Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 42 (1983)

Artikel: Numerical risk acceptability and mitigation evaluation criteria

Autor: Philipson, Lloyd L.

DOI: https://doi.org/10.5169/seals-32442

Nutzungsbedingungen

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Mehr erfahren

Conditions d'utilisation

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. En savoir plus

Terms of use

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. Find out more

Download PDF: 13.01.2026

ETH-Bibliothek Zürich, E-Periodica, https://www.e-periodica.ch

Numerical Risk Acceptability and Mitigation Evaluation Criteria

Critères numériques d'évaluation et diminution des risques

Kriterien zur numerischen Risikoannehmbarkeit und -schätzung

Lloyd L. PHILIPSON
Senior Science Advisor
J. H. Wiggins Company
Redondo Beach, CA, USA

Lloyd L. Philipson received his doctorate in mathematics from UCLA. He conducts research in, and carries out applications of systems safety and risk analysis and teaches safety analysis methods. He is a member of the Hazardous Materials Transportation Committee of the National Academy of Sciences, National Research Council's Transportation Research Board.

SUMMARY
The development of risk acceptance and risk mitigation evaluation criteria in various contexts is reviewed. Past and present attempts to derive such criteria for use by decision-makers on public hazards are noted. A structured presentation of the generic approaches that have evolved for the development of these criteria is provided in order to establish a foundation for their consideration as elements of potential risk-based decision-making on ship/bridge collision hazards and their possible mitigations.

RÉSUMÉ
Il s'agit d'une étude de la mise au point de critères permettant d'évaluer l'acceptation et la diminution des risques dans différents contextes. Celle-ci passe en revue les efforts passés et actuels pour définir de semblables critères devant servir aux preneurs de décision. Elle propose une présentation structurée des approches génériques développées pour mettre au point ces critères, et ce afin que soient fournies les bases qui permettront de tenir compte de ces derniers dans le cadre des décisions pouvant être adoptées dans le domaine des risques de collisions de navires avec des ponts, et de leur possible diminution.

ZUSAMMENFASSUNG
Die Entwicklung von Kriterien zur Risikoannehmbarkeit und -minderungsauswertung wird in verschiedenen Zusammenhängen überarbeitet. Frühere und gegenwärtige Versuche zur Ableitung solcher Kriterien für Entscheidungsträger bei öffentlichen Gefahren werden aufgeführt. Eine strukturierte Darstellung der artmäßigen Annäherungen, die zur Entwicklung dieser Kriterien entstanden sind, soll eine Grundlage für ihre Berücksichtigung als Elemente potentieller, risiko-abhängiger Entscheidungen bei Gefahren durch Schiffskollisionen mit Brücken und deren mögliche Minderung bieten.

1. INTRODUCTION

The fundamental question, "How safe is safe enough?" or, equivalently, "Is a given risk acceptable?" continues to exercise policy makers and decision makers. Unless the question can be answered on some basis, no limits can be assigned to the expenditure of resources for safety improvement in any given activity. Since resources are finite, critically important mis-applications of resources will be (and are being) made to attain smaller and smaller improvements in the safety of some activities that happen to receive attention, while others with more significant safety problems must go ignored. But any postulation that "enough" safety has been established is clearly subjective, and, as is very apparent in all western societies at present, subject to controversy.

This paper attempts to provide a brief assessment of the pro's and con's of the generic numerical approaches to risk acceptability and risk mitigation evaluation that have evolved in response to this problem. It is intended that this will establish a basis for the consideration of similar approaches and the numerical criteria they may provide in the context of ship/bridge collision hazards. The generic approaches that are discussed are:

- Comparisons to ambient risks
- Comparisons to revealed preferences
- Risk-cost-benefit evaluations

2. COMPARISONS TO AMBIENT RISKS

Many catalogs, tabulations and graphs have been published that exhibit the risks from existing natural and technological hazards, based on past experience or modeling estimates. It is argued that if the risk from a new hazardous activity is lower than the "standards" implied by society's acceptance of these ambient risks, everyone should be satisfied that the new hazardous activity is "safe enough."

The Environmental Impact Report for a proposed liquefied natural gas terminal at Oxnard, California (Socio-Economic Systems, 1977), illustrates this concept. The various cumulative risk curves shown in Figure 1 apply to the total population exposed to potential LNG terminal accidents at Oxnard. Note the shaded area in Figure 1. It shows the effects of uncertainty in the predictions of the LNG facility applicant's estimate (the SAI (Science Applications Incorporated) curve); the upper boundary is that of a "reasonable worst case" estimate established from a review of other analyses that had been made of the risks and of the applicant's process of estimating them. It is seen that the LNG terminal might not meet a standard of acceptance based on comparisons to ambient risks, in view of the uncertainties in the estimates of the LNG risk. Uncertainty in the risks of an activity essentially add to the predicted risks in considerations of their acceptability, and may well be an important such addition.

