Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 41 (1983)

Rubrik: Theme E: Acceptance criteria: accepted risk levels

Theme E

Acceptance Criteria - Accepted Risk Levels

Critères d'acceptation - Niveaux de risques acceptables

Annehmbarkeitskriterien - Akzeptiertes Risiko

Leere Seite
Blank page
Page vide

Acceptable Levels of Risk for Technological Undertakings

Niveaux acceptables de risque pour les projets techniques

Annehmbare Risikoniveaus für technische Projekte

William D. ROWE
Director
Institute for Risk Analysis
Washington, DC, USA

William D. Rowe is director of the American University's Institute for Risk Analysis and professor of operations research and risk analysis in the university's Center for Technology and Administration of the College of Public and International Affairs in Washington, DC. From 1972 to 1978 Dr. Rowe was the deputy assistant administrator for radiation programs in the Environmental Protection Agency.

SUMMARY
This paper first provides a short tutorial of various methods for establishing acceptable levels of risk. However, in the marine area, risks of collisions and groundings are different than for many other types of technological undertakings. In addition, the paper provides some original ideas on how information on risks can be used to direct design and construction operations toward achieving acceptable risk levels at reasonable costs.

RÉSUMÉ
Le rapport rappelle diverses méthodes d'établissement des niveaux acceptables de risques. Cependant, dans le domaine de la navigation, les risques de collision et d'échouage diffèrent de ceux d'un grand nombre d'autres projets techniques. Le rapport présente un nombre d'idées originales concernant la manière d'utiliser les informations sur les risques pour le projet et la réalisation de constructions présentant des niveaux acceptables de risques à des coûts raisonnables.

ZUSAMMENFASSUNG
Der Bericht erwähnt die verschiedenen Methoden zur Errichtung annehmbarer Risikoniveaus. Die Risiken einer Kollision oder eines Auflaufens im Bereich der Schifffahrt unterscheiden sich aber von denen vieler anderer technischer Projekte. Der Bericht anthält einige neue Ideen über die Verwendung von Risikoauskünften zur Steuerung der Projektierungs- und Bauvorhaben, in Richtung annehmbarer Risikoniveaus bei angemessenem Aufwand.

1. INTRODUCTION

Every technological undertaking benefits certain groups in society and increases risks to other groups. This inequitable distribution of risk and benefits throughout society leads to necessity of the existence of some levels of risk to be assumed by society as a whole for the societal benefits of new technology. These "residual" risks can be treated in both aggregate and specific analyses to develop acceptable levels for these risks.

Unquestionably, some risks are acceptable. Some conditions that support this contention are evident:

1. A risk is perceived to be so small that it can be ignored -- threshold condition;
2. A risk is uncontrollable or unavoidable without major disruption in lifestyle -- status quo condition;
3. A credible organization with responsibility for health and safety has, through due process, established an acceptable risk level -- regulatory condition;
4. A historic level of risk continues to be an acceptable one -- de facto condition;
5. A risk is deemed worth the benefits by a risktaker -- voluntary balance condition.

The means for establishing acceptable levels of risk for a new technological undertaking are quite different from those for historical risks as a result of risk consciousness in present society. This means that the residual risks from new technological undertakings, such as the construction of bridges and off shore facilities, must be addressed specifically, and acceptable risk levels derived.

Many methods have been developed for setting acceptable levels of risk. In general, these can be broken down into three categories: (1) risk comparisons; (2) cost-effectiveness of risk reduction; (3) risk-cost-benefit balancing. None of these methods are useful for all purposes. Rather, the particular situation determines which methods might be applied for a specific problem.

The first part of this paper is a short tutorial of various methods for establishing acceptable levels of risk. Most of this information has been published in similar, but more extensive, form elsewhere (1,2). However, in the marine area, risks of collisions and groundings are different than for many other types of technological undertakings. Exposure to hazard in terms of early mortality and morbidity is focused primarily on users and geographically identified risk recipients. Liability and property damage can often be addressed by risk spreading such as insurance and by risk mitigation, respectively.

The second part of the paper provides some original ideas on those methods of risk acceptance which might be particularly useful in the maritime area. The objective is to determine how information on risks can be used to direct design and construction operations toward achieving acceptable risk levels at reasonable costs.

2. METHODS FOR ESTABLISHING ACCEPTABLE LEVELS OF RISK

2.1 Definitions

2.1.1 What is Risk?

"Risk" in its broadest definition is the chance for harm. Mankind has always been subject to risk, and will continue to be. The concern of an entrepreneur or manager is to balance a variety of risks, technological,

economic, and personnel, in the pursuit of organizational goals. These are risks which the organization voluntarily adopts as the risks of conducting its business. In contrast, the concern in society today is focused primarily on involuntary risks imposed upon members of society by technology whereby the risk takers are either not aware of the risks to which they are subjected or they do not necessarily share in the benefits of technology.

More formally, risk is the potential realization of unwanted consequences of an event. Both a probability of occurrence of an event and the magnitude of its consequence are involved. The term "hazard" implies the existence of some threat, whereas risk implies both the existence of a threat and its potential for occurrence. Thus a threat (hazard) may exist without implying risk.

The very definition of risk as given above is inadequate when considering societal risk holistically. It focuses only on the negative side and tends to foster unwarranted concern on risks.

A more general definition of risk is 'the downside of a gamble'. While not in conflict with earlier definitions, it broadens the concept to require that a gamble, with gains and losses, be undertaken in order to have risk. Living, itself, involves gambles -- some of which are involuntary, but which often require tradeoffs between the quality of life and quantity (longevity). In this light, some of the major concerns of risk analysis are focused on inequitable gambles, i.e., a gamble where one part of a society gains while another part takes the risks.

2.1.2 Risk Estimation and Evaluation

The term "risk estimation" is used to describe the process of how risks are determined in terms of the probability of occurrence of an event and the magnitude of consequences. The term "risk evaluation" is used to describe the processes used for controlling such risks and arriving at an acceptable level of risk. This latter process is value oriented and is by nature subjective. Risk estimation purports to be value free, but when rare events are treated very large levels of uncertainty exist and the value judgments of scientists are sometimes used in the absence of hard data. Thus, both processes are subjective in nature to some extent, the treatment of uncertainties is risk estimation affects how risks are evaluated and vice versa. This means that the two processes cannot be entirely separated in practice, i.e., the scientist or enquirer making a risk estimate cannot ignore the problems involved in evaluating the risks, nor can the evaluators divorce themselves from an understanding of limits of risk estimation methods.

The subjective nature of risk evaluation leads to identification of factors that affect the way risk takers perceive risks. A number of such factors have been identified.

2.2 Factors Affecting How Risks Are Perceived

There are a number of factors that affect the manner in which people value risks subjectively. The following five factors seem to be of some significance.

2.2.1 Ordinary vs. Catastrophic Risks

The definition of a catastrophic risk is arbitrary. One such definition is for a single event in which 10 or more people are killed, 30 or more people are injured, or property damage exceeds $3 million, or any combination of these. Less than two percent of all accidents and about 0.1 percent of all deaths (1970) are caused by catastrophic events as defined above, and of these, over 95 percent are naturally occurring events. Nevertheless, media attention and public concern tends to focus on these events. The

perception of risk and subsequent public action are determinants of what risks will be tolerated by societies from large accidents.

2.2.2 Voluntary vs. Involuntary Risks

Most voluntary risks have some component of involuntary risk (e.g., the non-smoker in a smoke-filled room). Most people seem to accept higher levels of voluntary risks than involuntary ones. The definition of these two types of risk is complex and has at least four aspects involved.

- Degree of self-imposition: self-imposed vs. forced acceptance.
- Equity: degree to which the risk taker participates in receiving the benefits of the gamble.
- Level of information for decisions: adequacy of information to decide vs. purposeful withholding of information.
- Availability of suitable alternatives: real alternative choices must be availalbe.

These aspects combine to form various conditions for voluntary and involuntary risks.

2.2.3 Latency vs. Immediacy of Consequences

Delayed consequences of an event are often discounted on a voluntary basis such as cigarette smoking. However, involuntary risks are not usually discounted or are done so at very low discount levels. Such discounting is analogous to present worth in an economic sense for voluntary risks, where alternative choices as to use of money or life are available. For involuntary risks, such choices are not available. Neither opportunity costs for future money streams nor means of avoiding risks exist. This is, of course, true for affected progeny as well.

2.2.4 Spatial Distribution of Risks

Increased concern is focused on identifiable risk recipients in society as opposed to statistical populations at risk. This is particularly true for occupational hazards where the risk recipients are directly known.

