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Ethics and fundamental principles of risk acceptance criteria

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ABSTRACT

Ethics are concerned with distinguishing between what actions are "right" and "wrong" and what values are "good" and "bad", etc. and there is a long academic tradition in discussing ethics and ethical theories. Risk acceptance criteria, on the other hand, distinguish between levels of risks that are acceptable and levels that are intolerable. In some sense, one may say that risk acceptance criteria distinguishes between "good" and "bad" systems and activities with regards to the risk they expose the society or elements of a society to and there is thus an obvious link between ethics and risk acceptance criteria or to risk management at large. However, there are few references in the literature that explores this link, and in this paper, the ethical foundation of fundamental principles of risk acceptance criteria will be elaborated upon.

This paper considers some important principles for establishing risk acceptance criteria for safety critical systems and activities. The various principles and the philosophies behind them might at first sight seem contradictory and exclusive, but it is demonstrated how they may coexist in one and the same regulatory regime; They may complement each other in order to achieve the overall safety objectives of society. Then, some brief considerations of the ethical foundations for the principles will be given and some relevant examples of actual risk acceptance criteria will be given from the maritime industries. However, it is believed that the principles and discussions are of general interest and apply to all areas of technical risk and to safety regulations in a broader perspective.

1. Introduction and background

Nearly all activities in life involve risk in some way or another, and there are no universally agreed criteria for what levels of risk are acceptable. Identified and unidentified risks are always sought to be controlled and minimized. The most commonly used strategy for managing risk in the public interest is through legislation and regulation, although everyone is constantly voluntarily managing personal risk in daily life on an individual level, both consciously as well as unconsciously.

Risk reduction will come at a price and there will be a trade-off between the level of risk one accepts and the cost one is willing to spend to mitigate it. For decision-makers responsible for public safety, at the expense of the public wealth, this trade-off needs to be considered carefully and thoroughly. Also the varying needs of different stakeholders must be balanced. The overall objective is to best allocate the society's scarce resources for risk reduction, by supporting the implementation of efficient risk reduction measures and to avoid wasting efforts on inefficient ones.

Risks introduced to the society from a given activity may be of different types. Fatality risks or health risks are the risk of depriving members of the community of their lives or their good health. Other types are property risk, economic risk and environmental risks. When decisions about safety are made, all risks should be considered, and appropriate acceptance criteria for fatality, health, environmental, economic and property risks should all be met before an activity can be declared safe enough (Jonkman et al., 2003). However, this paper focuses on safety risk.

Safety is surely an important objective in society, but it is not the only one and allocation of resources on safety must be balanced with that of other societal needs. In the literature, different fundamental principles for appropriate risk acceptance criteria have been proposed (see e.g. Nathwani et al., 2009) and extensive research is continuously going on; new principles for establishing and evaluating criteria are continually being introduced. For example, in BRTF (2003), the following five principles for good regulation are established: Proportionality, Accountability, Consistency, Transparency and Targeting. Reference is also made to Aven (2003). As a consequence, new risk acceptance criteria are frequently proposed (see e.g. Moseman, 2011). Risk acceptance criteria will obviously depend on the legal framework of the society and different legal frameworks might yield different criteria (Hartford, 2009). A comparison of risk regulation in two European countries, the UK and the Netherlands, is presented in Ale (2005) and it is shown that even though the legal and historical context is different, the risk acceptance criteria and the levels of risk are very similar.

At any rate, the establishment of various risk acceptance criteria is one approach for managing risk on behalf of the public, even

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though it is acknowledged that there have been expressed some objections to the use of risk acceptance criteria and that other alternatives exist (Aven and Vinnem, 2005; Abrahamsen and Aven, 2008). However, Vinnem (2010) argues that risk acceptance criteria are superior to risk-informed decision making in some contexts, and also suggests that there should be regulations stating how risk acceptance criteria should be formulated. Meyer et al. (2007) also express the view that defining risk acceptance criteria is a good practice for risk management.

Having adopted a set of fundamental principles to govern the establishment of risk acceptance criteria, specific risk acceptance criteria can be formulated. In this paper, some important principles for establishing risk acceptance criteria are presented and discussed. At first sight, some of these may seem exclusive but it will be demonstrated how the different principles can be employed to complement each other in one and the same regulatory regime. Brief considerations on the ethical foundations of the various principles will also be given and it is argued that there is a close link between ethics and risk management and also that it will be fruitful to make ethical considerations and reflections when establishing risk acceptance criteria. Ethical justification for the principles behind risk acceptance criteria may be found in both deontological and teleological ethics. However, it is out of scope to try to evaluate and compare the ethical position of different regulatory regimes, as discussed in Aven (2007). Some examples of actual risk acceptance criteria will be given from the maritime industries, but the principles and discussions are believed be general enough to apply to all areas of technical risk. An abbreviated version of this paper was presented at the ESREL 2011 conference (Vanem, 2011).