Many presentations of comparable ambient natural and technological risks have been published, e.g., in Starr (1971), and Cohen and Lee (1979). An early argument for considering natural hazards as sources of risk acceptance criteria is that of Libby (1971). A most extensive compendium of ambient risk data is given in a recent Brookhaven National Laboratory report (Coppola and Hall, 1981). Kletz (1977) considers such risks in the United Kingdom and argues that they set standards of acceptability for U.K. industry. McGinty and Atherly (1977) rebut this argument, however, indicating that acceptability decisions must be made more democratically, and not merely on the basis of someone's views of past risk acceptance. After all, the past risks may have been accepted in ignorance, or

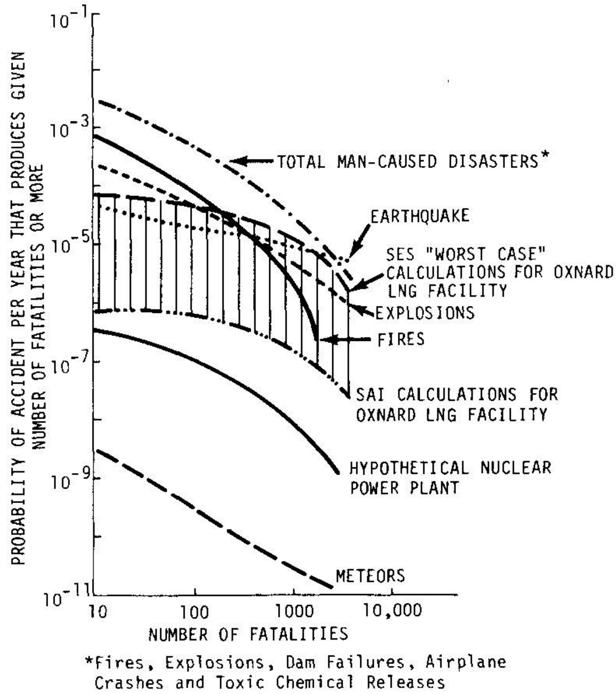

Fig. 1 Fatalities Risks from Potential Accidents in Oxnard Area (Socio-Economic Systems, 1977)

they may have been relatively unavoidable with the technology and economics that obtained in the past. Improved understanding of these risks and improved means to avoid them may now mean they are no longer "acceptable."

3. COMPARISONS TO REVEALED PREFERENCES

The notion that acceptable risk levels can be revealed by data on the relationship of the losses from past hazardous activities with the benefits associated with them was first put forward by Starr in an article in Science in 1969. The debate on risk acceptance criteria may be said to have originated with this article, and has since expanded in many directions and with growing intensity. Starr attempted to show, more or less quantitatively, what apparent past risk acceptance behavior was in U.S. society, and, due to its apparent consistency in certain ways, how it could provide a basis for judging what risks could be acceptable in the future. Otway and Cohen (1975), however, have critiqued Starr's findings and argued against the existence of the consistencies he claims. Baldewicz (1976), Pochin (1975, 1978), and others have extended Starr's data developments into occupational activities, where "voluntary" risk acceptance is presumably obtained by the relatively clear job benefits that are associated with it. Special concerns with catastrophic group or societal risks, as distinct from average individual risks, have been assessed, and arguments put forward on how society evaluates them, by Wilson (1975) and Ferreira and Slesin (1976), among others.

Figure 2 presents Starr's original curves of historically-accepted risks (i.e., "revealed risk preferences") versus the actual or perceived benefits he estimates accrue from their acceptance in society, from various types of hazardous man-made activities and possible natural events. These curves derive from statistical data on the average numbers of fatalities that resulted from the hazards in these activities per hour of individuals' exposures to these hazards in the past, versus dollar equivalents of the benefits (estimated in various direct and indirect ways) of such exposures.

Numerous arguments have been made against the application of Starr's conclusions, however. First, it is put that many past (and, for that matter, present) risk takers did not understand the risks they were accepting, so that the fact that they accepted them does not validate their or others' continuing to do so. Secondly, "voluntary" risk takers may not actually have accepted them "voluntarily," but because they had no viable alternative. As society and technology evolve, such alternatives may become more available, and, certainly, hazards may be reducible even for the same activity. Third, the use of average risks and benefits obviates the differences among specific risk takers and benefitters. Individuals accepting the highest risks may not be the same as those gaining the highest benefits. Finally, the use of averages "washes out" the disproportionate potential societal impacts of catastrophic hazards. Nevertheless, comparisons to relevant ambient risks remains a favored approach to acceptable risk criteria development in many specific contexts, as will be seen most particularly for nuclear power, below.

