

Risk assessment and decision making in civil engineering

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The motivation for and relevance of risk assessment as a means for decision support in civil engineering is outlined. The theoretical basis for decision making is summarized and it is shown how the prior, posterior and pre-posterior decision analysis from the Bayesian decision theory provides the theoretical framework for risk assessment. Typical generic decision problems from civil engineering applications are given and some central issues related to risk acceptance are discussed. By means of selected examples it is illustrated how risk assessments may be utilized for civil engineering decision making. Finally a critical appraisal is given with regard to societal risk management.

Key words: risk, assessment, civil, engineering, decision, making, Bayes, pre-posterior, acceptance, criteria, risk-consciousness, risk-responsibility.

1. Introduction

Over the recent years there has been a markedly increasing societal concern on sustainable developments focusing on the conservation of the environment, the welfare and safety of the individual and at the same time the optimal allocation of the available natural and economical resources of society, see e.g. Bruntland [1]. This problem complex may easily be realized to be a complex decision problem highly influenced by the possible consequences of our actions and the probabilities that these consequences will occur – the product of which is known as risk.

As a consequence the methods of risk and reliability analysis in civil engineering, mainly developed during the last three decades, are increasingly gaining importance as decision support tools in civil engineering applications. However, their value in connection with the quantification and documentation of risks and the planning of risk reducing and mitigating measures is

not fully appreciated in the civil engineering profession at large, although in some specialist areas and such as risk management, asset management, etc. it is increasing rapidly.

There are no signs that the focus on risks will decrease in the future. The future development and the preservation and maintenance of the infrastructure of society will even more likely demand an intensified focus on risk.

The continued successful development of society demands that the persons acting as decision makers on behalf of society are provided the means for managing the prevailing natural and manmade risks in a transparent, conscious, consistent and rational manner – this is in fact our challenge as engineers.

Several important tasks are lying ahead to achieve this, not least in the area of civil engineering. As always new civil engineering projects should be planned, designed and executed in a cost optimal manner taking into consideration the benefit of the projects as well as the possible adverse consequences such as loss of lives, damage to the qualities of the environment and of course the direct and committed costs. Integral approaches allowing for consistent and transparent risk assessments taking into account both short and long term benefits for all stake holders and considering all phases of the engineering projects (see Fig. 1) are still to be developed. Future safeguarding, maintenance and decommissioning of the infrastructure of society will even more likely demand an intensified focus on risks in the future. Not least in

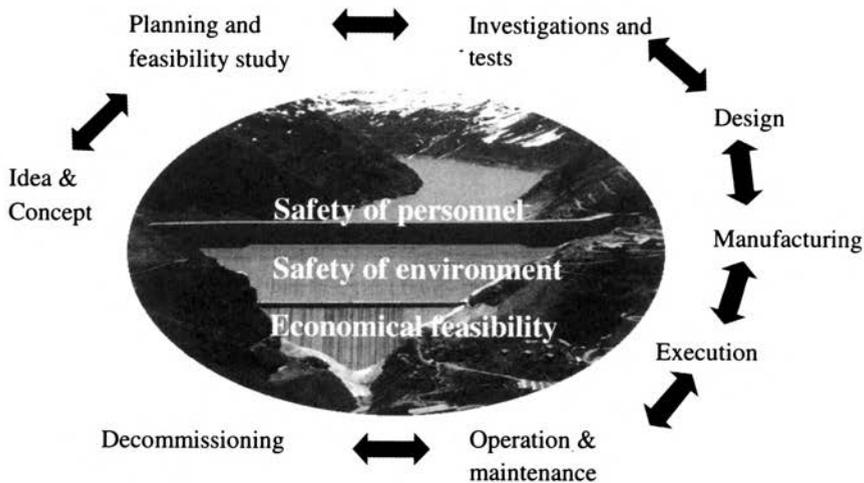


FIGURE 1. Holistic – life cycle approach to risk assessment.

the view of the seemingly ongoing and expected climatic changes and the enormous efforts they may initiate to safeguard our existing infrastructure.

Taking basis in Faber & Stewart [2] and Faber et al. [3] the present paper outlines a critical overview and discussion of risk analysis in general with a view to special problems arising in civil engineering facilities in particular. It is underlined that decision analysis forms a formal basis for risk assessment and the different types of decision analysis are outlined in summary and related to the different types of risk assessment. The principally different types of decision problems in civil engineering are described and examples of practical applications of such analysis are given. Thereafter the aspects of acceptance criteria are discussed with a special view to risk averseness. Finally a critical appraisal is given with regard to the aspects of ensuring an efficient and just risk management in society.

2. Theoretical Framework for Risk Assessment

Risk assessment is a term used in a large variety of situations with the general intention to indicate that an analysis is at hand where the most important aspects of uncertainties, probabilities and/or frequencies and consequences have been considered in some way or another. In the following risk is more specifically defined as the expected consequences associated with a given activity. In the most simple case risk may thus be quantified as the probability of occurrence of an event multiplied by the expected consequences of the event should it occur. As outlined later this definition is consistent with the basic principles of decision theory and also in accordance with the interpretation of risk used e.g. in the insurance industry (expected losses) and risk may, e.g., be given in terms of EUROS, dollars, the number of human fatalities, exposure limits to toxic substances, etc.