2.2.5 Controllability of Exposure

Both the actual level of control and the perceived degree of control over exposure to risk that a risk recipient has affects the willingness to take risks. The higher the degree of perception of control (coupled with the degree of voluntariness), the lower the anxiety that people have in exposing themselves to risk. The importance of these factors will become apparent in the process of risk evaluation that follows.

2.3 Methods of Risk Evaluation

There are many approaches to evaluating risks to determine acceptability. The most important of these have been grouped into three categories for discussion. These categories include: risk comparison approaches, the cost effectiveness of risk reduction, and cost-benefit balancing.

2.3.1 Risk Comparison Approaches

The risks estimated from a given undertaking or source of risk can be compared to benchmarks, criteria, or value judgments to determine acceptable levels of risk. Risks to individuals and populations must both be considered.

A major question involves the use of objective risk or perceived risk in estimating "actual" risks. This dichotomy arises from two sources: the uncertainty in measurement of risk; and, the variability in perception of risk by individuals. In the first case, the estimated risk cannot be fully equated with actual risk because probability and consequence estimates that make up a risk estimate may be inexact.

The variability of perceptions of risk is affected by many factors such as those discussed in Secton 2.2. There are only a limited number of methods for ascertaining the impact of these factors: revealed, expressed and implied preferences.

- Revealed preferences - this method is based on the assumption that, by trial and error, society has arrived at a nearly optimal balance between the risks and benefits associated with any activity. One may, therefore, use statistical cost, risk, and benefit data to reveal patterns of acceptable risk-benefit tradeoffs. Acceptable risk for a new technology is assumed to be the level of safety associated with ongoing activities having similar benefit to society.

- Expressed preferences - the most straightforward method for determining what people find acceptable is to ask them to express their preferences directly. The appeal of the expressed preference method is obvious. It elicits current preferences, thus being responsive to changing values. It also allows for widespread citizen involvement in decision making and, thus, should be politically acceptable. It has, however, some possible drawbacks which seem to have greatly restricted its use. For example, people may not really know what they want, their attitudes and behavior may be inconsistent, their values may change so rapidly as to make systematic planning impossible, they may not understand how their preferences will translate into policy, they may want things that are unobtainable in reality, and, different ways of phrasing the same question may elicit different preferences.

- Implied preferences - the implied preference method may be seen as a compromise between the revealed and expressed methods. It looks to the legal legacy of a society as a reflection of both what people want and what current economic arrangements allow them to have. Its proponents, like those of the democratic process, make no claims to perfection; rather, they see it as a best possible way of muddling through the task of bringing risk management in line with people's desires. The problems here are familiar to any participant in a democracy: our legal legacy includes not just laws adopted by our elected representatives, but also interpretations and improvisations by judges, juries, regulators, and others.

The objective of these methods is to obtain reference levels of risk that the public would accept as reasonable, and to use the references as benchmarks against which value judgments made for limiting specific risks can be compared.

The difficulty of setting acceptable levels of risk by considering risk alone is not only confounded by inequitable risk distribution, but by the size of the populations involved. Risk to an identified risk taker is different from that of a statistical member of the population. Large risks to a few people and small risks to large numbers of people are not directly reconcilable, and concern for both aspects requires dichotomous approaches in their consideration.

Informed consent is a process whereby a risk agent who is properly informed about a potential hazard and chooses to expose himself to it for whatever perceived benefit, is taking a voluntary risk. Thus, informed consent implies a transfer of an involuntary risk to a voluntary one under the control of the agent himself.

2.3.2 Cost-Effectiveness of Risk Reduction

When risk criteria alone are inadequate to establish acceptable risk levels, economics may be brought into consideration. This results in the cost-effectiveness of risk reduction, a paradigm that has many aspects. It is often called cost-benefit analysis in a narrow sense, since the benefit considered is that of risk reduction. Various actions to reduce risk may be ordered on the basis of the ratio of the magnitude of risk reduced and the magnitude of the cost of risk reduction. When smoothed, the resultant curve is concave upward (Figure 1), i.e., higher costs result in less risk reduction. The major question remaining is when to stop spending money for further risk reduction.

A number of arbitrary conditions may be considered (Figure 2), all involving external references. In all cases for cost-effectiveness of risk reduction, a referent is required to set acceptable levels of cost-effectiveness of risk reduction.

Different types of technological risk references that have been used or considered are shown in Figure 2. Conversely, if a goal is stated beforehand, such as the amount of risk to be reduced or the absolute level of risk to be achieved, then alternate strategies may be compared, each with a separate marginal cost-effectiveness curve as illustrated in Figure 3. Two alternative strategies, I and II, are shown, each with its ordered set of possible control options. The two strategies cross over at a particular point which indicates an indifference level for either cost or risk reduction, but not both. On a given cost basis, there are two points (circles) which can buy different amounts of risk reduction. Likewise, the vertical line indicating a fixed degree of risk reduction provides two alternate cost levels (crosses). The two squares illustrate the case where the ratio of the marginal cost and marginal risk reduction are equal to a specific value a. The square indicates where the slope of lines, are equal to a -- in this case a wide spread.

Another approach involves placing a value on an avoidance of a statistically premature death. Four approaches have been considered in the literature.(2) These also involve value judgments, and implicit social evaluation often takes place after a risk level has been set by other means, i.e., the value of lives saved is calculated from the decision.

- Human Capital Approach - the value of life is based on the premise that a person's worth to society depends on his productivity, and as a productive unit is considered human capital.
- Implicit Societal Evaluation - since society, through its political processes, does in fact make decisions on investment expenditures which occasionally increase or decrease the number of deaths, an implicit value of human life can be calculated. Such a method approaches the problem from a social point of view by estimating the expenditure society actually makes to save a life.
- Insurance Premiums and Court-Decided Compensation - it has been suggested that the amount of life insurance one is willing to purchase is related to the value one places on his life and the probability of being killed by some specific condition or activity.
- The Risk Approach - a more meaningful measure that often can be explicit is the amount of money society and the infrastructure are willing to pay to prevent a premature death. This can be observed by actually measuring what society pays for safety and antipollution measures. This is a derived measure.

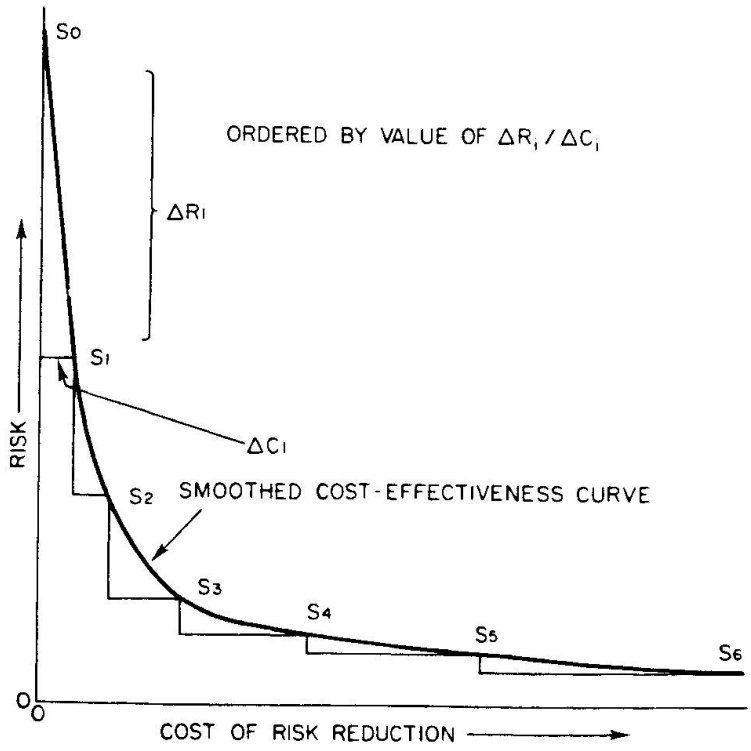

Fig. 1 Cost effectiveness of risk reduction ordered relationships for discrete actions. S_1 = Risk reduction action. ΔR_1 = Changes in risk for S_1. ΔC_1 = change in cost for S_1.

