7. pp. 922-944.
162. **Rackwitz, R., Joanni, A. (2008).** Risk acceptance and maintenance optimization of aging civil engineering infrastructures. *Structural Safety*. Vol 31, Issue 3. pp 251-259.
163. **Rackwitz, R., Lentz, A. (2006).** Risk Acceptability for Aging but Maintained Series Systems. *Proceedings of IFED conference*.

Modern risk acceptability criteria for structures are based on the life quality index. This criterion is meant to apply to a stationary stream of failure events and the entire structure. Because building cost have to be raised at the construction time a suitable modification of the criterion is necessary. The specific conditions of aging and maintained structures have not been studied before. Also, the fact that most structural facilities consist of many, possibly spatially distributed components or sub-systems each of which can fail has not been considered so far. In the paper the implications of a rational risk acceptability criterion for aging but maintained structural components in series systems are discussed. It turns out that in this case the transient behavior of the failure rate needs to be considered and the (admissible) failure rate depends on the specific maintenance strategy. Clearly, this failure rate must be related to the whole system.

164. **Rackwitz, R., Lentz, A., Faber, M. (2005)** Socio-Economically Sustainable Civil Engineering Infrastructures by Optimization. *Structure Safety*. Vol 27, Issue 3. pp 187-229

Sustainability is an important requirement for civil engineering infrastructures, technically and financially. The financial aspects are discussed. It is proposed to select a design and maintenance strategy where structures are systematically renewed by reconstruction or repair. An appropriate objective function for cost-benefit analyses based on a renewal model is established. An intergenerationally acceptable discounting scheme is proposed. As infrastructures also involve risk to human life and limb a socio-economic acceptability criterion to be added as a constraint to cost-benefit analyses is derived. Various renewal models for deteriorating structures including multiple failure modes are discussed. The paper includes various examples illustrating the developed theory. (c) 2004 Elsevier Ltd. All rights reserved.

165. **Rackwitz R**, The Philosophy Behind the Life Quality Index and Empirical Verification, http://www.jcss.byg.dtu.dk/Publications/Risk_Assessment_in_Engineering.aspx.
166. **Rackwitz R**, Chapter 7. Acceptable safety levels by a socio-economic approach, Chapter 7, Safety and Reliability of Industrial Products, Systems and Structures, Guedes Soares C (ed.), CRC Press 2010, 75-84.
167. **Rae, A.J. (2007)**. Acceptable Residual Risk-Principles, Philosophies and Practicalities. System Safety. Volume 2. pp. 26-31.

Safety is typically demonstrated by identifying hazards, mitigating those hazards, and then by showing that the remaining risk is acceptable. This paper begins by setting out some principles for assessing tests of risk acceptability. It then categorises and examines existing methods of testing for risk acceptability against those principles, and finds that they fall short. A new measure of risk acceptability is proposed, the Minimum Industry Safety Return on Investment (MISRI). MISRI is an industry-specific measure, which complies with ALARP and with the principles espoused in the early part of this paper.

168. **Reisch, T. (2009)**. Ne vont-ils pas sauter dans le vide α un autre endroit? Bulletin des m \O decins suisses. 90, pp.747-748.
169. **Reisch, T. (2009)**. Ne Springen sie nicht statt dessen woanders? *Bulletin des m \e decins suisses*. pp.747-748.
170. **Rheinberger, C.M., Brundl, M., Rhyner, J. (2009)**. Dealing with the White Death: Avalanche Risk Management for Traffic Routes. Risk Analysis. Vol 29, Issue 1. pp. 76-94.
171. **Rizzo, CM, Paik, JK, Brennan, F. (2007)**. Current Practices and Recent Advances in Condition Assessment of Aged Ships. Ships and Offshore Structures. Vol. 2, pp. 261-271.
172. **Rizzuto, E., Sorensen, J.D., Kroon, I.B. (2009)**. Robustness-Acceptance Criteria. Joint Workshop of COST Actions TU0601 and E55. pp. 35-43.

The paper describes the general framework on the bases of which acceptance criteria for requirements on the robustness of structures can be set. Such framework is based on the more general concept of risk-based assessment of engineering systems. The present factsheet is to be seen in conjunction with the one on the theoretical framework for Robustness. In the present factsheet, the focus is on normative implications.

173. **Sanchez-Silva, Mauricio, Rackwitz, Rudiger. (2004)**. Socioeconomic Implications of Life Quality Index in Design of Optimum Structures to Withstand Earthquakes. Journal of Structural Engineering. Vol 130, pp. 969-977.

Structures should be optimal with respect to economic investment, benefits derived from their existence, expected consequences in case of failure, and the degree of protection to human life and limb. This paper presents the implications of a new optimization strategy for the seismic design of structures. A renewal model for the sequence of structural failures is used to define the objective function of optimizing the design of structures in seismic regions. The life

quality index, which is a compound social indicator, is included in the optimization for efficiency of the measures to save human lives. This criterion balances quality-adjusted life years saved against the associated cost to society. The results show that safety standards used in current practice in earthquake engineering should be reviewed in light of optimization of resources and saving human lives. They also show the importance of different socioeconomic characteristics in the definition of risk acceptability.

174. **Sanchez-Silva, M., Arroyo, O. (2005).** Comparing target spectral design acceleration values by using different acceptability criteria. *Structural Safety*. Volume 27, Issue 2. pp. 73-91.
175. **Sanchez-Silva, M., Rackwitz, R. (2004).** Implications of the Life Quality Index in the Seismic Design of Infrastructure Systems. Life-cycle performance of deteriorating structures:assessment, design and man. Pp 263-273
176. **Schubert, M., Faber, M.H., Baker, J. (2007).** Decision Making Subject to Aversion of Low Frequency High Consequence Events. Special Workshop on Risk Acceptance and Risk Communication.

The present paper focuses on the risk assessment of low frequency high consequence events. In current policies often risk aversion is introduced either to account for the behavior of the public or to include follow up consequences. It is discussed in detail whether the introduction of risk aversion in the context of normative decision making can lead to rational decisions. It is concluded that only a clear distinction between different kinds of consequences can lead to rational decisions which maximize the utility of the decision maker. A framework is presented that accounts for direct consequences and two different kind of indirect consequences. The framework facilitates a differentiated identification and treatment of risks and specifically addresses the modeling of possible consequences caused by the perception of adverse events by stakeholders.

177. **Straub, D., Lentz, A., Papaioannou, I., Rackwitz, R. (2011).** Life Quality Index for Assessing Risk Acceptance in Geotechnical Engineering. *ISGSR*.
178. **Streicher H and Rackwitz R,** Optimization with a LQI Acceptance Criterion, http://www.jcss.byg.dtu.dk/Publications/Risk_Assessment_in_Engineering.aspx.

This example collection covers some typical applications in structural reliability and discusses several important aspects. It is meant to be the basis by example applications for practicable acceptance criteria for structural codes. The first three examples show the influence of the interest rates in an optimization for the public or the owner, the optimal and acceptable solutions for different cost values and the importance of the coefficient of variation of the resistance and load variables. Especially in the first two examples a number of parameter studies are performed. The next example deals with the realistic design for the buckling of a reinforced concrete column. Two examples for the optimal design under reliability constraints for different load combinations of intermittent load processes will be evaluated. Finally, an example from earthquake engineering is included. The objective functions are based on a systematic reconstruction policy and a constant benefit rate.

179. **Schubert M,** Konzepte zur informierten Entscheidungsfindung im Bauwesen, <http://dx.doi.org/10.3929/ethz-a-005899492>.