Risk assessments may be represented in a generic format, which is largely independent from the application or whether the risk analysis is performed in order to document that the risks associated with a given activity are acceptable or is performed to serve as a basis for a management decision. Figure 2 shows a generic representation of a risk analysis, in this case, a flow chart based on the Australia / New Zealand code on Risk Management [4]. The individual steps in the flow chart are described in detail in Stewart and Melchers [5]. In Fig. 3 an illustration is given summarising the main constituents of risk assessment and decision analysis.

Decision making in civil engineering can be seen as being equivalent to participating in a game with nature as the main opponent, see also Ditlevsen & Madsen [6]. Considering Fig. 3 the illustrated constituents of the decision problem system can be considered equivalent to the constituents of a

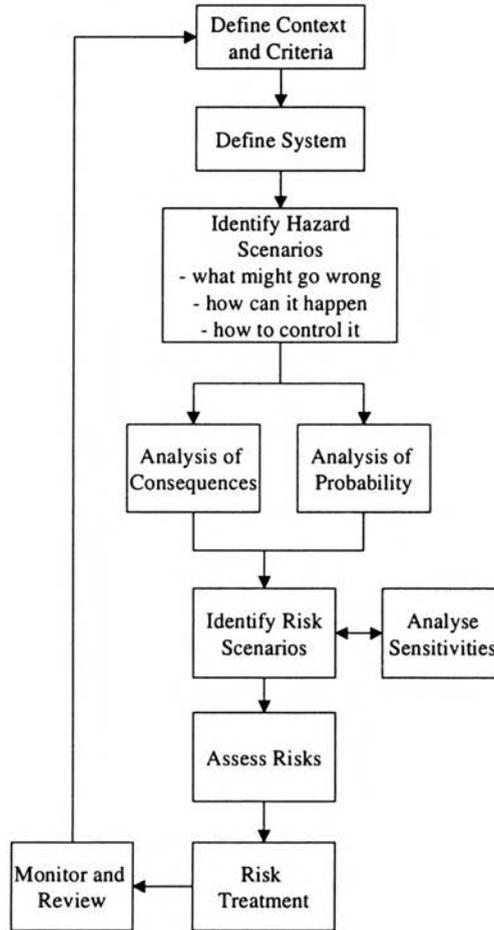


FIGURE 2. Generic process flow of a risk assessment.

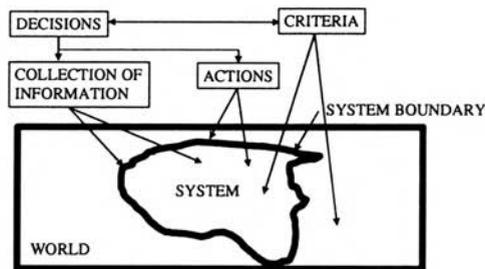


FIGURE 3. Main constituents in risk assessment and decision analysis.

game. Knowing the rules of the game, i.e. the (success or acceptance) criteria, the system, the boundaries of the system, the possible consequences for the system and how all these factors might be influenced by the world outside the system is decisive for the chances of winning the game. For this reason a very significant part of risk assessment in practice is concerned with the system identification/definition as well as the identification of acceptance criteria, possible consequences and their probabilities of occurrence. Playing the game is done by "buying" physical changes in the system or buying knowledge about the system such that the acceptance criteria are more efficiently met.

In typical decision problems encountered the information basis at hand is quite diverse. It is not unusual that it is required to take into account both historical data on failure rates for various types of equipment and operations, as well as predominantly subjectively assessed data on the failure probability of structural details. Moreover the available historical information often does not exactly correspond to the problem being considered but to a somewhat similar situation. Furthermore, as already outlined an important part of a risk assessment is to evaluate the effect of buying additional information, risk reducing measures and/or changes of the considered problem. It is therefore necessary that the framework for the decision analysis can accommodate diverse types of information available and allow decisions to be updated based upon new information.

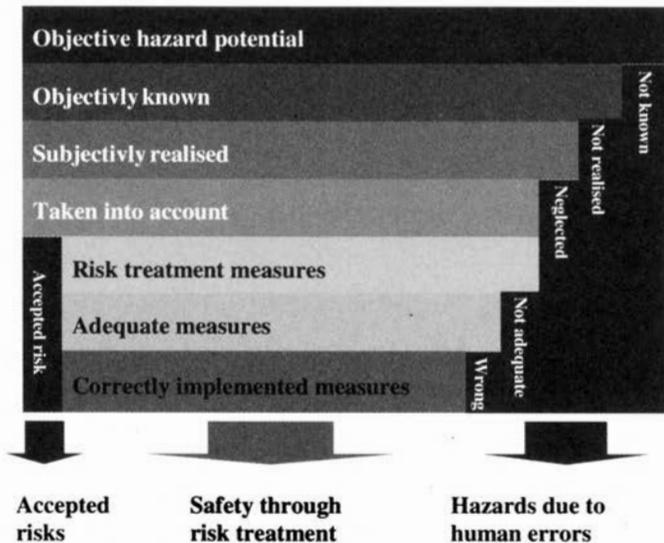


FIGURE 4. Illustration of the efficiency in risk treatment in structural engineering.