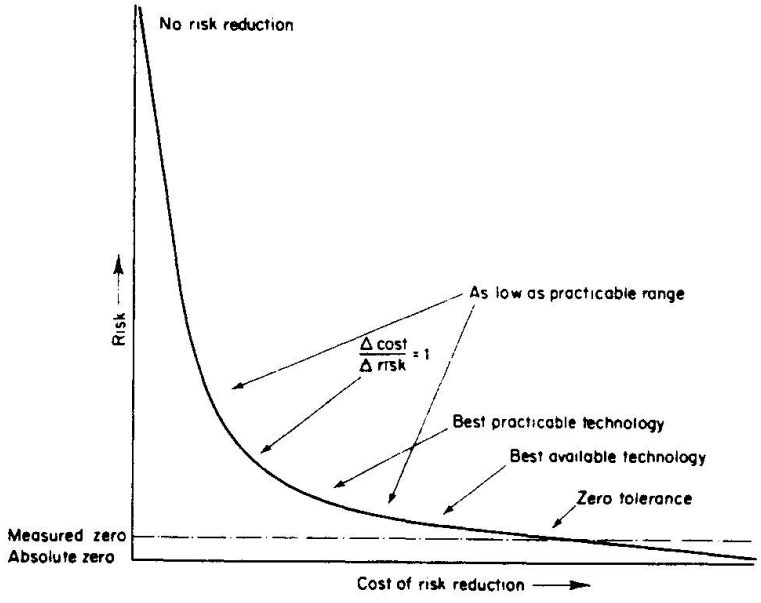

Fig. 2 Some criteria for acceptance levels of cost effectiveness of risk reduction.

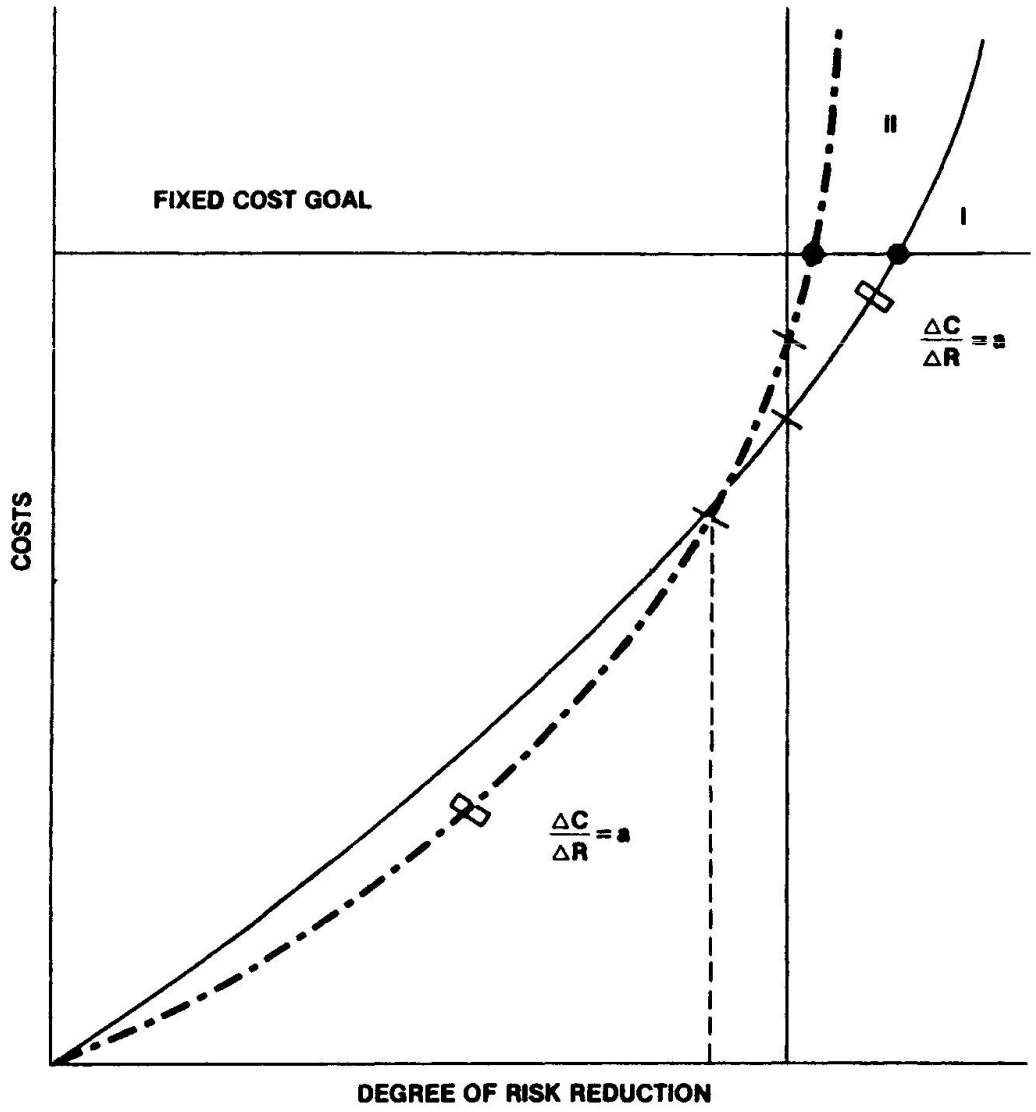

Fig. 3 Cost effectiveness of alternate strategies for goals set a priori.

2.3.3 Cost-Benefit Balancing*

So far, only direct expenditures for the purpose of reducing risks have been considered. While the reduction of risk is beneficial, there are other benefits to the activity causing risks that must be considered. The gains and losses, both direct and indirect associated with the activity are involved. Direct gains and losses are those undertaken by the program sponsor. Indirect gains and losses are those undertaken by society.

To make a cost-benefit balance, the indirect costs and risks (losses) reduced by direct and indirect expenditures (losses) must be balanced against direct and indirect benefits (gains). The concern for societal cost-benefit balancing is with the indirect components. Such a balance is made when one superimposes over the curve for cost-effectiveness of risk reduction (Figure 2), a curve for achieving the cost-effectivenes of obtaining direct and indirect gains (benefits). This latter curve is convex upward, since the steps to obtain benefits can be ordered by ratio of gain to direct cost. However, this generally requires a scale different from that used for losses (indirect costs). Both curves appear in Figure 4.

Economic theory indicates, assuming the scales for indirect losses and gains are identical, that balancing the two curves at the margin will provide an economically optimum condition. This means that when the slopes of the two curves (their first derivatives) are equal, another dollar spent to achieve benefits will be no more efficient than a dollar spent to reduce risk.

The assumption that the two scales are identical seldom holds in practice and is the exception rather than the rule. Attempts to find weights to assign to the scales to equate them involves considerable uncertainty.

The uncertainty in measuring each parameter is another limitation. Determination of risks involves uncertainty in knowledge of exposure-risk relationships, and uncertainties in specifying intangible benefits are often much greater than uncertainties in risk estimates. Even when gain and loss scales are identical, the uncertainties in measurement are so large that meaningful analysis probably is not obtained. This is illustrated in Figure 5 where the bands of uncertainty for indirect losses and gains indicate a relative basis of knowledge of each.

Finally, the distribution of cost and benefits are very seldom to the same groups of people. Thus, equity problems in distribution must be addressed and involve value judgments which are often political, i.e., which groups in society receive protection or not and which pressure groups receive benefit considerations. Often, subsidies may be involved in government decisions. The identification of subsidization must be separated from the desirability of carrying them out. Visible subsidies require explicit decisions, invisible ones may mask the need for such decisions.

From the discussion above, it is evident that no single method or approach is useful in all cases. What works in one case may not be valid in others. Moreover, combinations of these approaches may be necessary, especially when political problems are important.

---

*The term "cost-risk-benefit analysis" is often seen in the literature. The following equivalence with gains and losses is used here:
COSTS: Direct losses (economic and otherwise);
RISKS: Indirect losses (economic and otherwise);
BENEFITS: Gains, both direct and indirect.