Every decision maker tries to make optimal decisions with due consideration of her boundary conditions. In the field of economics, concepts have been developed in the recent decades which facilitate the identification, documentation and justification of the optimal decision alternative in many fields of human activity. These concepts have a large impact on many economic fields in our society since they build a sound foundation on optimal decision making. In the simplest case two different situations have to be compared: What is the *present state* and which influence has a *change*. Neither the present state nor the influence of a change is known precisely. Thus, decisions are always made under uncertainty. The calculation of the risk, defined as the expected value of the consequences, yields a direct possibility to compare different decision alternatives. Even though the definition of risk seems to be unique, the number of different methodologies and philosophies for risk assessment is large. This leads to a heterogeneous practice which makes it difficult to aggregate and compare risks and finally to identify the optimal decision alternative.

The aim of the thesis is to contribute to the development of a uniform basis for risk assessment in civil engineering. Principles of a sound risk assessment are summarized; aspects concerning the consideration of uncertainties, the modeling of consequences and the consideration of risk aversion are highlighted and discussed. The modeling of a system is a major part in risk assessment and decision making. A formalized indicator based approach for system representation is presented. It is proposed to describe every system by using three hierarchical levels: the exposure, the vulnerability and the robustness. The methodology allows the direct consideration and quantification of different system characteristics. Quantities are developed to describe the behavior of the system in different situations and under different conditions. The formalized indicator based system characterization also allows for the hierarchical modeling of portfolios of assets. It is shown how dependencies in a portfolio can be modeled and considered. Conditions that lead to dependencies in portfolios and how these dependencies influence the distribution of the risk are discussed.

The disadvantage of generic indicator based models lies in the fact that the establishment of these models is computationally expensive and time consuming. However, once established they offer the possibility to perform the risk assessment for a large number of objects with similar characteristics. Within this thesis a software tool for risk assessment of rockfall protection galleries was developed to illustrate how models can be established in the future for other areas in order to assist decision makers in practice.

The focus of risk assessment in the built environment is often set on personal safety and on the conflict to justify decisions in regard to the investment in personal safety. Theoretical foundations in this field have already been developed; though the steps towards a wide application in practice have not been demonstrated yet. These theoretical foundations are shown and a method to apply these concepts in practice is presented.

180. **Shang, Z., Liu, X. (2010).** Acceptable Risk and Disaster Research. Progress in Geography. Vol. 29. Issue 1. pp. 64.
181. **Skjong, R. (2009).** Regulatory Framework. *Risk-Based Ship Design: Methods, Tools, and Applications*. pp 97- 135
182. **Skjong, R., Ronold, K.O. (2004)** Criteria for Cost Effectiveness of Safety Measures. J. Offshore Mech. Arct. Eng. Vol. 126, Issue 1. pp. 129-135

183. *Tan, H.Z. (2006)*. Research Development and Trends on Disaster Epidemiology. <http://journal.9med.net/qikan/article.php?id=183985>.
184. *Tesfamariam, S., Sanshez-Silva, M. (2011)*. A model for earthquake risk management based on the life-cycle performance of structures. *Civil Engineering and Environmental Systems*. Vol. 28, Issue 3. pp. 261-27.
185. Trans-national Governance of Global Catastrophic Risks, <http://wholeandnotwhole.wordpress.com/2011/04/07/trans-national-governance-of-global-catastrophic-risks/#comments>.

The paper argues that the traditional approach of risk management, with its tendency to focus on risk assessment of individual hazard phenomena – be that natural hazards, acts of malevolence or health hazards – comes short of addressing the decision-making process in the context of risk governance on issues related to sustainable development and management of societal resources from a holistic and long-term perspective.

To account for a perceived disconnect between societal preferences and available knowledge, the paper suggests that risk-informed societal decision-making should be based on a normative procedure whereby risks are quantified and qualified in the sense of loss of expected utility, taking into account cognitive biases associated with the perception of what constitutes risk. This, the author proposes, should be done in two steps: (i) identifying societal preferences and the utilities associated with them and (ii) bearing in mind the uncertainties associated with a given decision problem, estimating the expected value of utility for each decision alternative. Hence, risk management is seen through the prism of “bookkeeping” potential losses by an envisaged centralized supranational authority tasked with the governance of global catastrophic risks.

Following a discussion of a taxonomy of categories used to classify different risks, the paper identifies three types of risk that would fall under the managing authority of the above supranational institution: (i) Type I: foreseeable large scale averaging events, (ii) Type II: “seepage” events resulting in continuous losses with generally unnoticed (and unforeseeable – my addition) intensities, and (iii) Type III: unforeseeable or low probability high impact events.

Subsequently, the paper examines various challenges associated with the management of each type of risk, including suboptimal public-private cooperation in methodology and the use of tools for the treatment of risks, lack of consensus among experts on basic principles of risk assessment and best practices, insufficient or inappropriate education about risk assessment at the level of decision-making, present ad hoc decision processes regarding prioritization of resources for global life safety risk reduction, and finally insufficient inclusion of issues related to sustainability in normative decision-making processes.

To address these challenges, the paper concludes with a proposal for a framework for risk-informed decision-making, providing a structure for a system representation at a relevant scale to the decision problem, a systematic approach to information and knowledge management, a method for resource allocation for the reduction of life safety risks using the

Life Quality Index (LQI), and the establishment of a global risk governance institute for the purpose of research and governance of risks of global concern.

How do events of natural hazards affect societies locally and globally? Thoughts on scale

With the Westphalian state now in long-term decline, both the relative and absolute decline in state power will continue to accelerate, taking us into an environment characterized on one hand by disorder and failed states, and on the other by the rise of (mega) cities as concentrations of economic and political power – a world order not unlike the one dominating the Middle Ages when cities, not nations, were the building blocks of social, economic and political structures. With global politics characterized by fragmented political authority, the state is simply one of many agents of governance, and not the most effective one at that. In particular, the inability of (weak) states to meet the needs of their citizens not only in times of natural disasters or conflict but also in times of relative stability, urbanization and the rise of megacities as alternatively governed spaces, redefinition of geopolitical borders along physical geographic and regional boundaries as well as resource scarcity are all factors that are likely to interact in a manner where simple local vs. global issues of governance, resource management and security and disaster management would have to be addressed on a different scale than the local-global polarity.

Looking at urbanization and the rapid growth of megacities for a model of governance that retains both local and global socio-economic and juridical elements could turn out to be not only a viable alternative but also crucial to the understanding of emergent multi-polar, non-state actor global power system comprised of city hubs, mega corporations, regional politico-economic alliances such as the Shanghai Cooperation Organisation (SCO) and the Association of Southeast Asian Nations (ASEAN) or symbolic power blocs of the BRIC type (Brazil, Russia, India, China). In a world dominated by multi-polar power structures, an organization of the UN type promoting values of multilateralism among nation states at best and being grossly inefficient under the weight of its bureaucracy at worst, lacks the capacity to deal with issues related to the global governance of risks affecting society as a whole such as climate change, trade liberalization, etc. The failure to reach consensus and implement actionable plans at the 2009 Copenhagen summit or the stalled Doha rounds are a clear indication that new and more agile bodies will inevitably come to replace it.

Where the UN lacks fitness and is showing clear signs of political fatigue, new entrepreneurial frameworks, based on urban, regional and geopolitical interests and relations, including transnational organized crime networks, are quickly filling the gap. However, while they offer the attraction of economic growth and wealth, they also potentially endanger public welfare in a number of ways from creating an even larger gap in wealth distribution to increasing the exposure and vulnerability of an ever increasing number of urban dwellers to a host of natural and man-made and health-related hazards. Thus, while the author of the paper “Critical Issues in the Management of Catastrophic Risks” correctly identifies a serious shortcoming in the focus of traditional risk assessment and risk management approaches treating risks as localized phenomena, characterized by their particular physical properties rather than by their inter-related impacts, his proposed solution for a centralized global governing body fails to account that power (economic and political) distribution as witnessed in the decline of nation states and the rise of jurisdictionally overlapping spaces (of which cities are an example) seem to be defying a linear concept of time, of which the industrial 19th century was so fond of, and taking us “back to the future” toward a Middle Age

Renaissance of urban power centers. This brave new world is unlikely to be one of a global village utopia, rather a dystopia of a network of different ones.