In Fig. 4 the efficiency in understanding and playing the game of design and operation of structures is illustrated (adapted from Schneider [7]). It is seen that a significant part of the total hazard potential gets out of control due to various types of human and organisational errors. The corresponding risks are typically significantly higher than those which have been identified as being acceptable.

2.1. General formulation

The good news is that a consistent basis for risk assessment already exists if the purpose is to enhance decision making. Decision theory provides the theoretical framework for such analysis.

General decision problems subject to uncertainty expressed in terms of frequency and/or subjective terms may be adequately treated within the framework of the Bayesian decision theory, see e.g. Raiffa and Schleifer [8] and Benjamin and Cornell [9].

Without giving the theoretical argumentation (see e.g. Ditlevsen and Madsen [6]) it is simply stated here that a fundamental principle in decision theory is that optimal decisions must be identified as those resulting in the highest expected utility.

In typical engineering applications the term "utility" may directly be translated into consequences in terms of costs, fatalities, environmental impact etc. In these cases the optimal decisions are those resulting in the lowest expected costs, the lowest expected number of fatalities and so on. Moreover, if costs and fatalities and/or other attributes are a part of the decision problem, full consistency may only be ensured if these attributes are expressed in terms of a common utility. This has for a long time been considered to represent a controversial problem, but recent works by Rackwitz [10] and Nathwani et al. [11] emphasize the need to do so and also provides the required philosophical and theoretical framework. The weighting of the attributes has to be done somehow, directly or indirectly, in order to make a decision, thus, in order for the decision maker to be sure that the decision is made in accordance with his preferences, the weighting should be made in a transparent way.

As the immediate consequence of the fact that any activity planned or performed in order to reduce and/or control the risk is only directly quantifiable in terms of costs, the most straightforward approach is to associate utility in terms of cost consequences. However, in some cases the requirements given by legislation are formulated in terms of fatalities and in such cases it is necessary to assess the risk both in terms of expected costs and in terms of the expected number of fatalities. However, it can be shown, see Evans &

Verlander [12], that the rational way to formulate acceptance criteria for risk analysis is by use of decision theory.

The simplest form of the decision analysis is the so-called prior-analysis. In the prior-analysis the risk (expected utility) is evaluated on the basis of statistical information and probabilistic modelling available prior to any decision and/or activity. This prior decision analysis is illustrated by a simple decision tree in Fig. 5. In prior and posterior decision analysis the risk (expected utility) for each possible activity/option is evaluated in the principal form as

$$R = E[U] = \sum_{i=1}^n P_i C_i \quad (2.1)$$

where R is the risk, U the utility, P_i is the i -th branching probability and C_i the consequence of the event of branch i see Fig. 5.

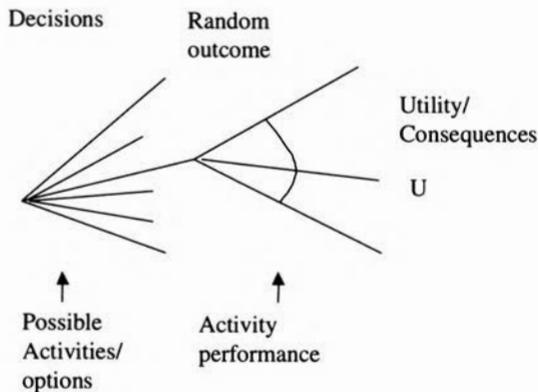


FIGURE 5. Decision tree for prior and posterior decision analysis.

Prior decision analysis in fact corresponds closely to the assessment of the risk associated with an activity. Prior decision analysis thus forms the basis for the simple comparison of risks associated with different activities. The result of a prior decision analysis might be that the risks are not acceptable and the risk reducing measures needs to be considered. The efficiency of different risk reducing measures is an issue which is treated in the posterior decision analysis.

Posterior decision analysis is in principle of the same form as the prior decision analysis, however, changes in the branching probabilities and/or the consequences in the decision tree reflect that the considered problem has been changed as an effect of risk reducing measures, risk mitigating measures and/or collection of additional information. Posterior decision analysis

may thus be used to evaluate the efficiency of risk reducing activities, which factually have been performed.

Pre-posterior decision analysis may be illustrated by the decision tree shown in Fig. 6. Using pre-posterior decision analysis, optimal decisions with regard to activities, which may be performed in the future, e.g. the planning of risk reducing activities and/or collection of information may be identified. An important pre-requisite for pre-posterior decision analysis is that decision rules need to be formulated specifying the future actions, which will be taken on the basis of the results of the planned activities.