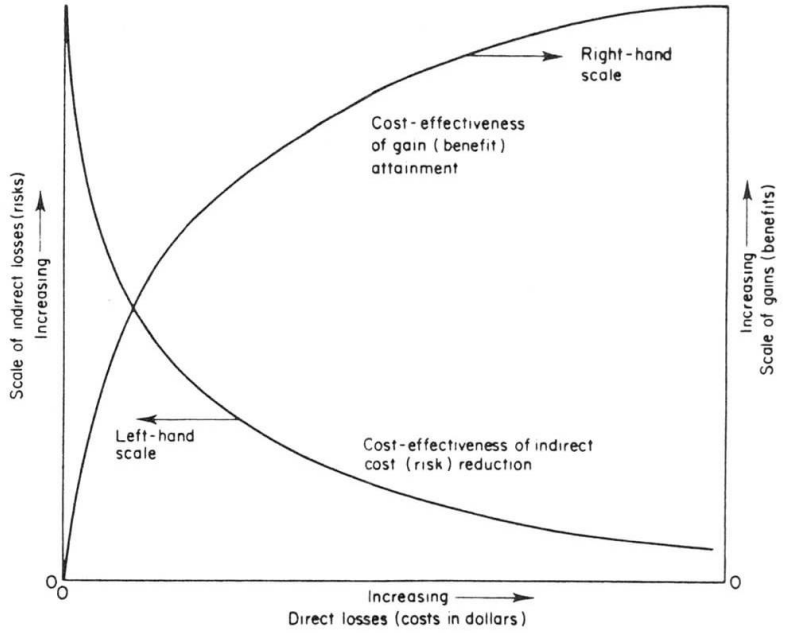

Fig. 4 Gain and indirect loss curves as a parametric function of direct loss (cost) expenditures.

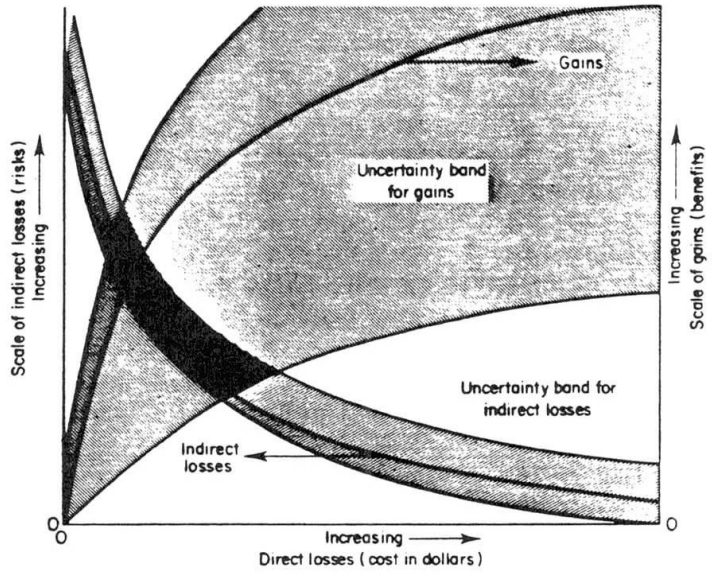

Fig. 5 Bands of uncertainty for gain and indirect loss curves.

3. RISK ESTIMATION AND EVALUATION PROBLEMS IN THE DESIGN OF BRIDGES AND OFF-SHORE FACILITIES

3.1 Overview

How can one estimate the risk of collision and the magnitude of consequences from such an event which is both rare and situation dependent? Moreover, what protective measurements should be designed into bridge structures and off-shore facilities at what additional cost? These are key issues in the estimation and evaluation of bridge and off-shore facility design. I will attempt to provide some different approaches to these problems.

3.2 Risk Estimation Problems

It is obvious that ship collisions with bridges and off-shore facilities are rare events and historic data provide anecdotal rather than analytically useful information (3). That this is so should not be surprising.

3.2.1 Limitations of Historical Data

Since catastrophes are hoped to be rare events, historical data should be expected to be sparse; in most instances this is borne out. In a related area data in the United States from the Department of Transportation, indicates that the number of incidents involving transportation of hazardous materials is on the increase. However, if one normalizes these for the volume of traffic in each case, depending on the normalizing parameter, for example, ton miles, many of these increases disappear. For example, in calculating ton miles in the United States, the total vehicle miles of truck travel on urban, main and local rural roads increased at about six percent per year from 1968 to 1978.

The statistics just do not show major changes in the rate of catastrophes from transportation of hazardous materials. Based upon historical data alone, one must come to the conclusion that the problem is under control. However, nearly all people who are participants in the industry have the intuitive feeling that the conditions for large disasters from hazardous materials accidents are getting worse, namely, the potential for catastrophe is increasing. Which is correct, data or intuition?

It may well be that we have been looking at the wrong data or the real problem is masked by the rarity of catastrophic events and by other factors. When the events are less rare, it becomes evident that large accidents cause more problems than small incidents. The number and volume of tank barge spills is a case in point. Table 1 shows the number and volume of tank barge spills in eight port systems over a five-year period. Six spills representing only about two percent of the number of incidents resulted in 66 percent of total volume spilled. Large accidents predominate although they happen less frequently.

Table 1 Number and Volume of Tank Barge Spills in Eight Port Systems (1973-1974) (For Spills $\geq$ 2.4 Barrels)

Spill Size (Barrels)	Number of Spills	Percent of Total	Volume of Spills (Barrels)	Percent of Total
2.4 - 10	211	63.2	1,029	1.8
10.1 - 50	79	23.6	1,885	3.3
50.1 - 100	12	3.6	915	1.6
100.1 - 200	11	3.3	1,677	3.0
200.1 - 2,000	15	4.5	13,716	24.3
> 2,000	6	1.8	37,259	66.0
Total	334	100	56,481	100

Source: PIRS, U. S. Coast Guard, 1978.

Is is possible to address rare events through use of historical data alone? Sparse data makes it virtually impossible to gain significant information about rare events in this manner. What has been attempted in the past is to look at either events of higher probability and smaller consequences whose cause and effect relationships are hypothesized to be similar to the rare events to be studied, or to look at other rare events that have occurred and hypothesize that the same processes are involved as those of concern. In the first case, extrapolation from consequence magnitude versus frequency of occurrence profiles is attempted. In the latter case, the data base is increased since the number of events is larger, but the validity of grouping these events is questionable. For example, the number of nuclear reactor accidents versus reactor years of operation usually group ship propulsion reactors with electrical generation reactors, or operating data for small and large pressurized water, boiling water and other types of power reactors are aggregated without close examination of the validity of such approaches.

The need to evaluate the possibility of future catastrophes from existing and new technological systems exists. For rare events whose potential consequence magnitudes are only limited by man's imagination, the usual methods of probability and statistics do not work.

3.2.2 Redundancy and Margins of Safety

Means to provide a more meaningful evaluation of catastrophic risks are postulated here, namely, that safety is a function of multiple, redundant systems, each with a margin for error intrinsic to the system. Moreover, accidents only occur when the margin of error in each of the redundant systems is overcome simultaneously for whatever reasons. For example, a near miss or a collision of passing vehicles is only a margin of distance or lack of such margin, respectively.

As long as margins of error (or safety) are not exceeded, accidents do not occur. What is not known is how much margin of error and redundancy exists and whether these margins are being reduced. For example, in the marine transportation of hazardous goods, as traffic builds up to capacity in a port, redundant systems of traffic control, separation and maneuvering room during passage, and ship-to-ship communications all work to prevent collisions. Once capacity is exceeded, all margins for error may disappear and a steep rise in collisions and rammings may be expected. The change in hazard potential is abrupt and non-linear, once redundancy and safety margins are used up. The impending conditions may be well masked up to the point of exhaustion.

An analogy using control theory parlance may be useful. The measurement difficulty here is similar to that of trying to measure the parameters of a high gain control system with negative feedback. The objective is to measure the open-loop gain and system transfer function without disconnecting the feedback loop or exceeding the gain of the system. The feedback masks the parameters to be measured. Thus, any measures of system performance will not be very precise. In specifying system open-loop behavior, a resultant set of indices derived from such analyses will be more descriptive than normative.

It should be possible to develop some understanding of the effect of safety systems such that the degree of redundancy and margins of safety can be ascertained on either an absolute or relative basis. In the first case, an absolute measure of redundancy and safety margins can provide insight as to how far one is from potential catastrophe. In a relative sense, alternate systems can be evaluated as to their degree of safety, allowing attention to focus on those with the least margins.

Alternatively, the impact of alternate safety approaches can be evaluated as to how much redundancy and how many safety margins they add to a system, for example, double hulls in barges.

3.2.3 Event Tree/Fault Tree Analysis

Probabilistic analysis using combinations of event and fault trees may be used to examine system vulnerability to random, human, systemic, and common mode conditions. The purpose is not to establish absolute levels of risk, but to determine system weak points and alternative methods of reducing the system vulnerability at these points.

The difficulty with this approach is with its mis-use, i.e., attempting to use risk estimates from event/fault tree analyses to provide absolute risk estimates for risk acceptance or to establish a stopping point for applying reductions in system vulnerability. The large uncertainties in rare event estimation as discussed previously make this use unacceptable as it can neither provide acceptable estimates nor means to establish when particular risk levels have been achieved.