2. Individual and societal risk acceptance criteria

Depending on the system under consideration, both individual and societal risk acceptance criteria might apply. For large systems exposing a large number of people to risks, and where a large number of people are affected by possible accidents, societal risk acceptance criteria are deemed to be most appropriate. In general, societal risk are expressed in terms of frequency versus number of fatalities, and two of the most commonly used methods of describing such risks are risk matrices or FN-curves. In an FN-diagram the number of fatalities, N, is plotted against the frequency of events with N or more fatalities, F, and gives an illustration of the estimated risk, e.g. as a result of a risk analysis. Risk matrices can be considered as a discrete version of an FN-curve and usually divides the frequencies and severities into a few categories. Fig. 1 shows an example of risk acceptance criteria expressed by way of a risk matrix. An FN-diagram with criterion lines representing risk acceptance criteria is shown in Fig. 2. Potential Loss of Lives (PLLs) is another measure of societal risk for a defined system or activity. Societal concern is a related concept to societal risk that is somewhat wider in scope, including e.g. consequences such as lack of trust in the government and other impacts on society. Societal risk is considered to be a subset of societal concern (HSE, 2002a,b).

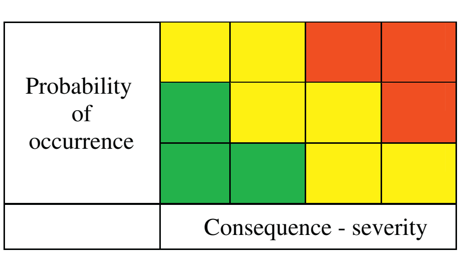

Fig. 1. Examples of societal risk acceptance criteria expressed in a risk matrix.

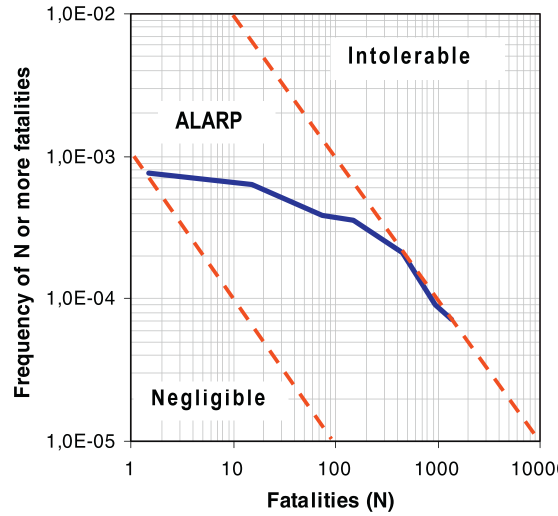

Fig. 2. An FN diagram with criterion lines representing absolute values for intolerable and negligible risks and an ALARP area in between where cost-effectiveness criteria apply.

On the other hand, if identified individuals or a group of individuals are exposed to additional risks, criteria based on individual risk are most appropriate. When individual risks are discussed, it will often be suitable to consider an exposed user, i.e. an imaginary person that is especially exposed to the hazards imposed by the system. The individual risks consist of risks of death, injuries and ill health, and the level of risk will be described by the probability of such outcomes per some appropriate measure of exposure, e.g. year, work-hours, travelled distances, etc. Individual risk acceptance criteria will determine the limits between acceptable and unacceptable probabilities of accidents causing death, injuries or ill health. Factors such as voluntariness, direct benefit and degree of control influence what level of risk are regarded as acceptable, and it may therefore be distinguished between acceptable risks for e.g. workers (Rimington et al., 2003) and third parties.

For complex systems, risks will often be introduced to the general public as well as to a special group of individuals, typically workers or nearby residents, and both criteria for societal risk and individual risk will have to be complied with. Often, special consideration is given to the risk of events with low frequency but high severity, as addressed in Henselwood and Phillips (2009).

3. Principles for establishing risk acceptance criteria

Various principles can be employed when deriving and establishing appropriate values for risk acceptance criteria for use in risk management, decision-making and safety regulation. The adopted principles will naturally influence the criteria arrived at. Furthermore, by applying some fundamental principles, it may be ensured that the risk acceptance criteria are based on a sound rationale and that they may easily be justified in a transparent manner. It may also facilitate high-level discussions on risk acceptance by discussing the underlying principles, and the actual criteria can be derived based on agreed principles.

3.1. Absolute risk criteria

This principle for establishing risk acceptance criteria does not consider the cost associated with achieving the corresponding risk level. Only the level of risk itself is studied and the risk criteria will be formulated as a maximum level of risk that is not to be exceeded, without any regard to the cost and benefit associated with achieving it. An example of a criterion (for individual risk) according to this principle could be "the frequency of death (e.g. due to a specific hazard) shall not exceed 10^{-6} per person-year". The utopian vision of zero tolerance towards risk is another example of an absolute probabilistic risk criterion.

An alternative way of formulating absolute risk criteria might be to formulate criteria based solely upon considerations of the cost, without due regard to the actual risk. Examples of such criteria could be to set a maximum monetary value that is to be used for overall risk reduction measures in society, i.e. to state that expenditure exceeding this value is not justifiable regardless of the level of risk. Such criteria might not be explicitly formulated, but will be implicitly imposed upon a given society by the economy of that society, i.e. the resources spent on risk management in western industrialized societies exceeds, by many orders of magnitude, the resources spent in developing countries even though the risks to life and health are by far greater in developing countries. This is partly due to an implicit but absolute risk criterion related to the overall economics of the society, setting absolute restraints on the available resources that can be used in controlling the risks.