According to the 2010 Global Cities Index (a collaboration between Foreign Policy magazine, management consulting firm A.T.Kearney and the Chicago Council on Global Affairs), the seats of traditional political power aren't necessarily the most global, with only four of the top 10 cities being national capitals (London, Tokyo, Paris and Seoul) and two being laws unto themselves (Hong Kong and Singapore). To define "global", the Index uses indicators such as business activity, human capital, information exchange, cultural experience and political engagement. In an article for the September/October 2010 edition of Foreign Policy, Parag Khana puts forth the argument that in the advent of global megacities, we need to reassess whether state sovereignty or economic might is the prerequisite for being seen a relevant actor in global diplomacy. While he doesn't discount the individual importance of either, he points out that eroding state sovereignty is offering cities a competitive advantage on the market for global influence. In this context he also sees the UN as "an even more inadequate symbol of universal membership in our global polity" and proposes that the World Economic Forum (WEF) of Davos offers a much more suitable framework to fit the present environment in that its structure and membership is better representative of society at large in the present multi-polar power distribution. In his words, "(WEF) brings together anyone who's someone: prime ministers, governors, mayors, CEOs, heads of NGOs, labor union chiefs, prominent academics, and influential celebrities. Each of these players knows better than to rely on some ethereal "system" to provide global stability – they move around obstacles and do what works."

The warning sounded off in Faber's paper on the need to adjust current approaches and practices of risk management to the 21st century reality is salient and timely. To borrow from military parlance, tactical success does not necessarily translate into strategic success. Applied to the field of risk management, this wisdom confirms Faber's observation that the preference for assessment and management of Type I risks, whose localized treatment is analogous to tactical operations at the battlefield rather than the more strategic, long-term Type II "seepage" risks or potentially catastrophic black swans of the Type III kind, requires a re-evaluation of present governance structures for the management of global (catastrophic) risks.

A new, non-state-centered option may seem heretic but would better represent the rapidly evolving multi-polar reality, characterized by urban power hubs. Failure to recognize the decline of the state as an institution will bring equally severe consequences for military and civil actors involved in the management of security threats and natural hazard risks. The notion of the New Middle Ages or Neomedievalism, as popularized by journalist Robert D. Kaplan and scholars such as Philip Cerny and Jorg Friedrichs, is particularly salient when considering alternative governance structures for the management of global risks.

Mass urbanization is furthermore distorting another clear demarcation of the past: the societal gap in consequences of natural hazard events as they are experienced in rich and poor countries – a development ripe with consequences not only for the management of natural hazard risks but for the very philosophy on which the humanitarian aid sector is based. Mass urbanization should force development and aid institutions to reconsider their mission: are they going to help poor countries or poor people?

It is a fairly common "urban myth" that urbanization spurs economic growth, creates wealth, broadens socio-cultural opportunities and fosters a climate for innovation and creative growth.

This may well be (partly) true for the artificial “knowledge cities” springing up in the Arabian desert, the Asia-Pacific financial hubs such as Hong Kong, Seoul, Shanghai, Sydney and Tokyo, or cultural capitals such as New York, London and Paris. For the millions of urban squatters pouring into the megacities, life quality is little other than a doomed existence in squalor, high exposure to health and direct and indirect consequences of natural hazard events, chronic unemployment, and threats from organized crime gangs as well as random acts of violence. It is interesting to note that alongside the mass urbanization trend, the socio-economic problems remain virtually the same. In that respect, the only visible difference is the lexical exchange between developed – developing country and city – slum dweller. The economic inequality in urban areas is manifest in myriad directions, not least what I would like to call the “vertical divide”, i.e. the penthouse executive suites at the tops of high-rise buildings vs. the slums below. So the assumption that scale and growth positively correlate would hardly be a representative opinion of those unfortunate slum dwellers in cities like Mumbai or Cairo or the townships of South Africa, where poverty, crime, precarious sanitary conditions and lack of basic passive and/or active protection measures against natural hazards of all types run rampant.

Finally, another apparent difference when looking at the highly skewed wealth distribution in knowledge city utopias vs. slums is that the former are in a position to better mobilize emergency response to disasters, which in turn helps to limit consequences (though not entirely, of course) to direct consequences, for which the wealthier part of society has relatively well-developed technological solutions both in terms of prevention and mitigation. In contrast, poverty-stricken dwellings, in developed and developing countries, are where the massive blows of direct consequences in the form of human lives and economic losses are plagued in addition with a host of indirect consequences, resulting in relentless, chronic impoverishment. Before people in these dwellings have had time to recover from one disaster, the next one is looming at the corner. As the saying goes, when it rains, it pours. Finding a way to limit hubristic grand visions of urban planners in developing countries who seem set on winning the race of who’s going to top the indicator for population density while disregarding the susceptibility of people to disasters due to overcrowding, is the most immediate challenge to risk governance as well as finding the appropriate scale at which regulation should be executed.

Interesting post. I’d just like to make a subsidiary point: Statistics about urbanization places like China have to be treated with a great deal of caution.

Here’s an example. Often, people begin by citing urbanization figures from an “authoritative” source, the UN Statistics Division, that say China is only 47% urban. Usually, they go on to discuss a wonderful convergence story for productivity and wealth in China compared to the US’s 82% urban figure, or Germany’s 74%.

Think again. The UN uses each country’s individual definition of urban. Dig into the details of the UN statistics and it turns out that the Chinese definition of a city is 1,500 people per sq. km (though the overall definition is complex), and the US and definition of a city (which we share with most of the developed world) is 400 people per sq. km. In short, China is already a lot more urban than you’d think looking at the “authoritative” UN Statistics Division headline figure (which people assume are comparable because they all come from the “same” UN source)! As usual in risk management, generalization is difficult, and the “devil is in the details”.

For more information and sources,
see:<http://silberzahnjones.wordpress.com/2011/04/08/statistical-cautions/>

Thank you for this valuable input. We could extend the truism “the devil is in the details” to include that he/she is also in the definition. Statistical “definitions” in a sense should always be placed in quotes.

Thank you also for the source reference.

186. **Thomas, P. (2012).** “Discount rates for use in calculating the J-value”

The Life Quality Index (LQI) and the J-value use discount rates in two contexts:

(i) to discount the utility of the individual's future earnings and (ii) to discount costs and benefits from schemes that have societal benefit. The former is termed the "net discount rate" while the latter is termed the "social discount rate", and used to convert the stream of costs that is reasonable for a protection scheme at a J-value of unity into a single, up-front figure. The net discount rate is shown to depend on the three parameters: the pure time discount rate, the nation's growth rate, and the average person's risk-aversion. An appeal is then made to Ramsey's economic model, and a derivation of Ramsey's result is given, which links the social discount rate to the same three parameters. It is then established that the net discount rate is equal to the social discount rate minus the rate of growth of Gross Domestic Product. The difficulties associated with the subjectivity of the pure time discount rate are discussed, but these may be bypassed in the UK context if the Treasury-recommended value for the social discount rate is accepted. Accepting the Treasury's view on the UK's average growth rate also then enables the net discount rate to be found by subtraction.

Different countries will experience different conditions, particularly for growth rate. Nevertheless the mathematical framework developed in this paper may be used to estimate appropriate figures for those countries.