However, when the methods of event/fault tree analysis are used appropriately, they are effective approaches for both vulnerability analysis and comparative risk analysis.

3.2.4 Combining Vulnerability and Fault/Tree Analysis for Bridge and Off-Shore Facility Risk Estimation

Risk models for bridges have been developed in the past for a geometric analysis of ships out of control, for different size vessels, and for different conditions (4). The problem with such models is to determine when and where a ship or navigation failure occurs and how it will affect the propensity for uollision.

An alternate approach suggested here is to make an analysis of the margins of safety of different class vessels during normal operation using the assumed navigational aids, procedures, and design for achieving safe passage. Then an event fault/tree analysis is made by analyzing a range of traffic events under different fault and error conditions to identify margins of safety.

Any such analysis must take into account three different sub-systems (5): (1) vessel, (2) vessel cargo, and (3) bridge-channel (or off-shore) characteristics. The vessel sub-system involves ship maneuvering characteristics, e.g., acceleration, turning radius, length, etc; onboard information and control systems and their operational state when entering the bridge-channel system (or off-shore), the crew in terms of experience, level of manning, and level of training, the maintenance level of ship, equipment, and crews.

Since many ships carry hazardous materials, the type of cargo, in terms of flammability, toxicity, and potential for explosions, must be taken into account as well as the design of the vessel to withstand collisions, rammings, and groundings should an incident occur. For risks to bridge structures hazardous cargos, e.g., ignition of bilge gases in tankers, which can affect bridge structures if the events occur in proximity to the bridge, must be considered also. These events which may be initiated by events other than collisions, rammings, and groundings can cause extensive damage due to explosions and fires from flammable cargos and exposure of people, workers, and rescue personnel from toxic cargos.

The bridge-channel sub-system has three zones: an upstream zone, a bridge proximity zone, and a downstream zone depending upon channel current and tidal characteristics. An off-shore facility might have a close proximity zone and upwind and downwind zones or some other variation. In each zone,

there are a number of factors which are characteristic of the bridge-channel sub-systems:

1. Existing regulatory considerations and their degree of enforcement;
2. Facilities or services provided by the channel or bridge authorities, including navigation aids;
3. Hydrography -- channel configuration and width;
4. Hydrography -- depths and heights;
5. Channel traffic density;
6. Short-term variables, including current and tidal factors;
7. Seasonal factors;
8. Temporary restrictions to navigation;
9. Weather;
10. Line of sight.

An event tree/fault tree analysis must be made for each zone. The event tree outlines combinations of occurrence in each zone for normal operation of vessels under a variety of different conditions of weather, seasonal and short-term variables for different traffic densities. Average and worst case traffic and cargo situations can be ascertained using the event trees. Fault trees are superimposed over the event tree structure to understand the impact of failure of each component and various combinations of operational systems to determine the comparative margins of safety. Margins which are shown to be low compared to others can be dealt with by either preventive or mitigative measures.

A number of investigators have attempted quantitative approaches in related areas (6). There is insufficient space here to review this work to show how it can be applied in an event/fault tree analysis.

3.3 Risk Evaluation Problems

Risk evaluation for bridge structures and off-shore facilities to people are unique in that the risk recipients are workers rather than the general pubic, except for one specific case, namely, user traffic on bridges. In the case of off-shore facilities, the risk recipients are workers on the facility, supply boat personnel, rescue workers, or ramming vessel crews. Bridge employees, rescue workers, and ramming vessel personnel are involved for bridges.

3.3.1 Risks to the Public

For bridge-channel systems the only major public exposure attributable to the bridge are injuries or deaths to users on the bridge during an accident. There is, perhaps, a slight increase in risk to those living on-shore in proximity to bridge-channel systems, especially from hazardous cargos. However, if one assumes that the channel would be used for these same cargos, irrespective of the bridge, then this is not a change in risk. The new channel constraints due to bridge abutments and the bridge span may provide an increased exposure to collision, but channel deepening and navigation aids decrease exposure. Thus, the bridge may actually reduce the risk from present practice.

On this basis, the risk evaluation to people is constrained to workers and to people on the bridge. The latter case is an interesting one, because the very benefit of the bridge is to increase traffic between the embankments and provide a convenient means of transport. Alternate means of transport without a bridge, e.g., boats and ferries, may entail even higher risk. One control action is apparent -- to prevent loss of life to bridge users is to restrict traffic under conditions where margins of safety are minimal from examination of the event/fault tree analysis, i.e., under severe weather conditions or when emergency procedures are in force to restrict traffic.

3.3.2 Risks to Workers

Risk to workers is not necessarily increased by the presence of the bridge or off-shore facilities any more than any other navigational obstruction. Therefore, the risks of the presence of the structure is not a major contributor to worker risk. On off-shore facilities, job-related risks involving drilling, maintenance, production, and threats from weather, dominate. On bridges, construction and maintenance work dominate. Certainly steps to reduce such risks are important and system safety practices are aimed at reducing these risks.
Risks to emergency rescue personnel are another concern. In these cases, there is often a unique risk-benefit trade-off in a voluntary sense. Emergency rescue personnel are not always paid in direct salary for the risks they take, but the nature of the job and the excitement involved provide benefits in themselves to the kinds of people who are attracted to these professions. Again, system safety procedures to minimize risks to emergency workers are usually practiced.

3.3.3 Structural Damage

Perhaps the major risk problem is from structural damage to the bridge from a ramming or grounding with or without a hazardous cargo problem. The loss involves the cost of rebuilding the structure and the loss of use of the structure for traffic or drilling during repair.

The case where the collision is a kinetic one, without cargo problems, is the one most often considered. How much should be spent in design to prevent collision damage versus the hypothetical accident risk is the major question. The development of hypothetical accident risk profile and the effectiveness of design measures to mitigate such accidents are, along with costs, the critical variables. Presumably, the event/fault tree margin of safety approach may provide meaningful trade-offs. Prevention of accidents through careful control of traffic may be the most effective approach once reasonable design considerations for mitigating rammings and groundings has been made. This becomes obvious when hazardous cargos are considered.

Hazardous cargos containing explosives or inflammables are probably the major impact problem should a ramming or grounding occur. The explosion or fire resulting from cargo ignition will have more impact than the kinetic energy of collision alone. There is no way that any structural design for withstanding a ramming can account for the cargo ignition damage. If this is the case, then careful traffic control, e.g., prevention of hazardous cargo movement when margins of safety are minimal, such as during adverse weather conditions or high traffic density must be implemented.

3.4 Conclusions

The problem in estimating rare events is that they are rare. Large uncertainty will always exist. However, the risks to the public and generally to workers from rammings and groundings is generally minimal. The benefits to bridge users outweigh the risks by far. Only workers are involved in off-shore platforms.

Hazardous cargo transport makes the construction of ramming resistant structures only partially effective. The most risk reduction in this light may be provisions for operational control of traffic during times when margins of safety either for vessels, cargos, and the bridge-channel systems are lacking.

4. REFERENCES

1. ROWE William D., Risk Assessment Approaches and Methods. Society Technology and Risk Assessment (J. Conrad, ed.). Academic Press, 1980, pp. 3-29.

2. ROWE, William D., Corporate Risk Assessment. Marcel Dekker, Inc., 1982.

3. IABSE Proceedings P-31/80. International Association for Bridge and Structural Engineering, May 1980.

4. IABSE Proceedings P-31/80. International Association for Bridge and Structural Engineering, May 1980, pp. 84-85.

5. DANAHY, P. J. and GATHY, B. S., Equivalent Safety and Hazardous Materials Transportation. ASME Paper 73-ICT-86 presented at the Intersociety Conference on Transportation, Denver, Colorado, September 1973.

6. Equivalent Safety Concept for the Marine Transport of Materials. Report of the Panel on Equivalent Safety Concept of the Committee on Maritime Hazardous Materials, Publication NMAB-389, National Academy Press, 1982.

Risk - A Subjective Notion Differently Perceived

Le risque - une notion subjective différemment perçue

Risiko - ein subjektiver unterschiedlicher aufgefaßter Begriff

Jean-Michel PLANEIX
Scientific and Technical Advisor
Bureau Veritas
Paris, France

Jean-Michel Planeix, born in 1920, took engineering and university degrees in Paris and received his Ph.D. in Nuclear Engineering at the University of Michigan, in 1958. He served with the French Navy until 1967, retiring as Captain. Before becoming advisor, he directed developments in hydrodynamic and finite elements calculations at Bureau Veritas and was head of its offshore department. He is chairman of the "Design Philosophy and Criteria" Committee of the International Ship Structures Congress

SUMMARY
This introductory paper proposes a few thoughts on the perception of risk in individual life as a member of society, in the face of development and economic constraints, and in engineering activities. The accent is placed on a general transition from determinism to probabilism in many domains of man's endeavours and on the rôle of engineers in promoting safety. A plea is made for the development of the individual sense of responsibility as the most efficient way of meeting accepted risks.