3.2. The ALARP principle

Another widely used principle for determining criteria for acceptable risks is the ALARP principle. The ALARP principle dictates that risks should be managed to be as low as reasonable practicable. Both risk levels and the cost associated with mitigating the risk are considered, and all risk reduction measures should be implemented as long as the cost of implementing them is within the reasonable practicable according to cost effectiveness considerations. Before this principle can be used in establishing risk acceptance criteria there is thus a need for some standard measures of practicality to which the risk levels can be compared. Again, there are several principles for defining such standards of practicality for comparison.

Two alternative criteria often used in safety regulation to determine limits of what is reasonable practicable in combination with the ALARP principle are the Gross Cost of Averting a Fatality (GCAF)[1] and the Net Cost of Averting a Fatality (NCAF). These are cost effectiveness measures used to evaluate risk control options in terms of ratio of additional cost to the reduction in risk in terms of fatalities averted. The NCAF criterion also account for the possible economic benefit of the risk control option.

Based on the GCAF or NCAF criteria discussed above, other criteria can be developed that also accounts for reductions in quality of life due to injuries and poor health. A criterion based on the cost of gaining a Quality Adjusted Life Year (QALE) or a Healthy Life Year (HeaLY) (Hyder and Morrow, 2002) might be an example of such a criterion, where the state of health is more explicitly taken into account.

3.3. The principle of equivalency

A principle commonly used for establishing risk acceptance criteria for novel activities or systems is to compare with known levels of risks for similar activities or systems that are widely regarded as acceptable and to require that an equal level of risk is obtained. Alternatively, one can compare with historical risk data, and if the risk level has generally been considered to be acceptable one can require that future levels of risk shall be equivalent to that of the past. Another possible criterion can be to require that proposed new technologies shall be equivalent regarding safety to past and present best practice. In order to develop explicit criteria, one must thus determine what safety level current best practice corresponds to.

Another approach in line with the equivalency principle is to compare with known risk levels implicit in human nature, e.g. a human life is expected to be of the order of 100 years or 10^2. Statistically, this implies an inherent background risk to human life of about 10^{-2} per year for all people. Realizing that this is the sum of all risks to life, one can develop acceptance criteria for specific areas based on the exposure and the contribution to the total risk one allows this area to constitute.

3.4. The principle of maximum benefit to all

Another principle is to manage risk to maximize the total expected net benefit for society as a whole. Accordingly, this should be a sufficient and rational principle for risk reduction efforts on behalf on the public. Both the expected risk reduction and the cost of proposed risk reduction measures are considered, and it is argued that if so much efforts and resources are being spent on reducing risk with the goal of improving health and safety that the net benefit are not maximized, this expenditure is not justifiable. An ethical basis of such a principle could clearly be found within utilitarianism (e.g. Bentam, 1789).

In order to apply the principle of maximum net benefit to all in risk management, there is the need for an objective measure of this benefit. A measure that is widely accepted as appropriate for this is to use the expected length of life in good health for all members of the society. The principle of maximum net benefit to all thus indicates that risk should be reduced in order to maximize the expected length of life in good health. Other measures may consider both mortality and wealth as well.

Although this principle seeks to maximize the net benefit to all, another sometimes conflicting principle, with a deontological ethical basis, states that no individuals are to be sacrificed for the sake of others, i.e. it is not deemed acceptable to expose certain individuals to additional risk in order to reduce the risk or increase the benefit to others. The utilitarian principle of maximum net benefit to all is thus not ideally suited for managing risks that are not equally distributed among the population. According to e.g. the Kaldor–Hicks compensation principle, unevenly distributed risk should imply compensation to the ones most exposed, in order to transform the losers to non-losers (e.g. Nathwani and Narveson, 1995).

The Life Quality Index (LQI) has recently gained much attention as a summary index for the net benefit (e.g. Ditlevsen, 2003, 2004; Ditlevsen and Friis-Hansen, 2005, 2009; Pandey and Nathwani, 2004). It is a social indicator that is derived to reflect the length of quality life for a society and it is constructed from two aggregated indicators, i.e. the life expectancy at birth and the gross domestic product per capita. These aggregated indicators are readily available for different countries. The Life Quality Index as a measure of the net benefit to all can thus be used for judging risk and risk reduction efforts for a country, and according to the Life Quality Index criterion, safety interventions are regarded as justifiable as long as they contribute positively to LQI. The expression for the Life Quality Index is given in Eq. (1), where g is the gross domestic product per capita, e is the expected length of life at birth and w is the ratio of time spent in economic activity (e.g. in increasing g).