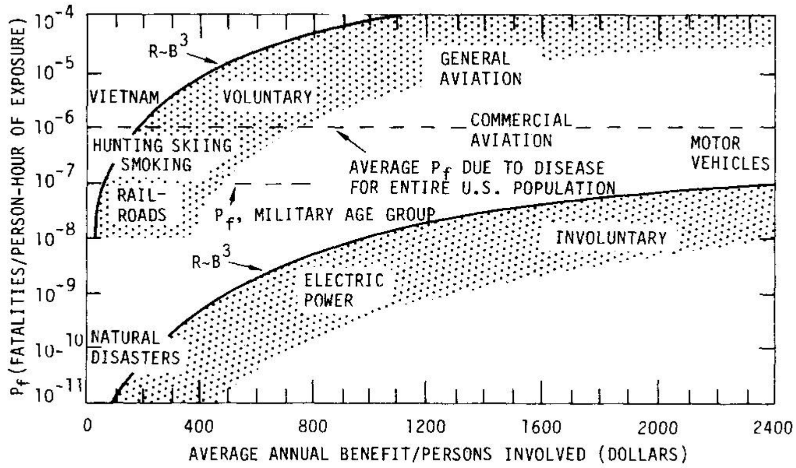

Fig. 2 Starr's Risk vs. Benefit Curves (1969)

4. RISK-COST-BENEFIT EVALUATIONS

Another basic approach to evaluation of the significance of the risks of a hazardous activity is to assess these risks in relation to the specific benefits the activity provides (Wilson, 1975ii). Three variations in this approach are considered.

First, and quite simply in principle, if alternative means are or can be made available to provide the desired benefits, the alternative that does this at the lowest risk is to be preferred (see, e.g., Figure 3, for alternative energy sources). It is assumed in this that costs of the alternatives are all more or less equally acceptable. This procedure is referred to as that of equi-benefit risk comparison. The risk of the lowest risk alternative defines the de facto level of acceptable risk (provided it is agreed that one of the alternatives must be selected).

Second, and more generally, the risks and benefits of an activity can be compared in some common terms, and the risks be deemed acceptable if, in these terms, they are not greater than the benefits. This is referred to as the balancing of risks and benefits. (Costs are assumed able to be neglected or subsumed as negative benefits.)

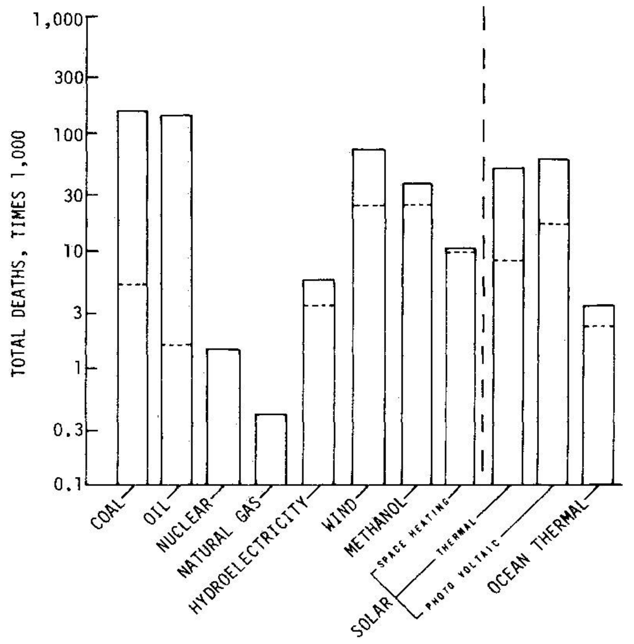

Fig. 3 Upper (U) and Lower (L) Bounding Estimates of Total Deaths (Public and Occupational), Times 1000, per Megawatt-Year, as a Function of Energy System (Total Fuel Cycle) (Inhaber, 1979)

Third, and perhaps most applicable to a risk management process employed in the optimization of ship/bridge safety decisions, resources can be applied to safety improvements until the value of the marginal risk decrease attained for an additional unit cost (in common terms with risk) becomes less than the cost. The residual risk remaining when optimality is reached is then the de facto acceptable risk level, in the sense that it would be an inefficient use of resources to attempt to reduce it further. This argument is best made when resources are limited and several hazards are competing for them so that it is accepted that they must be employed efficiently.