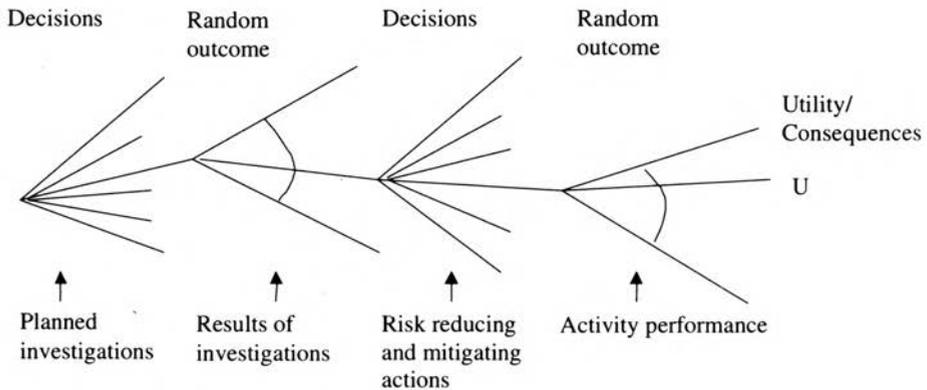


FIGURE 6. Decision tree for pre-posterior decision analysis.

In the pre-posterior decision analysis the risk (expected utility) for each of the possible investigations is evaluated as

$$\begin{aligned}
 R = E[U] &= \min_a E'_Z \left[E''_{|Z} [U(a(z), z)] \right] \\
 &= \min_a E'_Z \left[\sum_{i=1}^n P''_i(a(z), z) C_i(a(z)) \right] \quad (2.2)
 \end{aligned}$$

where $a(z)$ are the different possible actions that can be taken on the basis of the result of the considered investigation z , $E[\]$ is the expected value operator; ' and '' refer to the probabilistic description of the events of interest based on prior and posterior information respectively, see e.g. Lindley [13].

Pre-posterior decision analysis forms a strong decision support tool and has been intensively used for the purpose of risk based inspection planning, see e.g. Faber et al. [14]. However, so far the pre-posterior decision analysis has been grossly overlooked in risk assessments.

3. Decision Problems in Civil Engineering

In principle two different types of decision problems can be isolated as representative of decision problems in civil engineering applications:

1. Optimal collection of information about the engineering system/facility:
 - planning of laboratory experiments,
 - planning of site investigations,
 - planning of structural calculations,
 - planning of structural monitoring,
 - planning of inspections.
2. Identification of optimal risk reducing measures by physical changes of the engineering system/facility:
 - design of new structures and components,
 - calibration of design codes,
 - repair and strengthening of existing structures and components,
 - maintenance planning,
 - feasibility studies.

Often the two principally different decision problems are intertwined in one another as, e.g., in the risk based inspection and maintenance planning, feasibility studies and in the planning of assessment and strengthening activities. In these situations the identification of cost optimal collection of information and the planning of physical changes to the system are performed in one operation. For the decision problems of type (2) prior and posterior decision analysis suffices. However, whenever decision problems of type (1) are involved the pre-posterior decision analysis is required.

For the decision problems of type (1) the main issue is the control of risks by means of improving the state of the knowledge about the rules of the game. The uncertainties reduced by improving the state of knowledge are the so-called epistemic uncertainties. For decision problems of type (2) the main issue is the so-called aleatory uncertainties, i.e. inherent natural uncertainties which only can be changed by changing the nature.

In the following two examples of decision problems from civil engineering which efficiently may be solved by means of risk assessment are given.

3.1. Optimal design of extraordinary structures

Traditionally exceptional structures are usually associated with structures fulfilling new purposes, of extreme dimensions or innovative designs see e.g. Fig. 7.

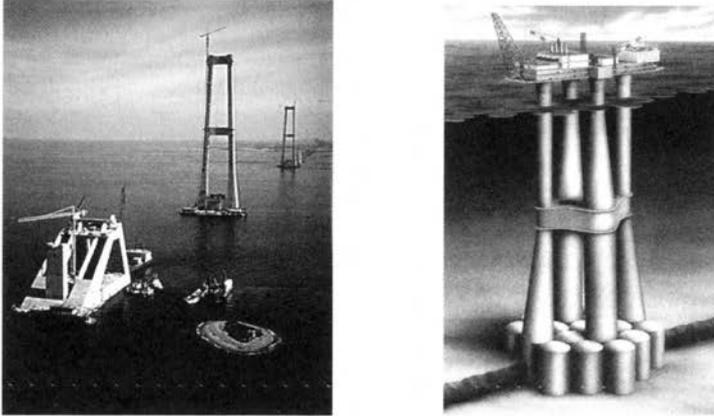


FIGURE 7. Examples of structures of extreme dimensions. To the left the Great Belt Link under construction and to the right a principal sketch of the Troll offshore platform.

Exceptional structures in principle include all structures falling beyond the application area of the design and assessment codes. When categorizing such structures it is useful to differentiate between new structures, i.e. structures to be designed and existing structures i.e. structures, which for some reason are subject to a reliability assessment, see also Faber [15].

For new structures exceptional structures include structures:

- fulfilling new purposes or of exceptional dimensions and innovative designs,
- building ones using new materials or innovative combinations of materials,
- constructed and maintained according to new methods and strategies,
- subjected to unusual loads and load combinations,
- subjected to unusual environmental exposures,
- associated with extreme consequences in the case of failure,
- being especially difficult to decommission.