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

The Life Quality Index criterion operates with quantum health, i.e. 0 = dead and 1 = alive. In order to explicitly model the effects of reduced health and thus account for mortality, wealth and morbidity, an alternative index based on the gross domestic product per

[1] Sometimes also referred to as Implied Cost of Averting a Fatality (ICAF).

capita and the health adjusted life expectancy at birth has been proposed. This Health Adjusted Life Quality Index (HALQI) can then be used as a criterion for assessing health and safety interventions in much the same way as the LQI criterion (Skjong and Vanem, 2004). Another proposed measure is the lifetime utility (Maes et al., 2003).

An alternative approach that is in line with the principle of maximum benefit to all is to base risk acceptance for a given activity on the economic importance to society (i.e. all). The acceptance criteria will then take the form of average fatalities per unit of economic production (Skjong and Eknes, 2001, 2002). This approach thus justifies a higher level of risk for activities that are of major importance to society compared to those activities with lesser economic importance. Optimization techniques have also been introduced for setting safety targets, for example in structural safety (Rackwitz, 2002; Rackwitz and Streicher, 2002; Faber and Stewart, 2003).

3.5. No mandatory risk reduction measures

Another approach to risk management is to remove all mandatory risk reduction requirements and let everything regulate itself according to the governing economics of the society. This principle is based on the assumption that resources are most efficiently spent on safety when distributed among the people, organisations and companies in the society rather than spent on implementing mandatory safety interventions and that the market forces efficiently internalize the risk (Viscusi and Gayer, 2002). This assumption is supported by the observation that the safety level is generally much higher in rich, industrialized countries where resources are available to the public for voluntarily expenditure on safety than in developing countries.

It is assumed that a high level of safety and reliability is desired from mere economic considerations, and that companies and organisations would be willing to spend sufficient resources on voluntary safety enhancing measures based on purely economic motives, i.e. that investment in safety will be cost effective up to a certain point, and that this point constitutes a natural criterion for the amount of resources to be spent on safety. Regulatory interventions aiming at correcting market failures that lead to an inefficient balance between risk reduction and the cost rather than solely focusing on eliminating the risk itself would be in line with this principle. Furthermore, it has been suggested that some regulations can lead to behavioral responses that unintentionally increase the risk (Hahn et al., 2000).

It can easily be argued that this principle will not provide a satisfactory level of safety to the general public and empirical evidence abound. It might be a reasonable approach for activities where the same stakeholder that is responsible for the activity imposing the risk is exposed to the risk, i.e. the ones that bear the cost of reducing the risk is also the ones that benefit form the risk reduction. However, in most cases this is not the case and for risks that are imposed on third parties, it is unrealistic to assume that acceptable levels of risk will be achieved if this principle is employed. It is thus commonly agreed that some sort of mandatory safety regulations are needed to control the risk to the public. However, there might be a limit for how much resources the society should spend on mandatory safety requirements, above which the resources would be more wisely spent on safety if released in free circulation.

3.6. The accountability principle

The accountability principle implies requirements for a single, open and clear process for managing the risks affecting the public and serves as the foundation for a professional ethic for public risk management. The decision making process should be transparent and decisions on risk should be proven to be justifiable and communicable to the public if they are to be defensible. Once such a process is transparently settled upon, decisions about risks to society can be made based on a sound rationale and thus transferred from the political arena to the professional arena of risk analysts. The accountability principle also ensures that resources are efficiently spent on reducing the actual risk and not just the public perception of risk.

The accountability principle implies transparent and clearly defined risk acceptance criteria that can be used in decision making, and this transparency will reveal the political, societal and personal values underpinning the criteria, as pointed out in Hartford (2009). Furthermore, these criteria should be quantitative rather than qualitative and based on objective assessments (as far as possible) rather than subjective interpretation of the risk picture. The formulation of criteria for acceptable risk should preferably be explicit rather than implicit, rendering little room for different interpretations of the acceptance criteria themselves.

3.7. The holistic principle

Decisions regarding safety on behalf of the public should be based on a holistic consideration of all risks and apply across the complete range of hazards. This means that systematic efforts to evaluate all the direct and indirect consequences of all hazards are required as a basis for risk management. Failure to take such a holistic approach to risk management may cause unproportional expenditure of resources on reducing risks in some areas in society at the expense of others. It is also possible that measures that reduce the risk in one area will increase the risk in another. For example, Philipson (1983) states that whether a certain risk is acceptable depend on the level of ambient risks and on whether other risks accruing from not accepting the certain risk may exceed it, and this agrees well with the holistic principle. Only when the total risk the public is exposed to is properly assessed, can proposed risk reduction measures be properly evaluated and criteria for acceptable risk be established.

High level risk acceptance criteria should therefore apply to the society as a whole and not be restricted to specific sectors, activities or areas. Possible derivation of lower level acceptance criteria for specific areas should then be made in accordance with the overall safety targets of the society as a whole in a hierarchical way.

3.8. Precautionary principle

The precautionary principle is a way of dealing with uncertainty that is especially associated with environmental risks. The principle was included in the Rio declaration on environment and development in 1992, and states that a precautionary approach should be applied in order to protect the environment (Rio, 1992). Basically, the precautionary principle, as laid down in the Rio declaration, states that where there are threats of serious or irreversible damage (to the environment), scientific uncertainty shall not be used as a justification for postponing cost-effective measures to prevent environmental degradation.