187. **Thomas, P. and Chrysanthou, N. (2012).** “Using real options to compare the economics of nuclear power and wind power with electricity from natural gas”, Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy vol. 226 no. 4 514-531

The real options method provides one objective basis for judging when (if at all) it is reasonable to invest in a product in competition with another, the future price of which may exhibit a high degree of uncertainty. This article uses the real options technique to find the economically desirable start-up dates for three carbon-free methods of generating electricity, nuclear, onshore wind, and offshore wind, when facing competition from electricity generated from natural gas. The fact that the same assessment method has been used for each of the three carbon-free options allows intercomparability of the results. Nuclear power is projected to become competitive with gas-based electricity in 2015, even when no benefit is claimed for its carbon-free properties. Using the same yardstick, unaided onshore wind power first becomes competitive with gas in 2032 and unaided offshore wind power in 2040. There is thus a wide disparity among the dates of competitiveness for the three methods of generation considered. Judged on a level playing field for carbon-free technologies, nuclear power emerges as a much better investment than onshore wind, while onshore wind is better than

offshore wind. The analysis provides an explanation for the significant number of utilities who have declared an interest in New Nuclear Build in the UK in the near future. It shows that these utilities can be expected to make money immediately after their plants start up, even if they are given no credit for the carbon-free nature of nuclear generation. By contrast, the economics of wind power look more problematic. Even given the current level of intervention, £40/MWh, equivalent to £90/t CO₂ avoided, onshore wind farms are not expected to become competitive with gas generation for about 15 years. That timescale stretches to over 20 years if no intervention is made. The situation is worse for offshore wind farms, which do not become competitive until 2028 even when given twice the aid offered to onshore wind farms: £80/MWh, equivalent to £180/t CO₂ avoided. Without this high level of support, offshore wind farms are not expected to become competitive with gas generation for nearly 30 years even when allowance is made for the improved technology associated with series build. While wind technology is likely eventually to become competitive with gas, the real options analysis suggests that it would require significant cost reductions for a major, early deployment of wind power to become justified. It would appear to be a particularly questionable use of resources to spend money developing offshore wind farms so far in advance of their likely cost-effectiveness. The real options analysis suggests that large-scale construction of offshore wind farms should be delayed until the late 2030s.

188. *Thomas, P. and Jones, R., (2010).* "JT-value assessment of schemes to protect against accidents with high human and environmental costs", *Measurement + Control*, Vol. 43, No. 5, June, pages 152 - 155.

Society will continue to demand ever higher levels of safety for humans and protection for the environment as civilisation advances. But economic resources will always be limited as there will always be other things that, quite properly, people will want to do. So what is needed is an objective answer on how much ought to be spent on safeguards. Building on the work of Nathwani, Pandey and Lind¹, such an answer has been made available in the J-value^{2,3,4,5} for protection schemes that reduce the risk to human life. But while human harm may be the predominant risk in some cases, very often an industrial protection system will be designed to mitigate also against other economic and environmental costs. For example a shut-down system on a chemical plant or a nuclear reactor will protect against not only human harm but also damage to nearby plant and the spread of contamination to the environment.

For brevity, we shall refer to the costs associated with environmental clean-up, evacuation of people, loss of business, damage to plant and damage to reputation as "environmental costs", with the understanding that other costs may be brought under this umbrella in some cases. The trade-off between extra spending on the protection system and these environmental costs may be quantified using utility theory^{6,7,8}, and the result integrated with the J-value to produce a JT-value (total judgement value), which will indicate whether the total cost of the protection system is reasonable in view of its ability to protect both humans and the environment⁹. The application of utility theory in this case may be achieved through using the ABCD model.

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

A common yardstick against which to judge spending on health and safety across all sectors of the economy is needed if resources are not to be diverted away from areas of greater need. It is argued that the J-value is an objective, absolute and universal scale that fulfills that need. Previous judgments on the value for human life are reproduced, but the J-value demonstrates that significant differences exist currently in the regulatory standards for different industries. Case studies show that very different levels of health and safety spend have been demanded in practice in those industries.

190. **Thomas, P. and Stupples, D., (2007).** "J-value: a new scale for judging health and safety spend in the nuclear and other industries", Nuclear Future ,Vol. 03, No. 3, May/June, 140 - 145.

191. **Thomas, P. J. and Jones, R. D., (2009).** " Calculating the benefit to workers of averting a prolonged radiation exposure for longer than the working lifetime.", Trans IChemE, Part B, Process Safety and Environmental Protection, Vol. 87, 161 –

The J-value method enables health and safety schemes aimed at preserving or extending life to be assessed on a common, objective basis for the first time, irrespective of industrial sector. For this it requires an estimate of the improvement in life expectancy that the health and safety scheme will bring about. This paper extends the range of nuclear-safety-system lifetimes for which it is possible to calculate the increased life expectancy amongst nuclear-plant workers whose radiation exposure the safety system has reduced. Whereas the previous mathematical technique was able to cater for a nuclear-safety-system lifetime up to the working lifetime of the nuclear-plant workers (typically between 45 and 50 years), the new method extends without limit the range of tractable, safety system lifetimes. This is important now that the design lifetime of nuclear power stations can be up to 60 years. The development will also facilitate the assessment of safety systems and procedures to protect workers on long-term nuclear decommissioning and waste sites; in the latter case, the service life-time could be hundreds of years. The case when the safety-system lifetime is greater than the working lifetime is addressed by splitting the workforce into a set of three cohorts, one for existing workers and two for new recruits. The discounted life expectancy is found for each cohort, and then a weighted average is used to give the overall value. An additional mathematical device is then used to reduce the number of cohorts required from three to two, namely existing workers and new recruits. A similar mathematical device is applied (in Appendix A) to reduce from three to two the number of workforce cohorts needed when the length of the safety system's service lifetime is less than the working lifetime. Finally, a further mathematical instrument is incorporated in the model equations, which allows a unified treatment to be applied to each of the cohorts, existing workers and new recruits, across all possible service lifetimes of a nuclear safety system. Since new results on gain in life expectancy may be fed into a J-value analysis, this development extends significantly the range of nuclear-safety systems for which the J-value technique may be used to measure cost-effectiveness.

192. **Thomas, P. J. and Jones, R. D., (2009).** " The effect of the exposure time on the value of a manSievert averted", Trans IChemE, Part B, Process Safety and Environmental Protection, Vol. 87, 227 - 231.

The basis of the manSievert as a unit for collective radiation dose is discussed and previous recommendations are considered for how much should be spent to avert a collective dose of 1manSv. New calculations are given using the J-value method. It is shown that the value to be

assigned to averting a manSievert depends on the duration of averted exposure as well as on the net discount rate and the loan rate thought to be appropriate. Different figures will result depending on whether the exposed group consists of workers or the general public. The variation with dose duration is so large that it is not possible to recommend a single figure for the value of a manSievert. Instead, tables are given at two conservative, loan and net discount rates for the value of a manSievert as a function of exposure time. The base data for the *J*-value method need to be updated annually, and this means that the values given in the tables will increase over time as people live longer and become richer.

193. **Thomas, P. J. and Jones, R. D., (2009).** "Incorporating the 2007 recommendations of the International Committee on Radiation Protection into the *J*-value analysis of nuclear safety systems", *Trans IChemE, Part B, Process Safety and Environment*.

The newly released findings by the International Commission on Radiation Protection (ICRP) led to a review of the lifetime risk coefficients for fatal cancer used in *J*-value analysis of nuclear safety systems. The change in life expectancy a safety system brings about by averting a radiation exposure needs to be estimated in order to calculate the safety system's *J*-value, and this is done following the ICRP's practice of using risk coefficients that are uniform across both genders and all ages in the defined population group (either workers or the general population). The ICRP predicted uniformly lower radiation risks in 2007 than in 1990 on a like-for-like basis, but it was found that the ICRP's new risk coefficients needed to be multiplied by a compensating factor specific to each population when used in calculating the radiation-induced change in life expectancy. Incorporating the new compensating factor leads to a decrease in the *J*-value calculated of about 5% for workers and 15% for the general population compared with earlier, reported results. These adjustments are not large compared with the uncertainties associated with radiation harm and the economics of installing a safety system, but will strengthen slightly the case for spending on a nuclear safety measure.