For existing structures exceptional structures include structures:

- having been designed according to out dated standards,
- exhibiting unforeseen degrees of deterioration,
- having been subjected to accidental damages,
- having been subject to extreme loads or environmental exposures,
- subject to changed operational conditions,
- unexpectedly to be decommissioned.

In principle structure specific reliability and risk assessments must be made for all the above-mentioned structures. The engineering profession has to some extent recognized this fact but only within the last decade the problem has been approached in a more systematic and consistent way using the principles of decision analysis and structural reliability theory. Examples of risk and reliability based optimal design can be found in, e.g. Borkowski & Jendo [16], Rackwitz [17], Sorensen [18]. In Fig. 8 a decision-event tree taken from Kübler & Faber [19] is given where the optimal design of an offshore

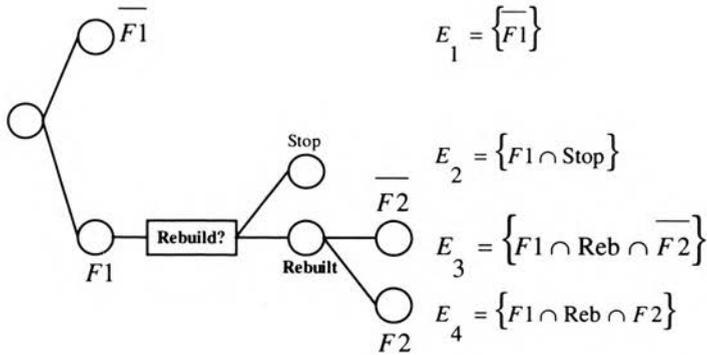


FIGURE 8. Decision-event tree used for the design optimization of the offshore structure shown in Fig. 9.

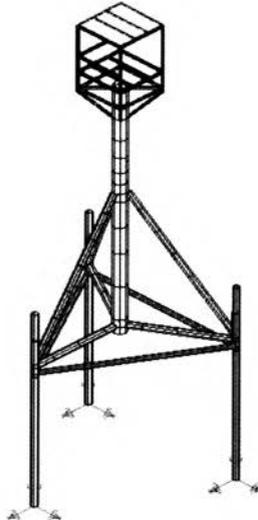


FIGURE 9. Illustration of the type of offshore structure being optimized.

structure (Fig. 9) is considered. The decision tree includes design decisions, i.e. regard to the choice of cross-sectional dimensions but also includes a decision on whether to rebuild or not after the first failure. In Fig. 8 the event E_1 denotes the survival event for the structure throughout the anticipated service life. E_2 is the event that the structure fails before the end of the anticipated service life and is not rebuild. E_3 is the event that the structure fails before the end of the anticipated service life, is rebuild and survives until the end of the anticipated service life. Finally E_4 is the event that the structure fails before the end of the anticipated service life, is rebuilt and fails before the end of the anticipated service life.

By appropriate modelling of the events shown in Fig. 8 it is possible to identify the optimal design by maximization of the net present value of the expected benefit $E[B]$ given by

$$E[B] = \int_0^T b(\tau) \delta(\tau) R(\tau) d\tau - CB - \int_0^{t_0} CRB \delta(\tau) g_1(\tau) d\tau - \sum_{n=1}^2 \int_0^T CF \delta(\tau) g_n(\tau) d\tau. \quad (3.1)$$

where T is the anticipated service life (finite or infinite), $b(t)$ is the benefit function, $\delta(t)$ is the discounting function, $R(t)$ is the reliability function, CB is the building costs, CRB is the rebuilding costs, CF is the failure costs, $g_n(t)$ is the probability density of the time to the n -th failure and t_0 is the time after which the expected benefit of reconstructing the structure is no longer positive, i.e. not profitable.

3.2. Risk based inspection and maintenance planning

Engineering systems such as offshore structures, bridges, ship hulls, pipelines and process systems are ideally designed to ensure an economical operation throughout the anticipated service life in compliance with given requirements and acceptance criteria. Such acceptance criteria are typically related to the safety of personnel and risk to environment.

Deterioration processes such as fatigue crack growth and corrosion will always be present to some degree and depending on the adapted design philosophy in terms of degradation allowance and protective measures the deterioration processes may reduce the performance of the system beyond what is acceptable. In order to ensure that the given acceptance criteria are fulfilled throughout the service life of the engineering systems it may thus be necessary to control the development of deterioration and if required to install

corrective maintenance measures. In usual practical applications inspection is the most relevant and effective means of deterioration control.

Planning of inspections concerns the identification of what to inspect, how to inspect, where to inspect and how often to inspect. Even though inspections may be used as an effective means for controlling the degradation of the considered engineering system and thus imply a potential benefit they may also have considerable impact on the operation of the system and other direct and indirect economical consequences themselves. For this reason it is necessary to plan the inspections such that a balance is achieved between the expected benefit of the inspections and the corresponding economical consequences implied by the inspections themselves.