Naturally, this principle could be extended to imply that for new developments or actions where the consequences are unknown but may be judged by some to cause irreversible negative effects on the environment, it may be better to implement all known risk control measures or even to not initiate the development rather than to accept the uncertain but high risk. Even though the precautionary principle is most commonly associated with environmental risk, it could also be applied to other types of risk where the consequences are uncertain but potentially severe. Risk acceptance criteria should reflect this principle, as appropriate.

3.9. Principle of parsimony

Finally, one might want to add the principle of parsimony, that is, that a simpler risk acceptance criterion might be preferable to a complex one. There could be various reasons to favor simplicity, and one is practicality. For risk analysts and decision makers that are going to apply the criteria or derive criteria from a defined procedure, it is important that the criteria and procedures are simple enough to be practical. Furthermore, simplicity in how risk acceptance criteria are derived and implemented facilitates clear risk communication to the public and involved stakeholders.

Notwithstanding this principle, risk acceptance criteria are important both with respect to public safety and public expenditure, so parsimony should not be allowed to take precedence over the other principles that apply. For example, one should not forsake a holistic view on the account of parsimony.

4. Regulatory regime combining the different principles

Although some of the principles discussed above seem to be in contrast to each other, they may be combined in the same regulatory regime. The combination of absolute probabilistic risk criteria is often used together with the ALARP principle. A normal procedure is to establish an absolute value for the maximum tolerable risk which is not to be exceeded regardless of the costs of keeping the risk to a level below it. Another absolute value can be established that identifies risk levels below this value as negligible, stating that no mandatory risk reduction measures are required for risk levels that are less than this value. Risk levels in between these two absolute values can then be required to be kept as low as reasonable practicable according to cost effectiveness consideration and the ALARP principle. This approach is illustrated in the FN diagram in Fig. 2, where the absolute criteria for intolerable and negligible societal risks are indicated by the dotted lines. The ALARP area lies between these boundaries and the ALARP principle applies to risks within this area. Even though the use of such criterion lines in conjunction with FN curves is a widely adopted approach, it is noted there have been some objections to this use (Evans and Verlander, 1997; HSE, 2003), i.e. that they can give unreasonable conclusions and that they are inconsistent.

Within the ALARP region, various principles for cost effectiveness considerations can be used to establish a criterion for what is considered reasonable practicable. The equivalency principle can be used to determine an optimum NCAF or this can be derived from the principle of maximum benefit for all using the LQI criterion. With this approach, a combination of all the principles outlined above are utilized, i.e. absolute probabilistic risk criteria, the ALARP principle, the principle of equivalency, the maximum net benefit principle and the no mandatory risk reduction measure principle can be used within the same regulatory regime. The principles of accountability and a holistic view on risks permeate the whole decision-making process and apply on top of these, as well as the precautionary and parsimony principles whenever they seem relevant.

5. The ethics of risk acceptance criteria

In a sense, risk acceptance criteria help distinguish between “right” and “wrong”; for example, they divide between risk control measures that should be mandatorily implemented and those that need not be. In this regard, there is a close relationship to ethics, which distinguishes between “right” and “wrong” and one could argue that the principles for setting risk acceptance criteria, and indeed the regulatory framework for managing risk as a whole, need to have an ethical foundation, i.e. it should be defendable and justifiable by an ethical theory. A similar argument was presented in Mingers (2011) for linking ethics to operational research and decision making. An ethical dilemma arises however, when moral appraisals are to be made regarding actions with uncertain outcome, i.e. a probabilistic mixture of outcomes, and this is discussed in Hansson (2003). Roeser (2006) argues that emotions are a normative guide in judging the moral acceptability of technological risks and consequently that it is necessary to take emotions into account when moral judgments regarding acceptability of risk are to be taken. However, this will not be considered in this paper.

5.1. Central concepts in ethics

Two central concepts in applied ethics are values (what is regarded as good) and moral norms (action norms that prescribe how one should act; duties and rights). There might be positive duties requiring some positive action or negative duties requiring actions that should be forbidden. There are also universal duties that are owed to everyone and special duties towards certain groups or individuals.

A moral agent is a person or a competent person that can have moral duties towards others and that can be held accountable for their actions and decisions. Typically, a decision maker in risk management would be such a moral agent. Moral subjects are beings that should be taken into account in moral assessments, i.e. a moral subject has moral status. Within ethics, there have been discussions on who should be regarded as moral subjects and a central debate has been if there are only (living) human beings that have moral status or if also animals, plants and the environment and future generations are moral subjects with moral status. With regards to risk acceptance criteria, this would be important considerations when discussing what moral duties decision makers have towards e.g. future generations and the environment.

5.2. Ethical theories

An ethical theory aims at answering systematically what moral standards one should take when actions and decisions are assessed and how such moral standards should be justified. Hence, one could argue that risk acceptance criteria should have foundation in an ethical theory. Two types of ethical theories are teleological theories which are value based and deontological theories based on moral norms.