RÉSUMÉ
Cette contribution propose quelques réflexions sur la perception du risque dans la vie individuelle, dans la vie en société, en présence de contraintes de développement et de contraintes économiques et dans l'activité de l'ingénieur. L'accent est mis sur une transition générale du déterminisme au probabilisme dans de nombreux domaines de l'entreprise humaine et sur le rôle des ingénieurs dans l'amélioration de la sécurité. Un appel est fait pour le développement du sens individuel de la responsabilité, qui apparait comme la façon la plus efficace de faire face à des risques acceptés.

ZUSAMMENFASSUNG
Dieser Artikel beinhaltet einige Überlegungen zur subjektiven Risikowahrnehmung vor, als Mitglied der Gesellschaft angesichts der allegemeinen Entwicklung und wirtschaftlichem Zwang sowie im Rahmen von Ingenieurtätigkeiten. Das Schwergewicht liegt hierbei auf einem allgemeinen Übergang vom Determinismus zum Probabilismus in vielen Bereichen des menschlichen Strebens sowie auf der Rolle des Ingenieurs als Förderer der Sicherheit. Die Entwicklung des eigenen Verantwortungsbewußtseins wird befürwortet als die beste Art und Weise, akzeptierten Risiken zu begegnen.

1. ETYMOLOGY

The organizing committee of the International Colloquium on Ship Collision with Bridges and Offshore Structures has honoured me in asking me to prepare an introductory paper for this symposium. For the sake of brevity, I choose to use no illustrations, only a few tables and to make no references.

Having to affront the peril of discussing risk, it is perhaps well that I make first an attempt at finding out what risk means. Dictionaries define "risk" as: "the chance of injury, damage or loss", "danger, inconvenience, more or less foreseeable". The word might stem from the latin "riscus" or "resecare". In turn, we find that "riscus" means an object made to contain jewels, clothes ..., and that "resecare" means to sever, to shorten, for example: "collum resecare", to sever the head (Seneca). Also, "risk" might come from the French "risque", for which Latin dictionaries give the equivalent of "alea", for example: "alea belli", the risks of war (Varro). Interesting is the synonym "periculum"; "rem periculi sui facere", to undertake something at one's own risk.

This little etymological trip was only meant to introduce the character of risk: (1) risk is not easy to define; (2) risk is a subjective notion, associated with fear that an unwanted event may occur: for example, losing one's jewels or having one's head severed; (3) risk is associated with randomness (alea).

My modest purpose, in this talk, is to develop the subjective and aleatory character of risk (sometimes, I shall substitute the opposite of risk: safety) in some domains:

- individual life,
- life in society,
- risk/safety with development and economic constraints,
- risk/safety in engineering,
- and, as a peroration : imposed safety against self-responsibility.

2. RISK IN INDIVIDUAL LIFE

The sense of risk is not, by and large, innate, but acquired by experience in life. To be sure, the instinct of fear corresponds to a broad perception of risk and, perhaps, in some cases, to a more precisely defined danger. I have read (a long time ago, so that I cannot make the proper quotation: Julian Huxley?) that the feeling of free-fall, which sometimes wakes us up, comes down from our ancestors, small mammals, which slept in trees to avoid predators. The fact that the species which survived were those having the keenest perception of falling and the reaction to grab for support is sufficient to explain the hereditary transmission of that perception and that hereditary transmission has nothing to do with the experience gained by the animals, i.e., that, if they fell from the tree, they would probably end up being eaten by predators.

Infants have no sense of risk. They have to be taught what represents a danger. Even if not taught, however, a normal human eventually develops a substantial sense of risk, by experience (unless some early risk is fatal to him; present aborigines show this to be true). But, a complete "imbecile", left to his own devices, might never acquire the broad notion of risk and, therefore, we may say that risk may never "exist" for him. There are such "imbeciles", as we shall see in a moment.

The last statement may shock you. However, you will agree with me that many (not to say, most) of us are impervious to the notion of risk when we act on our free will. Examples are easily found: most ordinary citizens do not check that

they may be short-circuited when working on the house electrical lines or appliances (not so many years ago, a famous singer was electrocuted while removing a bulb, both his feet in his bathtub), or that their chain saw does not drive the chain when the engine is at idle speed. There are also people - a fair percentage - who, not only go skiing, but even fight to get a reservation to some resort, returning, as a final result, with a broken limb. I found statistics of accidents for a Western European middle-sized country, for the year 1977, which indicate 13,000 deaths by accidental fall.

In opposition to the sense of risk, there is the feeling of safety, which we derive from experience, even more so than the sense of risk, since most of our actions are safe. We use public - or mass - transportation, on land, on the water or in the air, without particularly worrying about the accident rate involved. Here, we - not quite as complete "imbeciles", but like sheep in a herd - implicitly accept risk.

But the "activity" which tops them all, for our purpose, is driving - or riding in - an automobile. In a certain country of around 50 million inhabitants, there were 12,500 killed two years ago (1980) in automobile accidents. If all these inhabitants had been driving or riding in automobiles, this would give a yearly death rate of 2.5 deaths per 10,000 people. But, people, especially if we consider the whole population, do not spend, on the average, one hour a day, all year round, in their car (meaning more than 18,000 km car travel a year), while 8 hours a day are spent at work. So, compared to death by work accidents, the auto death rate, in the (real) example is over 10^{-3} deaths/person-year. As we shall see later, this compares very "favourably" with the rates of all kinds of industrial endeavours. There is more : for the same year, in that same example country, there were more than 300,000 wounded in automobile accidents. Say, that out of these, 125,000, or less than one-half, were seriously injured, as would be the case for recorded accidents at work, then the auto rate is 10^{-2} accidents/person-year, a rate that beats, by far, any record in industry. For car drivers and passengers, we might say that risk does not exist. Yet, who would be so idealistic as to believe that, today, he can educate his fellow beings in automobile risks? We should never forget such figures of self-imposed risk in discussing other aspects of risk perception or, more positively, of safety enhancement.

3. RISK IN SOCIETY

The perception of risk in society evolves under three influences which are: (1) groups of "users of safety" - that is, people engaging in some activity for a salary, or who feel that some activity in which they do not take part may impinge on their safety - exert a pressure to obtain an increased safety; (2) national and international regulators have the vocation of ensuring safety; (3) the prevention of accidents in industrial undertakings is of paramount importance for humanitarian, employees' morale (with increased pressure for improvement), image, and economic reasons.

Users' pressure invariably comes from some responsible people in a group who make a speciality of looking after the safety of the group, rather than from individuals in their separate ways. In this case, like in the case of regulators and that of a company working for increased safety on humanitarian grounds, the altruistic aim is to protect the individual better than he can protect himself, a situation very akin to teaching an infant not to put his fingers into an electrical socket.

This attitude has a somewhat self-defeating tendency, asking too much from the entity "society" and not enough on the part of the individuals, in what should be a common effort to improve safety. In group action, too much results from attractive slogans for factual aspects of risk to be perceived.

On the contrary, interest of industry in reducing risks for economic reasons might stick too much to facts and somewhat inhibit progress towards more safety.

There is thus a need to strike a balance between a somewhat irrational - and often demagogic - clamour for more safety, on humanitarian grounds which are well accepted in their principle, if not, often, in the use that is made of them, and a perhaps too down-to-earth approach to the avoidance of risks. One might think that regulations would bring that needed balance. One would be wrong. For one thing, official regulators shrink at defining risk and even more - to using a pretentious verb - to "quantify" it. For another thing, they are loath to take the real responsibility of accidents. Risk levels are obviously implicitly assumed, and accepted, and the endorsement of this acceptance by the public is considered "de facto" acquired, as in the case of public transportation. The public might be informed, by sundry media, of accident rates, it never is officially, unless some individuals (who cannot, by their sheer paucity, represent the public) engage in an arduous hunt for official statistics.

I am sure you will agree this is a very unsatisfactory situation for engineers, who devote an increasing proportion of their activities to designing systems ensuring an increased safety, or, even more, to devising new procedures for improving safety and to indicating the appropriate way for their incorporation in new designs.