During the last 10 to 15 years reliability based and risk based approaches have been developed for the planning of inspections, see e.g. Faber [20] for an overview. These approaches have by now been developed further into

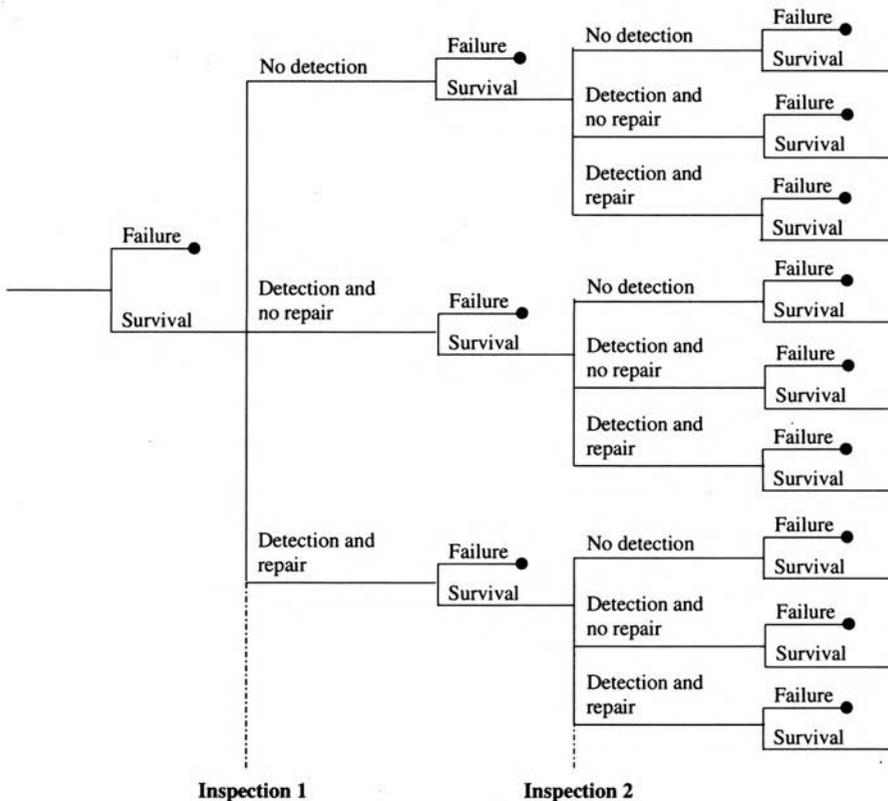


FIGURE 10. Illustration of decision-event typical for decision analysis concerning optimal inspection and maintenance planning.

practical applicable procedures and are applied in various industries, see e.g. Goyet et al. [21], Sindel and Rackwitz [22] and Moan et al. [23]. A common feature of the developed procedures is the decision theory, used in order to minimize overall service life costs including direct and implied costs of failures, repairs and inspections.

Typically the decision-event trees to be considered in the service life costs minimization are of the form shown in Fig. 10. The probabilistic analysis of such trees easily becomes numerically demanding as the number of planned inspections increases.

Recently, however, highly efficient generic formulations have been developed for the utilisation of risk based inspection planning for welded con-

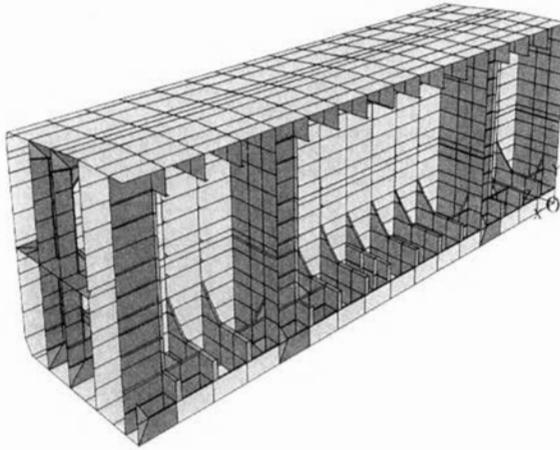


FIGURE 11. Ship-section subject to fatigue crack growth.

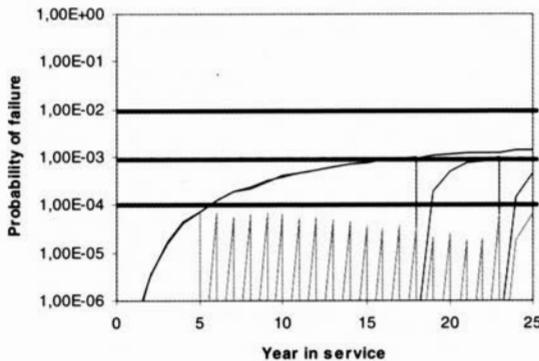


FIGURE 12. Updated probability of failure for different inspection plans.

nections in steel structures, see e.g. Faber [24], whereby the inspection and maintenance plans may be pre-defined and later assigned to welded connections in accordance with the standard fatigue design parameters and the consequences of failure repair and inspections. In Fig. 11 a typical structural sub-system subject to fatigue crack growth is illustrated. In Fig. 12 the updated probability of failure for a welded detail is shown for different inspection plans complying with different acceptance criteria.