Consequentialism is a teleological theory where acts are judged solely on the consequences of the act and universal consequentialism takes into account how the consequences will affect all parties involved. Utilitarianism is a form of universal consequentialism based on the principle of utility, i.e. the morally right decision is the one with the best overall consequence of the utility of all parties affected (see e.g. Bentham, 1789; Mill, 1863). As stated above, the principle of maximum net benefit to all has a strong foundation in utlitarian ethics, more specifically in rule utilitarianism, where the rules or regulations should be chosen based on the principle of utility. Also the ALARP principle may be regarded as having a basis in utilitarianism.

Deontologists, on the other hand are more concerned with moral duties or obligations independent of consequences (Kant’s categorical imperative is a famous example of deontological ethics (Kant, 1785). See also Ross (1930)). Risk acceptance criteria based on this ethics should thus focus on the duty to protect e.g. the public and the environment to risk. As mentioned above, there can be universal duties as well as duties towards specific individuals or members of certain groups. Criteria for individual risk can thus be argued to have a deontological ethical foundation: Exposed individuals should be protected from risk, even if the overall utility of the population as a whole might be decreased as a result of associated risk reduction measures. In other words, regulators and stakeholders have moral obligations towards those exposed individuals. The accountability and precautionary principles can likewise be justified from a deontological point of view, where it is deemed a moral duty to be accountable and precautious. However, utilitarianism may also easily be used in arguing for those very same principles.

5.3. Ethical theories as foundation for risk acceptance criteria

Establishment of risk acceptance criteria is one approach to risk management, but there exist other regimes (Aven and Vinnem, 2005). Even though this paper aims at demonstrating how the principles underlying the development of risk acceptance criteria can be justified by ethical theories, it is emphasized that this should not be construed as stating that risk acceptance are ethically superior to other approaches. As discussed in Aven (2007), the preference for either approach may stem from considerations other than ethics and such a discussion is out of scope of this paper. The ethical basis of risk management approaches is also discussed in Ersdal and Aven (2008). Hansson (2003) proposed a tentative moral criterion for risk acceptance that relates to the social system: Exposure of a person to a risk is acceptable if and only if this exposure is part of an equitable social system of risk-taking that works to that person's advantage.

It should be noted, in fact, that both utilitarianism and deontology can arguably be used as ethical foundation for many of the principles outlined above. For example, the principle of no mandatory risk reduction measures can be construed as being based on some form of deontological ethics, where it is implicitly assumed that the stakeholders have no moral obligations to anyone but themselves, but on the other hand, if assuming that the cost of risk reduction measures beyond what is economically desirably decreases the overall utility, this principle may be justified from an utilitarian point of view. The same applies to many of the principles, and in many cases both types of ethical theories may be invoked as justification. However, this is in no way problematic. On the contrary, if two ethical theories, both aiming at distinguishing "right" from "wrong", end up with the same moral judgment, albeit with different reasoning and justification, this should be reassuring, indicating that the assessment in some sense is universal. Indeed, it could be argued that a sound principle for risk acceptance criteria should preferably be possible to justify from both types of ethical theories as these are just different approaches to the same truth, i.e. what is morally "right" and what is "wrong". Of more concern would be the well known caveat in ethics is that there is no generally accepted ethical theory and that different theories may result in different judgments. Furthermore, one and the same ethical theory may, in many cases, be used to justify mutually exclusive actions or decisions. For example, it is easy to construct moral dilemmas without any clear-cut answer on "right" or "wrong". Therefore, there may not be a one-to-one correspondence between adopting a particular ethical theory and the resulting risk acceptance criteria that are derived from that theory. Similar conclusions were arrived at in Ersdal and Aven (2008).

Notwithstanding, it is believed that there is a close relationship between ethics and risk management for protecting the public, environment and society as a whole against risk and it is deemed meaningful to make ethical considerations related to principles for risk acceptance criteria. In particular, when risk acceptance criteria are scrutinized and subject to debate, it may be helpful with a conscious idea about the underlying values and norms that are implicitly contained in the principles. Foundation in an ethical theory might also be a great help in communication and justification, for example towards the public, of adopted risk acceptance criteria.

In order to illustrate the relationship between ethical theories and the principles for risk acceptance criteria, an ethical theory versus risk acceptance criteria table is presented in Table 1. This gives an example of how the two main types of ethical theories can be used to justify the different principles and also illustrates the ambiguity since many of the principles can be equally justified with either type of ethical theory. An "X" in the table indicates that there is no lucid justification for the principle from the ethical theory, but it does not mean that justification is not possible. For example, the principle of parsimony is not essentially based on ethics but rather on practicality even though it may be possible to justify it ethically. It is emphasized that the justifications in Table 1 are meant as examples for illustrative purposes only.

6. Risk acceptance criteria: examples from the maritime industries

The FN diagram in Fig. 2 has commonly been applied as societal risk acceptance criteria within the maritime industries for various applications of Formal Safety Assessment (FSA), and different ship-types have been associated with different boundaries of the ALARP area (see e.g. IMO, 2000, 2007; Vanem et al., 2007c; Vanem et al., 2008a, 2008b). However, in recent years the notion of risk-based ship design (Papanikolaou, 2009) have become increasingly promoted as an alternative to the more traditional prescriptive approach, and this makes the establishment of appropriate risk acceptance criteria even more important. In the following, some examples of actual risk acceptance criteria used or proposed for the maritime industries will be presented.