"Decipimur specie recti" wrote the Latin poet, Horace - we are deceived by the appearance of what is good -. I am prone to agree with my old Latin book.

4. SAFETY AGAINST DEVELOPMENT AND ECONOMIC CONSTRAINTS

The crux of the discussion of risk is, I believe, centred on the perception of risk by those who "do the job". This vast group includes technical people, in administrations, designers, builders and their subcontractors, and the specialists who have to evaluate the worthiness and safety of a project, from "assurance of quality" to "certification". This group is extremely documented and is, by and large, at the top of those capable of understanding and using the most modern techniques for design, incorporating an added degree of safety.

Of course, added risk avoidance - or, as we prefer saying, safety improvement, which is a more constructive concept - can only be achieved with a cost. The problem then is: up to what cost are we capable of ensuring safety? Posed by an industrial concern, the question would seem ludicrous, not to say unacceptable. Safety, by all standards of developed societies, must, implicitly, be ensured at all costs by all those who employ paid personnel... except states, which regulate for a certain "social security" coverage, never (that I know of) challenged by courts.

Yet, it is comparatively easy to assess the industrial cost of given safety measures, with modern methods of analysis. It is not acceptable to evaluate safety, in the industrial domain, in terms of deaths or of personal injuries. Rather, if this is done, the level of safety, taken as a threshold is considered as at least equal to a tacitly accepted level. For example, an accepted level of personal accidents of all kinds and severity in public transportation might be 300 in 10 billion passengers, as is the case in the Paris "Métro". It is

obvious that the pursuit of safety - perhaps extended to the more encompassing notion of welfare (but with limits difficult to define) - has economical constraints and, conversely, exerts a constraint on economic development. This is to be borne in mind, at a time when, at the bottom of the fourth industrial cycle of Kondratieff, we are in want of innovations to climb from depression to the expansion and prosperity of a fifth cycle. Table 1 shows that we are in the recessive (R) stage of a cycle, which, in the past, has been followed by depression (D), then by an innovative, recovery period (I), leading to the years of prosperity (P) of the next cycle. If this evocation of the impact of an uncontrolled demand for safety on economic development, in connection with the theories of Kondratieff, Schumpeter, Mensch and Kuznets, seems far-fetched to you, just remember the ecologist agitation concerning nuclear power plants. We might forecast many difficulties with "safety-oriented" people when biogenetics - seen as an important domain of activity in the next upswing - really gets on the move, not to mention spatial activities.

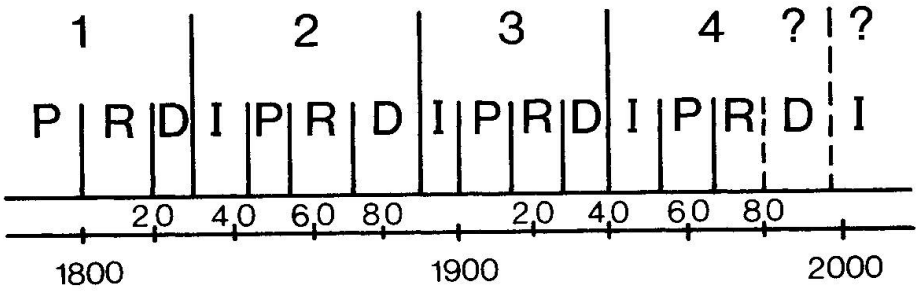

Table 1. Industrial/economic cycles (after Mensch - "Stalemate in Technology")
I - innovative, recovery stage
P - prosperity stage
R - recession stage
D - depression stage

The economic rules of the game we have to obey set natural limits to our endeavours. Safety can be superimposed on these rules, but cannot supplant them altogether, for fear of having to forego the activities involved, if it is meant to achieve it at all costs.

I remember visiting a plant, a few years ago, in a faraway, large, developing country. To a question about the total lack of posters reminding workers of possible accidents, the reply of the plant manager was: "we do not have time for that".

I have said a few moments ago, that only states - I mean, of course, governmental administrations - can, with impunity, get away from the costs of safety. And yet, it is not because their solvency is illimited, as we know. It is just because they, alone, have the right to impose regulations. Let us take, for example, the regulations concerning civil construction, in particular those relating to scaffolding protection. It is often pernickety enough to be a hindrance to builders and not enough imaginative to be a real addition to safety. Yet, that I know of, never was any study made, not only of the impact of regulations on industrial activity, but also of the expected gains in safety.

This leads me to the next argument of this short and general introduction: all in all, safety is left in the hands of the engineer.

5. SAFETY IN ENGINEERING

Engineers, by virtue of their basic work, are devoted to safety. Whether they design or they build, their products have to be safe if they are to be of practical use. Thus, engineers have always used "factors of safety". Such factors were, until less than 25 years ago, matters of "engineering judgment". Their evolution in that span of time follows, naturally, the evolution of the philosophy of design. For structures, both in civil engineering and in marine engineering, probabilism has to a large extent replaced determinism and, thus, safety factors - often referred to as "factors of ignorance" - can, in principle, be replaced by a given probability level of structural safety or the complementary level of risk. This is not to say that it is often done or, even, possible. Perhaps, spending a moment on this transition from determinism to probabilism is appropriate. For this, we shall take the example of ships and, generally, marine structures.

Probably long before Homer wrote the Odyssey, man has recognized the aleatory character of the sea and a nineteenth century poet said: "The sea never tells what it means to do ... it advances and retreats, it proposes and retracts, it prepares a squall and then gives up its plan, it promises destruction and does not keep its word". Treating wave action in a probabilistic manner requires many more calculations than using, as in the past, a single deterministic wave. Yet, it is not the advent of easy computer calculation which promoted this transition: the statistical representation of the sea was introduced in 1953 by Saint-Denis and Pierson, with the use of wave energy spectra, and the spectral motion response of ships was first calculated by hand. To be sure, refined treatment of wave action, taking explicit account of diffraction, and of the entrained water effect, as well as the estimate of the structural behaviour of a ship at sea, could not be dealt with by hand calculation and were made possible by the computer.

Along with the development of computational tools, sea-state data have been acquired for areas of important activity at sea, both by ships and by offshore platforms. This gives the engineer the possibility to assess the demand on a structure from the dominating sea action, although he is less advanced concerning winds and currents. Programmes exist today for the obtention of stress histograms, including stresses resulting from vibrations, and for fatigue estimates. What often prevents the engineer from being able to make a real risk/safety analysis is the lack of corresponding data on the capability side: distribution of the material properties, of the resistance characteristics of the welded connections ... It is not easy to obtain data on fabrication defects, for example.

This situation is reflected in the national regulations concerning fixed and mobile offshore platforms and in the Classification Societies/Certifying Authorities rules relative to ships and to offshore structures. It is also reflected in civil engineering codes, such as the code of the Fédération Internationale de la Précontrainte (International Federation of Pre-stressing) and the Code Européen du Béton (European Concrete Code). The transition from determinism to probabilism is gradual and the design procedures invoked are, at the most - in the hierarchy of development - semi-probabilistic procedures, using partial safety factors. A measure of probabilism is added by attempting to determine the partial safety factors by more advanced procedures, based at least on a more or less precise knowledge of the mean value and variance of the stochastic parameters from which depend the demand and the capability (these simpler advanced procedures are the First Order Second Moment - or FOSM - procedures for the structural buffs).

The situation is thus that proven methods, implicitly recognized in regulations, rules and codes, do not completely allow for a safety/risk analysis, nor do these documents call for such an analysis. But this short recollection shows the magnitude of the engineer's effort toward a rational assessment of the structural safety/risk.

This effort is pursued, not only in developing advanced design procedures which will, tomorrow, allow for safety/risk analyses to come into the purview of codes, but also through a number of special studies, for example, aiming at comparing the safety level achieved for typical jacket platforms, concrete gravity platforms and semi-submersible platforms, when using accepted safety factors (such work was carried out by the Association de Recherche sur l'Action des Elements - Research Association of Environmental Actions) or at presenting possible schemes of risk/cost trade-offs for jacket structures (P.W. Marshall, Shell Oil Company).

Considering a structure as a system of structural elements, the engineer is attempting to approach the estimate of its safety by application of the methods used for systems, i.e., reliability theory, fault-tree induction and event-tree deduction, taking into account the eventual redundancy at some locations of the structure.