194. **Thomas, P. J. and Jones, R.D, (2010).** "Extending the *J*-value framework for safety analysis to include the environmental costs of a large accident", *Process Safety and Environmental Protection*, Vol. 88, No. 5, September, pages 297 - 317.

A severe accident on an industrial plant has the potential to cause, in addition to human harm, general damage and hence expense, associated with ground contamination, evacuation of people and business disruption, for example. The total cost of damages, given the name "environmental costs" in this paper, may be comparable with or larger than the cost of direct health consequences, as assessed objectively by the *J*-value approach. While the low probability of the accident may mean that the expectation of monetary loss is small, the paper develops a utility-based approach to determine how much should be spent on protection systems to protect against both environmental costs and human harm. The behaviour of the fair decision maker in an organisation facing possible environmental costs is represented by an Atkinson Utility function, which is dependent on the organisation's assets and on the elasticity of marginal utility or, equivalently, the coefficient of relative risk aversion, "risk-aversion" for short. A Second Judgment Value, J_2 , may be derived from the spend on the protection system after subtracting the amount sanctioned to prevent direct human harm. This net, environmental expenditure is divided by the most that it is reasonable to spend to avert environmental costs at the highest, rational risk-aversion. The denominator in this ratio is found by first calculating the maximum, sensible spend at a risk-aversion of zero, and then multiplying this figure by a Risk Multiplier to give the maximum, fair amount to avert environmental costs. The Risk Multiplier incorporates a risk-aversion that is as large as it can

be without rendering the organisation's safety decisions indiscriminate and hence random. An overall, Total Judgment Value, the *JT*-value, may also be calculated, which takes into account the reduction in both human harm and environmental cost brought about by the protection system. The new *JT*-value will show similar behaviour to the original *J*-value, in that *JT*-values up to unity will indicate reasonable value for money, while *JT*-values greater than unity will indicate a *prima facie* overspend on protection that will need to be justified by further argument. While the analysis is phrased in terms of environmental costs, the treatment is sufficiently general for all costs, including onsite damages, loss of capability etc. to be included. The new, *JT*-value method provides for a full and objective evaluation of the worth of any industrial protection system. A worked example is given.

195. **Thomas, P. J., (2010).** "An absolute scale for measuring the utility of money", Proc. 13th IMEKO TC1-TC7 Joint Symposium Without Measurement no Science, without Science no Measurement, September 1-3, City University, London, UK, IOP Publish

Measurement of the utility of money is essential in the insurance industry, for prioritising public spending schemes and for the evaluation of decisions on protection systems in high-hazard industries. Up to this time, however, there has been no universally agreed measure for the utility of money, with many utility functions being in common use. In this paper, we shall derive a single family of utility functions, which have risk-aversion as the only free parameter. The fact that they return a utility of zero at their low, reference datum, either the utility of no money or of one unit of money, irrespective of the value of risk-aversion used, qualifies them to be regarded as absolute scales for the utility of money. Evidence of validation for the concept will be offered based on inferential measurements of risk-aversion, using diverse measurement data.

196. **Thomas, P. J., Jones, R. D. and Boyle, W. J. O. (2010).** "The limits to risk aversion: Part 1. The point of indiscriminate decision", Process Safety and Environmental Protection, Vol. 88, No. 6, November, pages 381 - 395.

The paper uses utility theory to investigate how much should be spent to avert all costs from an industrial accident apart from direct human harm. These "environmental costs" will include those of evacuation, clean-up and business disruption. Assuming the organisation responsible will need to pay such costs, the difference between its expected utility with and without an environmental protection system constitutes a rational decision variable for whether or not the scheme should be installed. The value of utility is dependent on the coefficient of relative risk aversion, "risk-aversion" for short. A model of an organisation's decision-making process has been developed using the ABCD model, linking the organisation's assets, *A*, the cost of the protection scheme, *B*, the cost of consequences, *C*, and the expected utility difference with and without the scheme, *D*. Increasing the organisation's risk-aversion parameter will tend to make it less reluctant to invest in a protection system, but can bring about such investment only when the scheme is relatively close to financial break-even. For such borderline schemes, the amount the organisation is prepared to spend on the protection system will rise as the risk-aversion increases. The ratio of this sum to the break-even cost is named the "Limiting Risk Multiplier", the maximum value of which is governed by the maximum feasible value of risk-aversion. However, the mathematical model shows that increasing the risk-aversion will reduce the clarity of decision making generally. Although the reluctance to invest in a protection scheme may change sign and turn into a positive desire to invest as the risk-aversion increases, the absolute value of this parameter is a continuously decreasing function of risk-aversion, tending asymptotically to zero. As a result,

discrimination will gradually diminish, being lost altogether at the “point of indiscriminate decision”. Here the decision maker will be able to distinguish neither advantage in installing the scheme nor disadvantage in installing its inverse. There is a close correspondence between this mathematically predicted state and that of panic, where an individual has become so fearful that his actions become random. The point of indiscriminate decision provides a natural upper bound for the value of risk-aversion. This bounds the Limiting Risk Multiplier in turn, and so sets an objective upper limit on the amount that it is rational to spend on an environmental protection system.

197. *Thomas, P. J., Jones, R. D. and Boyle, W. J. O. (2010)*. "The limits to risk aversion. Part 2: The permission point and examples", *Process Safety and Environmental Protection*, Vol. 88, No. 6, November, pages 396 - 406.

Part 2 extends the analysis to show that it is possible to find the “permission point”, the value of (the coefficient of relative) risk-aversion, at which decisions to sanction environmental protection are most likely to be made. The mathematical model describes the process by which the decision maker varies his risk-aversion over a range of feasible values to find the risk-aversion that will give him the greatest desire to invest in the protection system under consideration. If he can find such a risk-aversion before losing discrimination (because the system is too expensive, given its performance), he will adopt it as his “permission point” and decide in favour of the expenditure. The permission point is, of course, bounded above by the point of indiscriminate decision. A maximum Risk Multiplier calculated at the point of indiscriminate decision may be applied to the protection expenditure at monetary breakeven to give the maximum, rational outlay on protection. Moreover, it is possible to model how the average UK adult should take decisions on protection to maximise his utility. Different situations will call for different values of risk-aversion, which may explain why economists have come up with differing estimates of this parameter in the past. However, a central, average risk-aversion may be calculated for the average UK adult as 0.85, which is within 4% of the value, 0.82, found from the newly reported method based on a trade-off between income and future free time, and is consistent with several recent economic estimates. Worked examples assess how much an organisation should spend on a protection scheme to prevent accidents with very large environmental consequences.

198. *Thomas, P. J., Jones, R. D. and Kearns, J. O. (2010)*. " The trade-offs embodied in J-value analysis ", *Process Safety and Environmental Protection*, Vol. 88, No. 3, May, pages 147-167.

The paper presents a new derivation of the *J*-value method for assessing health and safety expenditure that highlights the fact that two trade-offs are involved. The trade-off between safety spend and the resulting improvement in life expectancy rests on a prior trade between free-time fraction and income, made at a societal level. It is suggested that each trade is a specific instance of a more general exchange between expected free-time and income, and that the terms of the trade-off are similar, so that the percentage increase in life expectancy has the same value as a similar percentage increase in total expected free-time. The theoretical framework suggests that the average person values all his time equally, but perceives that he has sold his expected working time to an employer, so that, while he will still place a value on it, he does not see that value as coming to him, but rather going to his employer in exchange for the compensation he is being paid. Thus he values the extra years of life expectancy he obtains from a health and safety measure solely in terms of the extra years of free-time he expects to gain. The value of the exponent in the life-quality index has been shown to be

equal to both the modulus of the elasticity of expected future free-time with respect to income and the modulus of the elasticity of life expectancy with respect to income. The indifference curves on the planes of income versus life expectancy and income versus discounted life expectancy have been shown to be the loci of $J = 1$. The actuarial basis for the calculation of working time fraction to the end of life has been explained, and data on the share of wages in Gross Domestic Product have been discussed. Based on recent statistics from the UK economy, the average person would be prepared to forego about 5½% of his income to the end of life in order to increase his life expectancy or discounted life expectancy by 1%, and would require his lifetime income to be increased by 5½% to compensate him for a loss of 1% in his life expectancy, discounted or otherwise. A small degree of asymmetry will, however, occur for larger percentage changes in life expectancy, with the average person requiring somewhat more compensation for a loss of life expectancy than he is prepared to pay for a gain.