6.1. Individual risk acceptance criteria

The individual risk consists of risk to life and health of individuals exposed to the hazards of a given activity. If the risk to life is regarded as considerably greater than the risk of injuries and ill health (due to the higher severity of the consequence, not necessarily due to a higher probability), the latter is often neglected and risk acceptance criteria are given in terms of probability of death per some appropriate measure, e.g. per year. The FSA guidelines (IMO, 2007) also suggests to convert minor and sever injuries to fatalities according to the risk equivalency concept by equating one fatality to ten severe injuries and one severe injury to ten minor injuries so that only acceptance criteria for fatalities applies. The guidelines continue to suggest explicit boundaries for the ALARP region for individual risk in terms of annual probability of death. Probabilities less than 10^{-6} are deemed negligible, whereas the suggested target risk values for new ships (maximum tolerable annual fatality risk) are 10^{-4} for crew and 10^{-5} for third parties (passengers or public ashore).

6.2. Societal risk acceptance criteria

For some activities or technological projects of large scope or size, there might be a demand for other risk acceptability criteria on top of the criteria for individual risk. These criteria should take the possibilities of catastrophic accidents of major societal concern into account, and ensure that the risks imposed on the society from the activity are controlled. Developing and justifying such criteria are not as straightforward as for individual risk, and both the severity of the consequence and the frequency of occurrence of incidents need to be considered. Nevertheless, one methodology for doing this has been widely adopted, i.e. the use of criterion lines in conjunction with FN curves. One alternative way of formulating societal risk acceptance criteria is by use of risk matrices.

Table 1
Moral justification of risk acceptance criteria principles from the main types of ethical theories.

Principles for setting risk acceptance criteria	Moral justification for the principles	
	Teleological theories (value based)	Deontological theories (based on moral norms)
Absolute criteria	Assigning a negative moral value to high risk in moral assessments could be used to justify absolute risk acceptance criteria	It is a moral duty to keep risks to identified individuals or groups from becoming intolerable high
ALARP principle	Basis in utilitarianism – what is ALARP gives the overall best consequences, balancing the risk with the effort of reducing it even further	It is a moral duty to keep risks as low as reasonable practicable
Principle of equivalency	Relies on the assumption that prevailing criteria are ethically adequate, either teleologically or deontologically, and demand the same of new criteria.	
Max benefit to all	Clearly an utilitarian basis – rule utilitarianism	X
No mandatory risk reduction	Further risk reduction decreases overall utility	Stakeholders have moral obligations only to themselves
Accountability principle	Being accountable gives the overall best consequences/utility	Moral duty to be accountable
Holistic principle	Holistic view is needed in order to assess the overall best consequences or utility. Universal consequentialism.	Moral obligations to all prescribes a holistic view – moral duty to take everything and everyone into account
Precautionary principle	Irreversible serious consequences might be assigned a very low moral value, so that teleological theories prescribe precaution	A moral duty to be precautious, e.g. in environmental protection, by assigning moral status to future generations and the environment itself, the precautionary principle can be justified by deontological theories
Principle of parsimony	X	X

In general, FN curves are just a means of presenting descriptive information about the probabilities and consequences of accidents related to a certain activity or system. However, adding anchor points or criterion lines to FN curves has become a widely recognized method for describing risk acceptance criteria for societal risk. An anchor point in a FN diagram is a fixed point with a corresponding pair of consequence (N) and frequency (F) as coordinates: (N, F). Such anchor points have been proposed as acceptance criteria, and drawing lines through such anchor points can extend the acceptance criteria to incidents with other consequences. There are thus two parameters that are determining FN criterion lines, e.g. an anchor point and the gradient of the FN lines.

The slope of FN criterion lines has been subject to some debate although most lines are drawn with a slope between -1 and -2 on a log–log diagram. The slope of the lines describes the weighting in preference of avoiding large accidents. FN criterion lines with a slope of -1 are sometimes referred to as risk neutral, whereas lines with slope -2 are referred to as risk averse. However, realizing that a large portion of the potential fatalities comes from contributions with small N, and that these contributions are as intolerable as the comparable small contributions with large N, lines with slopes -1 does indeed correspond to risk-averse criteria. The criterion lines in Fig. 1 are shown with a gradient of -1, and this has been mostly used in maritime FSA studies.

Having settled on the appropriate gradient of the FN criterion lines, an anchor point is needed in order to describe the risk acceptance criteria. In general, different sectors will require different acceptance criteria, and one cannot assume that it will be satisfactory to apply acceptance criteria from one sector in another one. However, on a higher level, there might be possible to achieve some unified safety requirements. A number of different anchor points for societal risk have been suggested in the literature and in regulations, e.g. $(10, 10^{-4})$, $(500, 2\times10^{-4})$, $(100, 10^{-4})$ and $(10, 10^{-5})$ as referred to in Ball and Floyd (1998). In IMO (2000) and Safer Euroro (2003), societal risk acceptance criteria for different ship types are developed based on the economic importance of the corresponding activity, going through the anchor points in Table 2.