These methods have been in use for quite some time for electronic systems and are employed today for a variety of functional systems and operations. This last application covers a vast domain of activity, from the operation of an industrial plant (a refinery, a nuclear power plant, for example) to transportation systems (ships, trains, aeroplanes). Using maritime traffic data, experimental data and calculation of the drift of disabled ships, risks of grounding can be estimated along with the risk of collision for ships in general. Such studies can be complemented by an evaluation of the danger of explosion of ships carrying dangerous cargoes, in turn threatening sensitive installations - like nuclear power plants - close to the sea (as by J.P. Jaunet and Y. Le Gal, Bureau Veritas).

This type of application amounts to a mutation in the philosophy of conducting the operations concerned. It was first the object of indepth studies for aircraft piloting and new concepts of philosophy were developed at the time "Concorde" was conceived (Etude de la Securité des Aéronefs en Utilisation - ESAU - in French; Investigation on the Safety of Aircraft and Crew - ISAAC -in English; son and father in the Bible!). The study of the safety of operations gives, aside from the reliability of material subsystems, a prominent place to human action.

In today's industrial situation, and in general, human action, in the physical sense, can only intervene during the fabrication of the elements of a system and during the use of the system. However, human action, in the full acceptation of the word, includes intellectual work and, thus, exerts an influence at the design state of the system (to begin with, of its components) and of its mode of operation (including the safety philosophy adopted and the maintenance planned). Yet, this aspect of human influence is difficult to take into account, although it is, implicitly but quantitatively, incorporated in factors of safety selected from engineering judgment. Lest this would seem like adding unnecessary difficulties to an already intricate problem, let us note that a domain of probable accelerated development toward the next economic cycle is robotics and that, while tracing a physical human action at the origin - note that we do not say "as the cause" - of an operational incident or accident, is comparatively easy, it will be much more difficult to do so for an intellectual action.

Everyone recalls an electronic fraud - amounting to a large amount of money being robbed by computer action - which was only discovered because the perpetrator was too talkative. We may also note that vote counting by computer is illegal in some parts of the USA for fear of undetectable fraud. I am reasonably sure that all those who have had something to do with debugging computer programmes will agree with me on this score. We might initiate as of now the study of methods capable of enhancing the success of our future hunt for bugs!

It is interesting to look at the probability level (in terms of return period) associated with the description, using adjectives, of the "chance" that an accident will happen. Table 2 shows, from a report by T. Moan, this correspondence in the case of mobile platforms. For comparison, the same correspondence between word description and probability description of load occurrence, but used for environmental loads in offshore (P.W. Marshall, Contribution to the Report of Committee V.1, "Design Philosophy and Criteria" to the 1982 International Ship Structures Congress) is also given in the table.

In aeronautics, the same correspondence looks somewhat different, being expressed, for the probabilistic description, in failure probabilities per flight hour. Table 3 shows this correspondence.

Word description of occurrence	Average return period years	
	Accidents	Loads
Probable	10^2	10
Reasonably probable	$10^2 - 10^4$	$10 - 10^3$
Remote	$10^4 - 10^7$	$10^3 - 10^6$
Extremely remote	10^7	10^6

Table 2. Word and return period description of the chance of occurrence of accidents to mobile platforms and of environmental loads in offshore.

Word description of occurrence	Failure probability per flight hour
Probable	10^{-5}
Rare	$10^{-5} - 10^{-7}$
Extremely rare	10^{-7}
Extremely improbable	10^{-9}

Table 3. Word and probabilistic description of the chance of failure occurrence in aeronautics.

When compared, on the basis of average yearly flight hours (or distance flown) of aircraft, and with some assimilation concerning the adjectives used in both cases, Table 2 and Table 3 appear compatible. What is interesting in both examples is the use of adjectives to describe the occurrence frequency of accidents: dealing with risk, our imagination has a better grasp of such a description than of dry numbers. This may tend to show the need, not only for the public at large, but also for those who are involved in this domain, of an adequate education concerning risk/safety. Aviation accidents are classed according to their severity, critical accidents, for example, being those which might make a forced landing necessary and catastrophic ones being liable to entail the loss of the aircraft and its occupants.

Examples of safety criteria in aeronautics are a probability below 10^{-5} for a critical accident and a probability smaller than 10^{-7} for a catastrophic accident, corresponding to the "rare" and "extremely rare" ranges in the word description and thus satisfying our psychological conception of safety. Levels of safety implicitly accepted in codes range from probabilities of a few 10^{-4} to a few 10^{-2}, over the life of the stucture. Levels quoted either as recommendations or accepted levels, as yearly probabilities of failure, include values such as 10^{-5} without qualification of severity, 10^{-6} for severe consequences (European Convention for Construction Steelwork), 10^{-6} - 10^{-7} for industry onshore, and 10^{-4} - 10^{-6} offshore (CIRIA). Table 4 compares annual rates of fatalities - gathered from various sources - in different domains of human activity.

Activity	Fatalities per 1000 person -years
Navigation	2.1
Mines	0.9 - 1.4
Construction onshore	0.3
Industry onshore	0.15
Offshore (before March 1980)	1.5 - 2.0
Offshore (before 1982)	3.5 - 4.7
Automobile	1.0 - 3.0
Air transport	0.8 - 1.0

Table 4. Frequency of fatalities in various fields.

6. A TENTATIVE CONCLUSION AND RECOMMENDATION

Safety/risk analysis is, if not coming of age, at least gaining ground in the evaluation of the possible, or likely, human, ecological or economic consequences of man's endeavours. It is, in effect, a tangible manifestation of a mutation in our philosophy which pervades - or will pervade - many, if not all, of our activities, in business and politics as well as in engineering : a transition from a deterministic outlook to a probabilistic outlook. The transition being in the making, some - perhaps many - parts of our industrial, sociological, or legal tissue are lagging behind in this development. There are thus gaps which we must strive to fill.

It is clear that work must be pursued both in the development of rational procedures of analysis and in the acquisition of data before the engineer is, in many areas, in a position to produce quantitative - and trustworthy - safety/risk estimates, particularly where structures are concerned.

In this effort, it is imperative to study critically scenarios of accidents in order to delineate possible sets of causes. Serious accidents indeed result, according to the unanimous opinion of those who have studied in depth such cases, from a group of causes, the elimination of any one of which would have considerably reduced the seriousness of the accident. A similar conclusion applies to the study of near-misses: the addition of an additional anomaly to those found to exist would have resulted in a catastrophe.

This last consideration is of utmost importance when considering that, in a majority of catastrophic accidents which have aroused public attention in the recent past, legal action has appeared to be aimed at finding a culprit at all costs. This is extremely counter-productive as concerns safety enhancement, as it encourages at the least omissions - perhaps distortions - in the presentation of the accident's circumstances, and since there is an imbalance in the principle of responsibility allocations: generally, administrations have the privilege of penal irresponsibility.

Such a philosophy, not only runs counter-current with the transition to probabilism, but also violates a basic principle: a conscious fault, consisting in voluntarily transgressing a law, a regulation or even an accepted code of practice, is certainly punishable, while an involuntary human error is not punishable.

Of course, the strength of the above argument mainly rests on the quality of the regulations imposed on the developers of projects and the operators of industrial systems. In many cases, these regulations leave much to be desired, particularly in defining areas - and limitations - of responsibilities, e.g. in the case of organization of rescue at sea. Laws, regulations ... are often designed - and felt such by the public - as means to protect, as much as the people, administrations, already legally irresponsible, against criticism. Hence, such helpful signs on the roads as "deer crossing", "rock falling" ... or a maze of signs from which the really useful one cannot be distinguished in time.

The official and semi-official effort to promote safety with a variety of texts, ever increasing in number and often un-coordinated, has the unfortunate effect of reducing the awareness of individual responsibility and of promoting a feeling of being an indirect member of an assisted group.

It appears to me that a real transition to the acceptance of risk and the correlated and imperative quest for more safety is, above all, a matter of education and that giving each individual a true sense of responsibility - not as the best means to avoid punishment, but as the only efficient way to improve safety - is a task of highest priority. It would be strange if, at a time when a broad-minded understanding - sometimes turning to laxity - is displayed by courts toward law-breakers, as a first step of their resertion into society, society did not make the necessary effort to teach responsibility in the first place.

This last comment takes added value in the light of our inescapable evolution towards the widespread use of automated systems with which a lack of uprightness and responsibility - very hard to detect - is liable to provoke catastrophes.

I am convinced that, in the important and exciting developments with which the present situation is pregnant, engineers will, as ever, make a decisive contribution. The level of the presentations and discussions at this colloquium are proof of it.

I shall leave you with these hopeful words.

Leere Seite
Blank page
Page vide