4. Optimality and Risk Acceptance Criteria

The decision-making process is a complex one, and one that is often entwined with so-called political processes. A number of issues that risk assessment attempt to resolve include: “Who is to bear what level of risk, who is to benefit from risk-taking and who is to pay? Where is the line to be drawn between risks that are to be managed by the society and those that are to be managed by individuals, groups or corporations? What information is required for *rational* risk management and how should it be analysed? What actions make what difference to risk outcomes? Who evaluates success or failure in risk management and how? Who decides what should be the desired trade-off between different risks?” (Hood et al. [25]).

The decision-making process aims to provide an “optimal” outcome that is acceptable to all involved parties by satisfying one or more risk acceptance criteria. Such decisions may be influenced by, among other things:

- anticipation of system failure and resilience against unexpected catastrophe,
- assumptions used to compute a numerical estimate of system risk,
- magnitude of uncertainties in estimating system risks (e.g., some regulatory safety targets may be inappropriate for system risks with large uncertainties),
- organisational vulnerabilities to system failure (e.g., safety culture),
- cost of risk reduction,
- size and composition of groups involved in decision-making process,
- aggregation of individual preferences (i.e., distribution of benefits and risks),
- counter-risks (alternatives may have other societal risks).

These matters are not easily resolved, are not for risk assessment to solve alone and are all related to risk acceptance criteria; namely, what risks are acceptable? The development and implementation of risk acceptance criteria involves:

- *perception of risk*: ensure that the level of system risk is acceptable (or tolerable);
- *formal decision analysis*: analytical techniques to balance or compare risks against benefits (e.g., risk-cost-benefit analysis, life-cycle cost analysis); and/or
- *regulatory safety goals*: legislative and statutory framework for the development and enforcement of risk acceptance criteria.

The risk acceptance criteria generally adopted by the U.S. Nuclear Regulatory Commission, U.K. Health and Safety Executive and other regulatory authorities is that risks and hazards should be “As Low As Reasonably Possible” (ALARP) or “As Low As Reasonably Attainable” (ALARA). The definition for such terms as “low”, “reasonably”, “possible” and “attainable” are highly subjective and prone to being interpreted in a conservative manner.

4.1. Individual and societal risks

It is worthwhile to recognise that the problem concerning risk acceptance has a fundamental and philosophical bearing to the rights of human beings. The United Nations Office of the High Commissioner of Human Rights regulates the rights of humans by the “Universal Declaration of Human Rights” UNOHCHR [26]. Here three of the relevant articles are given for easy reference.

Article 1:

All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience and should act towards one another in a spirit of brotherhood.

Article 3:

Everyone has the right to life, liberty and security of person.

Article 7:

All are equal before the law and are entitled without any discrimination to equal protection of the law. All are entitled to equal protection against any discrimination in violation of this Declaration and against any incitement to such discrimination.

The articles emphasize both the moral and juristic obligation to consider all persons as being equals and furthermore underlines the rights to

personal safety for all individuals. Therefore whatever criteria we formulate with regard to the acceptable risks we should always bear in mind that the above mentioned fundamental principles of these human rights are not violated thereby.

Safety has a cost – as we already know – therefore the level of safety to be guaranteed for the individual member of society is a societal decision with a strong bearing to what the society can afford. However, with reference to the “Universal Declaration of Human Rights” representatives of society have a general moral obligation to consider all investments and expenditures in the light of the question “could the resources have been better spent” in the attempt to meet the aim of this declaration.

When discussing the issue of “acceptable risks” the issue is often confused by the fact that some individuals might have a different viewpoint to what is acceptable as compared to the viewpoint of the society. Each individual has their own perception of risk, or as expressed in decision theoretical terms, their own “preferences”. In this connection it is also important to notice that informed preferences, i.e. preferences formed subject to the knowledge about what the preferences will lead to often deviate significantly from non-informed preferences. It is in general associated with significant difficulty to identify the informed preferences. The consequences of deciding to exploit nuclear power contra deciding not to are not easily assessable for the layman. Ensuring that all individuals behave rationally, e.g. in votes – in accordance with their own informed preferences would thus in many cases require a significant amount of information and study work – the benefit of which is not generally appreciated.

Considering the acceptability of activities related to civil engineering or any other activities with possible implications to third parties for that matter the main question is thus not the preferences of the individual member of society but rather the preference of the society as expressed by the “Universal Declaration of Human Rights” or some other generally agreed convention. It is important to appreciate the difference. The (partly un-informed) preferences of individuals may in fact be in gross contradiction with the preferences of society and it is necessary to view acceptability from a societal angle, yet at the same time ensuring that the basic human rights of individuals are safeguarded.

4.2. Societal risks and risk aversion

A distinction is often made between individual and societal risks. Individual risks are expressed in terms of fatalities per year, fatalities per year of exposure, etc, whilst societal risks are typically represented in terms of

an $F-N$ curve which is a plot of cumulative frequency (F) of n or more fatalities versus number of fatalities (N). The ways that risk is presented can well affect risk perception. For example, an individual fatality risk of 10^{-5} is equivalent (in a statistical sense) to a societal risk of 10^{-8} of killing 1000 people. Yet, society seen as the reaction of the population of society when confronted with the outcomes of events seems more concerned about catastrophic events that harm large numbers of people rather than a series of lesser failure events that collectively harm a similar number of people. This shows an increasingly risk-averse behaviour as the consequences increases; however, from a purely rational viewpoint this may be viewed as a somewhat illogical approach to increasing life-safety and it is severely doubtful if such an approach can lead to efficient and rational decisions. Despite the long tradition for using $F-N$ -diagrams in risk analysis it should be noted that these do not provide a consistent means for comparing the risks between different activities.