199. **Thomas, P. J., Stupples, D. W., and Alghaffar, M. A.**, 2006a, "The extent of regulatory consensus on health and safety expenditure. Part 1: development of the J-value technique and evaluation of the regulators' recommendations", *Process Safety and Environmental Protection*, 84(B5), 1 – 8.

The new J-value technique is developed from a life-quality index that is a function of life expectancy, average income and work-life balance. The method is used to assess the degree of consensus on health and safety expenditure amongst regulators across different sectors of the economy. A measure of agreement is found in the regulator's theoretical recommendations

200. **Thomas, P. J., Stupples, D. W. and Alghaffar, M. A.**, 2006b, "The extent of regulatory consensus on health and safety expenditure. Part 2: Applying the J-value technique to case studies across industries.", *Process Safety and Environmental Protection*, 84(B5), 9 – 15

The measure of agreement in the regulator's theoretical recommendations found by using the J-value technique is contrasted with the very large disparities found on practical health and safety schemes. The J-value method is proposed as a common yardstick for assessing health and safety spend for the use of decision makers in all sectors. Its adoption could lead to better targeting of health and safety spend in all areas of the economy.

201. **Thomas, P. J., Stupples, D. W., and Alghaffar, M. A.**, 2006c, "The life extension achieved by eliminating a prolonged radiation exposure", *Process Safety and Environmental Protection*, September, 84(B5), 16 - 27.

A key parameter for evaluating the worth of safety equipment is the extension to life expectancy that it brings about in the population it is intended to protect. Since this is numerically equal to the decrease in life expectancy that would occur were the equipment not there, its value may be calculated by estimating the effect of the prolonged radiation exposure that would occur in the equipment's absence. This paper describes a procedure for carrying out this computation efficiently for cost-benefit studies using the J-value method.

202. **Thomas, P. J., Stupples, D. W., and Jones, R. D.**, (2007). "Analytical techniques for faster calculation of the life extension achieved by eliminating a prolonged radiation exposure", *Trans IChemE, Part B, Process Safety and Environmental Protection*, 85 (B3) 230–240.

The life extension achieved by a safety scheme that reduces or eliminates a prolonged radiation exposure is a necessary parameter for calculating the Judgment-or J-value, which enables the scheme's worth to be measured on a common, objective scale against which health and safety spend across all economic sectors can be assessed. The life expectancy calculation for radiation exposure is necessarily complex because of the long and stochastic incubation periods associated with radiation-induced cancers. Analytical methods are presented to reduce the size of this calculation approximately a hundredfold. This renders the J-value assessment much quicker and easier for new safety systems that may be considered for nuclear plant

203. *Thomas, P., Boyle, W. and Kearns, J., (2010). "The quantum of wealth", Measurement + Control, Vol. 43, No. 5, June, pages 156 - 158.*

The reluctance to invest is a key dimensionless variable used in the JT-value assessment of schemes to prevent industrial accidents with high human and environmental costs. The decision-variable is equal to the difference between the expected utility of assets without the protection system and that with it, normalised by dividing by the starting utility of assets. Thus a 100% reluctance, equivalent to a point-blank refusal to invest, will be associated with a protection system that is so expensive that it is expected to reduce the utility of the organization's assets to zero, while a negative value will imply a positive desire to invest. In order to allow for risk-aversions that may be greater than unity (implying highly risk averse behaviour), it is necessary to use the Atkinson Utility function, which may be shown to provide an absolute scale for utility.

The Atkinson Utility function is a Scaled Power Utility function that takes as its datum one unit of money³, and thus gives a utility value of zero for one unit of money and a negative value for the utility of any positive amount of money less than one unit. While the negative value returned by the Atkinson Utility function when it is applied to a strictly fractional sum of money is fully understandable in the terms just set down, the situation would change if the Atkinson Utility function were to be regarded as a utility function assumed valid over all positive sums of money. In fact, its advantage in allowing for risk-aversions greater than unity and its closeness at risk-aversions less than unity to the Scaled Power Utility means that the Atkinson form is often used in practice as a utility function in its own right, without acknowledgement of its origin as a utility difference. From this viewpoint it appears anomalous that the utility of a strictly fractional sum of money should be negative. For, taking the unit of money to be £1, why should possessing just 50 pence leads to a negative satisfaction level? Equally, why should having £1 lead to no satisfaction? The resolution of these apparent anomalies is contained in the first line of this paragraph, but nevertheless the interesting question is raised as to whether there might be a quantum of wealth, the addition of less than which would be regarded by the average adult as giving him or her no discernible increase in wealth.

In support of such a premise is the fact that money is and always has been discrete. For example, the penny (£0.01) is the lowest denomination coin in the UK, and a difference in wealth less than £0.01 cannot register in a UK bank account. Similarly in Europe, €0.01 is the smallest change in wealth that will register, and in the USA, \$0.01. So while the dividend of a commercial company might be declared as, for example, 5.444 pence, this is only to ease calculation of the dividend on large numbers of shares. The cheque sent out to the holder of ten shares would be for £0.54, not for £0.5444. The result is that utility of money and hence

the utility of any asset must be of a similarly discrete nature. There will be discrete steps in utility in consequence, even if the steps are small enough to allow the discrete variable to be approximated by a continuous variable.

204. **Thomas, P., Jones, R. and Kearns, J. (2010).** "J-value safety assessment: the two trade-offs", *Measurement + Control*, Vol. 43, No. 5, June, pages 142 - 145.

In physics and engineering, we are fortunate in having a whole body of widely accepted learning on the governing laws. Von Neumann and Morgenstern¹ noted 60 years ago that this happy situation did not carry over to socio-economic theory, and while undoubtedly there has been major progress since then, there remain many areas where fully satisfactory theories have still to be developed. Here, as in engineering, the development of a workable mathematical model is the first priority, since it is only in this way that we can identify the parameters that need to be measured and calculated.

205. **Thomas, P.J., Taylor, R.H. (2011).** J-value analysis of different regulatory limits for workers and the public. *Process Safety and Environmental Protection*

The J-value technique allows an objective determination to be made of the resources that should be applied cost effectively to improve health and safety. This is essential if capabilities are to be employed optimally and risks reduced in a way that reflects their severity. Although other considerations such as good practice and socio-political influences may affect a final decision on the resources to be sanctioned, the incorporation of these additional factors should be made transparent if the decision is no longer to be based on cost effectiveness. The J-value provides an objective criterion by which to judge when "reasonable practicability" has been achieved in committing resources for safety improvement, which is the legal requirement under health and safety law in the UK.

Moreover, the J-value methodology also allows other related issues to be addressed objectively. Regulatory bodies apply different limits for workers and the general public, with higher risks being permitted for workers. Although a factor of about 10 has been used in several contexts, no objective rationale has been developed for this particular figure until now. However, it is shown that application of the J-value analysis can provide a justification for a ratio of workers' risk to public risk of approximately this size if certain reasonable assumptions are made. Thus the paper provides the first quantitative explanation for the different levels of protection demanded by regulators nationally and internationally for workers and public.

206. **Thomas, P., Jones, R. and Kearns, J., (2009).** "Measurement of parameters to value human life extension", *Proc. XIX IMEKO World Congress, Fundamental and Applied Metrology*, September 6-11, 2009, Lisbon, Portugal, pp 1170 - 1175.