It is to be noted that the implementation of the second or third process requires a common scale of measurement of risks, benefits and costs. This has given rise to many attempts to establish an economic (e.g., dollar) "value-of-a-life" (Linnerooth, 1975; Jones-Lee, 1976) or, because of the evident problems in this, an economic value of the avoidance of a risk of loss of life. (Alternatively, the application of utility theory has been attempted in order to assess risks, benefits and costs on a common scale provided by a "decision maker's" utility function; see, e.g., Keeney, 1980.)

5. SYNTHESES OF SPECIFIC NUMERICAL ACCEPTANCE CRITERIA

Attempts have been made to develop on the basis of the concepts that have been discussed, and especially through comparisons with ambient risks, generally applicable numerical acceptability criteria that it is then hoped will be adopted by sufficient authority. A primary example is the present effort to convince the U.S. Nuclear Regulatory Commission (USNRC) to accept a specified set of reactor safety goals defined in terms of acceptable risk levels (Nuclear Regulatory Commission, 1980; Griesmeyer and Okrent, 1981; O'Donnell, 1981; and others). Farmer (1967), Gibson (1977) and Bowen (1975) have previously developed such criteria for use in the United Kingdom.

While various qualifications apply, the basic idea in the nuclear power case is as follows. Table 1 and Table 2 present a set of individual and group risk criteria, respectively (O'Donnell, 1981). Consider, for example, the Atomic Industrial Forum (AIF) committee's values. The individual fatality risk criterion of 10^{-5} per exposed person per year is justified in that it equates to 0.1% of the total ambient mortality risk (10^{-2} per year) of individuals in the U.S. and about 1% of the total ambient accident risk. The AIF committee's preferred group or population acceptable risk level (median value) is 0.1 fatalities per year per 1000 megawatts - electric of nuclear power capacity. This number is justified by comparison to the total ambient mortality risk and the total ambient cancer risk in the U.S. Assuming a total of 200,000 MWe of capacity, the number translates to about 0.01% of the total mortality risk and 0.05% of the total cancer risk. The AIF's individual and group criteria are further justified by their comparability to the other proposed criteria or risk estimates given in the two tables.

NRC - RES	10^{-5}/YR UNACCEPTABLE 10^{-6} - 10^{-5}/YR WARNING RANGE (CASE BY CASE EVALUATION)
WILSON	10^{-5}/YR NEAR SITE 10^{-6}/YR NEXT TOWNSHIP
OKRENT	2 x 10^{-4}/YR ESSENTIAL ACTIVITY 10^{-5}/YR BENEFICIAL ACTIVITY 2 x 10^{-6}/YR PERIPHERAL ACTIVITY ASSESS RISK AT 90% CONFIDENCE LEVEL
CORKERTON ET AL (CEGB)	10^{-5}/YR PUBLIC 10^{-4}/YR WORKER
WASH 1400	8 x 10^{-7}/YR
GERMAN RISK STUDY	1 x 10^{-6}/YR
AIF	10^{-5}/YR

Table 1 Some Proposed Numerical Values for Individual Risk Criterion (O'Donnell, 1981)

LEVINE	0.2	FATALITIES/YR
WASH 1400	0.02	FATALITIES/YR
GERMAN RISK STUDY	0.4	FATALITIES/YR
AIF	0.1	FATALITIES/YR

Table 2 Some Proposed Numerical Values for Population Risk Criterion (Implied from Risk Curves) (O'Donnell, 1981)

The latest criteria under consideration by the USNRC are less conservative variations on the theme of the foregoing concepts: nuclear risks should not exceed 0.1% of the risks that might accrue if equivalent non-nuclear power generation were substituted for the nuclear power plants, and also 0.1% of the cancer fatality risks from all other sources.

6. CONCLUSIONS

After a risk accruing from an existing or proposed hazardous activity, such as ship operations requiring passage under bridges, has been estimated, a decision must be made on whether it should be accepted, or some alternative action taken that will mitigate the risk. Whether the original risk may be able to be decided to be acceptable may depend on whether it is small relative to ordinarily accepted "ambient" risks or whether the benefits in accepting it are sufficiently great, which may be able to be assessed by direct comparison of the risk and benefits in common terms, or by comparison to risk-benefit preference relationships in the past. Whether, on the other hand, some alternative action, such as a bridge or ship channel design change or a variation in ship operating procedures, should be decided upon may depend on whether its cost is justified by the risk decrease that it would provide.