A rational basis for avoiding the introduction of risk aversion is readily available if it is recognised that the reason for being risk averse is that the events involving high consequences often are associated with "follow-on" events which themselves may contribute significantly to the risk. The follow-on consequences for an offshore operator who in one event will lose an entire production facility with maybe a 100 fatalities are, e.g., a significant loss of reputation leading to declining sales figures, expensive investigations of safety procedures by the authorities, reduced chances of obtaining new oil production concessions and reduced government/tax revenue. If all such "follow-on" consequences are taken into account in the risk analysis then there is indeed no need to introduce any degree of risk averseness and the decision basis will be more transparent.

In principle the formulation for the assessment of the risk as given in Eq. (2.1) is already general enough if interpreted correctly. However, it might be worthwhile to use the following more general formulation for the utility U :

$$U = \sum_{i=1}^n I_i C_{\{E_i\}} \quad (4.1)$$

where the Boolean indicator function I_i is introduced as follows

$$\begin{aligned} I_i &= 1, \text{ if the consequence inducing event } \{E_i\} \text{ occurs,} \\ I_i &= 0, \text{ if the consequence inducing event } \{E_i\} \text{ does not occur.} \end{aligned} \quad (4.2)$$

The expected value of the utility $E[U]$, and thus the risk is then given by

$$E[U] = \sum_{i=1}^n E[I_i C_{\{E_i\}}] = \sum_{i=1}^n P(I_i = 1) E[C_{\{E_i\}}], \quad (4.3)$$

whereby focus is strengthened on more detailed assessments of the consequences.

4.3. Optimisation of expected utility and the Life Quality Index

Decision analyses provide decision-makers with analytical techniques to assess risk preferences; in particular, to compare or balance risks against benefits. A decision may therefore be based on activities that maximize expected monetary benefits, the expected utility or another index of performance such as the Life Quality Index, see e.g. Nathwani et al. [11].

A large variety of risk reduction measures may be considered for a particular activity. An example concerning risks to persons on offshore production facilities are gas detection systems, firewalls, sprinkler systems and separation of housing and production modules. Each of these risk reduction measures has their own efficiency. The question, however, remains how much should be invested in safety for a given activity. This question may be answered by a decision analysis by considering the expected total benefit associated with the considered activity $E[B]$:

$$E[B] = I(1 - P_F(C_R)) - C_R - C_F P_F(C_R) = I - C_R - (I + C_F) P_F(C_R) \quad (4.4)$$

where I is the benefit from the activity, C_F is the cost consequence in case of failure, C_R is the cost of the risk reducing measures and where the probability of failure is a function of the costs invested in the risk reduction. The optimal investment in risk reducing measures may then be determined. Ultimately, however, decisions based on rational or formal analyses may be overruled (or at least delayed) by such political considerations as electoral pressure, national security implications, or lack of funds.

5. Discussion and Conclusions

The decision problems of society are manifold and difficult, not least due to the fact that many decisions must be made subject to high uncertainties and might involve extreme consequences. However, the basic mathematical framework for the treatment of such decision problems is available and has in fact been available for some time – this framework is the decision theory. The decision theory indeed includes the features of usual risk assessment in terms of the prior and the posterior decision analysis but, moreover, opens up new possibilities as compared to usual risk assessment by means of the pre-posterior decision analysis. Surely the risk assessment profession, also in the area of civil engineering could benefit significantly from the potent capabilities of the decision theory.

The engineering profession has an obligation to provide societal decision makers with rational decision support tools and decision basis. However, the obligation is two way – society and societal decision makers also have an obligation to seek and implement rational decision support tools and decision basis. Otherwise the society and the individual decision makers acting on behalf of society might be (uninformed) violating the UN charter of human rights. Provided the limited resources of society – can society accept that “political” decisions are made which potentially violates the values upon which we have decided to build our society? – and might we not in this light need to rethink the appropriateness of the term political decisions altogether?

The statements made above are intuitively understood by everybody and are in many ways trivial, however, the gravity, lying behind the statements is not well appreciated in our daily lives. The question remains – how to improve and increase the general risk-consciousness in the population and for societal decision makers in particular? One answer to this question lies in the assignment and distribution of responsibility, i.e. the risk-responsibility. This principle has been recognized since decades as an efficient approach within organisations and companies – and it would appear timely to implement the same principle on a societal level. Holistic risk based reasoning must be implemented into the organisation of society counteracting “box oriented” decision making. Moreover, success criteria should be formulated for the decision makers at different levels in the administrations in terms of documented risk control efficiency. Thereby it would be made more attractive for decision makers to work for the long-term benefit of society and less tempting to consider personal short-term benefits and carrier possibilities.

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