207. **Thomas, P.,** "Extending the J-value into environmental protection as well as safety", 2010, *Hazards Forum Newsletter* 66 - Spring, pages 8 - 10.

208. **Thomas, P. J., (2009).** " J_T-value assessment of schemes to prevent industrial accidents with high human and environmental costs" , *Royal Academy of Engineering*, London, 26 November 2009.

Society will continue to demand ever higher levels of safety for humans and protection for the environment as civilisation advances. But economic resources will always be limited as there will always be other things that, quite properly, people will want to do. So what is needed is an objective answer on how much ought to be spent on safeguards. Building on the work of Nathwani, Pandey and Lind, such an answer has been made available in the J-value^{2,3,4,5} for protection schemes that reduce the risk to human life. But while human harm may be the predominant risk in some cases, very often an industrial protection system will be designed to mitigate also against other economic and environmental costs. For example a shut-down system on a chemical plant or a nuclear reactor will protect against not only human harm but also damage to nearby plant and the spread of contamination to the environment.

For brevity, we shall refer to the costs associated with environmental clean-up, evacuation of people, loss of business, damage to plant and damage to reputation as “environmental costs”, with the understanding that other costs may be brought under this umbrella in some cases. The trade-off between extra spending on the protection system and these environmental costs may be quantified using utility theory^{6,7,8}, and the result integrated with the J-value to produce a JT-value (total judgement value), which will indicate whether the total cost of the protection system is reasonable in view of its ability to protect both humans and the environment⁹. The application of utility theory in this case may be achieved through using the ABCD model.

209. **Thomas, P. J., (2009).** "J-value assessment of expenditure against harm to human life", Royal Academy of Engineering, London, 26 November 2009

210. **Von Radowitz, B., Schubert, M., Faber, M.H. (2008).** Robustness of Externally and Internally Post-Tensioned Bridges. *Beton-und Stahlbetonbau*. Vol 103, Issue 1. pp 16-22.

211. **Voortman HG, van Gelder PHAJM, Vrijling JK (2001).** Definition of Acceptable Risk in Flood-Prone Areas. *Structural Safety*.

In the Netherlands, risk-based methods for the definition of acceptable flooding risk are being explored. In this paper, an overview is given of the current approaches to risk in Dutch legislation. Alternatives for the existing approaches are developed based on the concept of economic optimisation and the life quality approach. It is shown that these two approaches can be combined to a method where two important dimensions of risk (economic consequences and casualties) are judged in one framework. A fictitious example is used to explore the practical application of the method. The results show that the extended life quality model provides a safety standard that is satisfactory in a variety of areas, differing in economic importance and population density.

212. **Voortman HG, van Gelder PHAJM, Vrijling JK and Pandey MD (2001).** Definition of Acceptable Risk in Flood-Prone Areas. *Int. Conf. Structural Safety and Reliability-2001*, Newport Beach, CA, June 17-22, 2001.

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consequences and casualties) are judged in one framework. A fictitious example is used to explore the practical application of the method. The results show that the extended life quality model provides a safety standard that is satisfactory in a variety of areas, differing in economic importance and population density.

213. *Mai CV, van Gelder PHAJM, Vrijling JK (2006)*. Safety of Coastal Defences and Flood Risk Analysis. Safety and Reliability for Managing Risk -- Guedes Soares & Zio (eds.), 1355-1366.

This paper is aimed at safety assessment of coastal flood defences and investigation of flood risk for coastal regions. Firstly, a general safety assessment procedure of coastal defences is performed by applying reliability analysis, which includes steps of identification of failure modes by various possible failure mechanisms, statistic description of hydraulic loads and resistance of the coastal defences and calculation of the failure probability. Secondly, overview of risk analysis of coastal defence system is followed, in which due to possible failures of the system, loss of life, economic, environmental, cultural losses and further intangibles can occur. It is necessary to determine the question if safe is safe enough and figure out acceptable risk levels. Acceptable risk is strongly related with the acceptable probability of failure and the acceptable amount of damages and losses. The state of the art in risk analysis will be reviewed and discussed. Application of the reliability and risk analysis to case studies of Vietnam coastal flood defences is investigated.

214. *Vrijling, JHK, Gelder, P.V., Goossens, LHJ. (2004)*. A Framework for Risk Criteria for Critical Infrastructures: Fundamentals and Case Studies in the Netherlands. Journal of Risk Research. Vol 7, Issue 6. pp 569-579.

Critical infrastructures are complex societal systems. For that reason, risk criteria for critical infrastructures are also 'part' of the risk criteria for complex societal systems. The questions to be resolved are: (1) are the societal risk criteria of complex systems defined and quantifiable; and (2) is it known how the risk criteria of critical infrastructures relate to the risk criteria of the complex system as a whole. In other words, what certainty is there that the risk criteria of critical infrastructures meet the risk criteria of complex systems as a whole. A complex system in this respect may be a society as a whole, e.g. a nation.

215. *Vrijling JK, van Gelder PHAJM, Goossens LHJ, Voortman HG & Pandey MD (2004)*. A framework for risk criteria for critical infrastructures: Fundamentals and case studies. 5th Conference on Technology, Policy and Innovation "Critical Infrastructures", in Delft, The Netherlands, June 26-29, 2001, Uitgeverij Lemma BV, ISBN 90-5931-019-5.

216. **Journal of Risk Research, 7 (6), 569-579 (2004)**. ISSN 1366-9877 online www.tandf.co.uk/journals/carfax/13669877.html.

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217. **Waddington, I., Boyle, W. J. O., Kearns, J., 2012, "Computing the Limits of Risk Aversion", *Process Safety and Environmental Protection*, in press. doi:10.1016/j.psep.2012.03.003**

Utility theory can be used to model the decision process involved in evaluating the cost-effectiveness of systems that protect against a risk to assets. A key variable in the model is the coefficient of relative risk aversion (or simply "risk-aversion") which reflects the decision maker's reluctance to invest in such safety systems. This reluctance to invest is the scaled difference in expected utility before and after installing the safety system and has a minimum at some given value of risk-aversion known as the "permission point", and it has been argued that decisions to sanction safety systems would be made at this point. As the cost of implementing a safety system increases, this difference in utility will diminish. At some point, the "point of indiscriminate decision", the decision maker will not be able to discern any benefit from installing the safety system. This point is used to calculate the maximum reasonable cost of a proposed safety system. The value of the utility difference at which the decision maker is unable to discern any difference is called the "discrimination limit".

By considering the full range of accident probabilities, costs of the safety system and potential loss of assets, an average risk-aversion can be calculated from the model. This paper presents the numerical and computational techniques employed in performing these calculations. Two independent approaches to the calculations have been taken, the first of which is the derivative-based secant method, an extension of the referred derivative method employed in previous papers. The second is the Golden Bisection Method, based on a Golden Section Search algorithm, which was found to be more robust but less efficient than the secant method. The average risk-aversion is a function of several key parameters: the organisation's assets, the probability and maximum cost of an incident, and the discrimination limit. An analysis of the sensitivity of the results to changes in these parameters is presented. An average risk-aversion of 0.8–1.0 is found for a wide range of parameters appropriate to individuals or small companies, while an average risk-aversion of 0.1 is found for large corporations. This reproduces the view that large corporations will be risk neutral until faced with risks that pose a threat to their viability.

218. **Wang, G., Boon, B., Brennan, F. P., Garbatov, Y., Ji, C., Parunov, J., Rahman, T. A., Rizzo, C., Rouhan, A., Shin, C. H., Yamamoto, N., "Report of Committee V.6, Condition Assessment of Aged Ships" in Proceedings of the 17th International Ship and Offshore Structures Congress, Vol. 2, Seoul (South-Korea), 16 - 21 August 2009. 309-365.**

Condition assessment calls for knowledge of a wide range of issues and the processes used in which these issues are addressed. This report places focus on these items: how 314 ISSC Committee V.6: Condition Assessment the industries assess structural conditions, how the industries develop best strategy for performing inspection, and mitigating the consequences of degradations. Over the years, ISSC Committees have covered extensively, and will continue to do so, the fundamental research and theory related to environment, loads, structural responses, design methodology, analysis and evaluation, and design principles. The reports of these ISSC Committees are also helpful in understanding the development and trends of condition assessment.