These decisions may impact specific exposed individuals or groups. Risks and benefits may directly accrue differently to different individuals and groups, and also may accrue indirectly to others, as well, including the decision maker, such as an activity operator; ship crews; a regulator; an insurer; society as a whole, insofar as harm to affected individuals or groups (especially from a catastrophic accident) could detract from society's present and future values.

This paper has attempted to assess some highlights of the very extensive and growing literature on these considerations. A more complete assessment is also available (Philipson, 1982). It is intended that the understanding of their potential applicability to the specific risk decision problems arising in the presence of ship/bridge collision hazards will thereby be advanced.

REFERENCES

1. Baldewicz, W. et al. "Historical Perspectives on Risk for Large-Scale Technological Systems," UCLA-ENG-7485, 1974.

2. Bowen, J. "The Choice of Criteria for Individual Risk, for Statistical Risk, and for Public Risk," Risk-Benefit Methodology and Application: Some Papers, Presented at the Engineering Foundation Workshop, Asilomar, California: UCLA-ENG-7598, September 22-26, 1975.

3. Cohen, B.L. and I-S Lee, "A Catalog of Risks," Health Physics, v. 36, pp. 707-722, June 1979.

4. Coppola A. and R.E. Hall. "A Risk Comparison," NUREG/CR-1916, Brookhaven National Laboratory, 1981.

5. Farmer, F.R. "Siting Criteria - A New Approach," Proceedings of a Symposium on the Containment and Siting of Nuclear Power Plants, International Atomic Energy Agency, Vienna: April 3-7, 1967.

6. Ferreira, J. and L. Slesin. "Observations on the Social Impact of Large Accidents," Technical Report No. 122, Operations Research Center, Massachusetts Institute of Technology, 1976.

7. Gibson, S.B. "Major Hazards - Should They Be Prevented at All Costs?," Paper presented to the Institute of Management Sciences, Athens: July, 1977.

8. Griesmeyer, J.M. and D. Okrent. "Risk Management and Decision Rules for Light Water Reactors," Risk Analysis, v. 1, no. 2, 1981.

9. Inhaber, H. "Risks from Energy from Conventional and Non-conventional Sources," Science, v. 203, pp. 718-723, 1979.

10. Jones-Lee, M.W. The Value of Life - An Economic Analysis, Chicago: The University of Chicago Press, 1976.

11. Keeney, R.L. Siting Energy Facilities, Academic Press, 1980.

12. Kletz, T. "The Risk Equation - What Risks Should We Run?," New Scientist, May 12, 1977.

13. Libby, L.M. "Technological Risk Versus Natural Catastrophies," Rand Corporation Paper P-4602, 1971.

14. Linnerooth, J. "The Evaluation of Life-Saving: A Survey," Research Report RR-75-21, International Institute for Applied Systems Analysis, 1975.

15. McGinty, L. and G. Atherley. "Acceptability Versus Democarcy," New Scientist, May 12, 1977.

16. Nuclear Regulatory Commission. "Plan for Developing a Safety Goal," NUREG-0735, 1980. (Also see U.S. Federal Register, v. 45, no. 209, pp. 71023-71028, October 27, 1980.)

17. O'Donnell, E.P. et al. "A Proposed Approach to the Establishment and Use of Quantitative Safety Goals in the Nuclear Regulatory Process," The Atomic Industrial Forum, 1981.

18. Otway, H.J. and J.J. Cohen. "Revealed Preferences: Comments on the Starr Benefit-Risk Relationships," Research Memorandum RM-75-7, International Institute for Applied Systems Analysis, 1975.

19. Philipson, L.L. "Risk Assessment Methodologies and Their Uncertainties: Vol. I, A Review of Risk Estimation Approaches; Vol. II, A Review of Risk Evaluation Approaches," Technical Report No. 80-1398, Prepared for the National Science Foundation, J.H. Wiggins Company, 1982.

20. Pochin, Sir Edward. "The Acceptance of Risks," British Medical Bulletin, v. 31, no. 3, 1975.

21. ___________. "Estimates of Industrial and Other Risks," Journal of the Royal College of Physicians, v. 12, no. 3, 1978.

22. Socio-Economic Systems, Inc. "Final EIR for the Proposed Oxnard LNG Facilities," 1977.

23. Starr, C. "Social Benefit Versus Technological Risk," Science, v. 165, September 19, 1969.

24. Wilson, R. "The Costs of Safety," New Scientist, v. 68, pp. 274-275, 1975.

25. ___________. "Example in Risk-Benefit Analysis," CHEMTEC, v. 6, 1975ii.