219. **Woodall, D., Lund, J. (2009). Dutch Flood Policy Innovation for California. Journal of Contemporary Water Research & Education. Volume 141, Issue 1. pp. 45-59.**

Flood risk management is an important part of life in the Netherlands. The Netherlands is formed by the deltas of three rivers- the Scheldt (rain-fed, originating in southern Belgium), the Meuse (rain-fed, originating in northern France), and the Rhine (glacier and rain-fed, originating in Switzerland). The country also borders the North Sea, with the Scheldt River connecting the sea to Antwerp Harbor. The Rhine is the largest of the three rivers, splitting into three branches (the IJssel, the Lek, and the Waal) as it crosses the border into the Netherlands (Tol et al. 2003). Two-thirds of the country lies below mean sea level (Voortman 2003).

The Dutch have a long history of attempting to control floods. As early as the ninth century, the Dutch started building dikes to protect reclaimed bog land (Kaijser 2002). These dikes started as local, individually-owned structures, but communities soon realized that closed dike rings were necessary to protect all sides of the region. These dike rings eventually became waterschaps, or “waterships,” regional districts charged with water management including drainage and dike building. These districts are still the administrative body for flood defense (Voortman 2003). The 14th century saw the first major recorded floods in 1313 and 1315, leading to the famine from 1314-1317 that killed 5-10 percent of the population. Periodic flooding continued through much of the Netherlands’ history. As sediment settled between the dikes, dikes grew taller. During the 19th century, reorganization of the water districts occurred and a national body was formed. Military engineers took over the construction and maintenance of the dike system (Tol and Langen 2000).

During the 20th century, as trained engineers and the central government took over flood control efforts, the analysis of appropriate techniques and construction increased. Prior to 1953 dikes were built to the height of the previously known high-water level plus a margin of safety (Jonkman et al. 2004). Following the catastrophic flood of 1953, the Delta Committee was formed to advise the government regarding flood control (Voortman 2003). One recommendation of the Committee was to establish an optimal exceedance frequency of the design water level based on risk of flooding and cost of protection. van Dantzig’s 1956 paper described this risk-based calculation. He proposed that flood management required integration of three areas with noted problems: statistics, hydrology, and economics. In the past 50 years, significant effort has been devoted to expanding on van Dantzig’s work and working on solutions to the problems he noted and the assumptions he made. Increased computing power, additional rainfall and hydrologic data, and watershed models have all added to the understanding of flooding while increased emergency preparedness and response have enhanced protection of land, homes, farms, businesses, and lives.

Northern California also has a history of devastating floods, although the history of floods and water management is much shorter than in the Netherlands. Throughout the past century and a half, winter rains and snowmelt have resulted in flood events that have caused billions of dollars in damage and multiple deaths. One of the largest floods in California history occurred in January, 1862 following four weeks of rain. No quantitative flows are known, but the banks of the Sacramento were breached and the water was, at minimum, three feet deep from Sutter’s Fort to Davis (Harding 1960).

This flood also brought significant mining debris, covering the land near Marysville with one to six feet of sediment. During the second half of the 19th century, mining techniques had developed from ditch and flume operations to high powered hydraulic techniques that discharged up to a million gallons an hour from a single nozzle (Kelley 1989, Larson 1996).

Over 1.5 billion cubic yards of sediment was discharged into the Feather, Yuba, Bear and American River basins from hydraulic mines (Larson 1996). However, the litigation between Woodruff and North Bloomfield Gravel Mining Company (1884) effectively stopped hydraulic mining by requiring complete containment of debris.

Early in the settlement of California, flood control was typically very local, with levees built by individuals or local governments. Following this major flood in 1862 and the resulting litigation, hydraulic mining ended and levee management moved to larger regional agencies and the state government.

The largest recorded flows in the Sacramento River were reached during the flood of March 1907. Although some tributaries have since exceeded their 1907 flows, the Sacramento River has not exceeded its peak flow of about 600,000 cubic feet per second (16,990 m³/s) (Harding 1960). Thirty to forty inches of precipitation across Northern California during the week before Christmas in 1955 led to severe damages and levee failures. Seventy-four lives were lost and over \$200 million in economic losses were attributed to the flood (Harding 1960). Record rainfalls led to major flooding in 1986. Levee breaks in the Sacramento River Basin led to 13 deaths and over \$400 million in damages. Two of the most expensive floods in California's history (1995 and 1997) occurred within two years of each other and together caused nearly \$4 billion in damages (Department of Water Resources website).

Early in California's history, no state or federal agencies managed flood control; flood control projects were managed locally. As settlement increased, however, state and federal funding and regional management became necessary. First, state and county agencies began acting to prevent flooding and then in 1917, federal authority for flood management was granted by Congress. Since then, there has been a fluctuating balance of power between regional and district, state, and federal flood control planning, funding, and management (Kelley 1989).

Six types of actions can be considered for flood management (Hoojier et al. 2004):

- Actions to prevent flood generation: land use management in the upstream basin,
- Actions to modify flood flows and elevations: flood storage, levees, by-passes, and channel improvements,
- Flood damage reduction actions: floodplain zoning, building codes, awareness raising,
- Preparatory actions: flood forecasting, warning and emergency plans,
- Flood event actions: crisis management, evacuation, and
- Post-flooding actions: aftercare, financial compensation, insurance.

The Dutch concentrated mostly on preventive flood control measures, and many of the measures implemented in California were first tested by the Dutch in their attempt to control flood waters. Some more recent Dutch innovations might increase California's ability to reduce flood damage. This paper is organized into three subjects. First is a review of Dutch flood control innovations. Next, implementation of each measure is discussed in California's context. The final section wraps up the discussion with a summary of key points and conclusions.

220. *Yasseri, S., Mahani, R.B. (2009). Examining the ALARP Principle. OME 2009.*

The ALARP (As Low As Reasonably Practicable) principle assumes that there is a level of risk which is tolerable and requires that the risk be at least below that level. The qualifying term "reasonably practicable" determines how low risks should be pushed towards the region of negligible risks. An infinite amount of effort could reduce the risk to an infinitely low level, but an infinite amount of effort will be infinitely expensive to implement. So ALARP

assumes that there is a risk level which is so low that "it is not worth the cost" to reduce it further. In essence this means that risk reduction measures should be implemented until no further risk reduction is possible without very significant capital investment or other resources expenditure that would be grossly dis-proportionate to the amount of risk reduction achieved. This paper examines the ALARP principle in the context of cost effectiveness using a case study.

221. **Zhang SK, Tang WY, Li LQ (2000)**. Risk Acceptability Updates on Marine Engineering. *Marine Engineering*. 96-102.

222. **Zhang, Y.D., Guo, J. (2010)**. Research on some key issues in engineering safety management of rail transit signal system. *Mechanic Automation and Control Engineering (MACE)*, 2010 International Conference.

223. **Zhou, Y., Huang, H., Hu, Q. (2007)**. The LQI Based Decision-Making Model of Risk Control in Tunnel Engineering. *Chinese Journal of Underground Space and Engineering*. Vol. 3, Issue 5. pp. 854-932.

The optimal ICAF is obtained based on the social indicator – Life Quality Index. According to the ALARP principle, the LQI based decision-making model of risk control for personal safety for personal safety in tunnel engineering is introduced based on the safety risk index derived from the characters of tunnel work in China. Finally, the decision-making flow is explained through the example of Jubilee line extension in UK.