Table 2
Proposed FN anchor points for various shiptypes.

Shiptype	Negligible	Intolerable
Tankers	$(10, 2\times10^{-5})$	$(10, 2\times10^{-3})$
Bulk and ore carriers	$(10, 10^{-5})$	$(10, 10^{-3})$
Passenger ro–ro ships	$(10, 10^{-4})$	$(10, 10^{-2})$

6.3. Cost-effectiveness criteria

When the boundaries between the ALARP area and the negligible and intolerable regions of risk are established, cost-effectiveness criteria are normally used as criteria for when risks are considered *as low as reasonable practicable*. Traditionally, this has been used for safety risks and different values of preventing a statistical fatality have been used in different industry sectors. More recently, proposals for cost-effectiveness criteria related to the risk of accidental oil spills at sea and operational emission of greenhouse gasses to air have been put forward. No consensus has yet been reached within the maritime industries, but a brief outline of the proposed approaches will be given below.

6.3.1. The cost of averting a fatality – CAF

The levels of risk that are reasonable practicable are often associated with the cost of further risk reduction measures and the willingness to pay such costs. Regarding individual and societal risk to life, measures of this can be the cost of averting a fatality (NCAF or GCAF), cost-per-life-saved, the value of life, the value of a statistical life, etc. This cost or value can thus serve as a risk acceptance criteria within the ALARP region, and by assigning an optimum value for these measures it can be compared to the effect of possible risk reduction measures. If the cost per life saved for a specific risk reduction measure exceeds the assigned value, the implementation of this risk reduction measure will not be required. The value or cost of preventing a fatality is constantly under debate, and in the following some proposed values are presented.

In Lutter et al. (1999) a cost-per-life-saved cutoff is sought, above which safety regulations is no longer effective in reducing the risk to life. The explanation for such a cutoff value is that parts of the income will normally be spent privately on risk reduction measures, and that a loss of income will result in increased mortality risk in the population. According to their results, a US$ 15 million decrease in income would lead to the loss of a statistical life. Furthermore, an increase in income of the same amount would save an additional statistical life. Regulations that cost more than

US$ 15 million per expected life saved are therefore expected to have a counterproductive effect on the mortality rate and US$ 15 million could thus serve as an upper bound for the cost of saving a statistical life through regulations.

Gerdtham and Johannesson (2002) reports a similar study for Sweden and according to this study, the income loss that would induce an expected fatality was between US$ 6.8 million and 9.8 million. In Skjong and Ronold (2002) life expectancy as a function of purchasing power is studied in order to obtain similar cutoffs for other countries, obtaining an average of approximately US$ 9 million for the OECD countries (ranging from over 16 million for USA and Luxenbourg to about 2 million for Turkey).

Estimates of GCAF for Denmark are given in Ditlevsen (2003) to be between US$ 1.1–7.6 million. In Pandey and Nathwani (2004) estimates based on societal willingness to pay for averting one fatality per year in a population of 1 million are found to be between US$ 1.1–3.3 million per year. These values are reported to be in agreement with other Canadian estimates of value of life. According to Viscusi and Gayer (2002), different American agencies have used values of a statistical life between US$ 3 and 6 million. Within the offshore industry, values in the range of US$ 0.9–9 have been used. Krupnick et al. (2002) reports a survey carried out to estimate individual's willingness to pay for mortality risk reductions and the willingness-to-pay estimates was found to imply a value of a statistical life in the range of US$ 1–3 million.

A comprehensive literature survey of the value of a statistical life based on market estimates studies are presented in Viscusi and Aldy (2003). In general, typical values of a statistical life are reported to be in the range of US$ 4–9 million for the several countries on different continents.

In Jackson et al. (2004) it is suggested that a range of US$ 3–6 million could be used for most applications. A model proposed for use in the regulation of the nuclear industry is then established where the value of the spend of saving a statistical life (VSSSL) is a function of the risk to be reduced. Low risks would correspond to low values of VSSSL, and higher risks correspond to increasing values. As the risk approaches 1, the maximum values for VSSSL in the range of US$ 1.5–7.5 million could be applied. It is also noted that a study on cost-effectiveness of actual life saving interventions across different sectors of American society, reported by Tengs et al. (1995) yields a median value around US$ 1.5 million, albeit with notable spread.

In IMO (2000), various published values of GCAF for use as acceptance criteria are reviewed, and based on these a GCAF criterion of US$ 3 million is suggested for use by IMO. This value has commonly been adopted in maritime FSA studies, and this value can also be shown to be consistent with actual decisions made at IMO; decisions about safety at IMO seem to be fairly consistent and imply cost effectiveness criteria in the range of US$ 1.5–5 million. Based on the above review, it can be concluded that these criteria continue to be valid cost-effectiveness criteria, although they should be reviewed and possibly updated at certain intervals.

6.3.2. The cost of averting an oil spill – CATS

Activities that impose additional risks to the environment need to meet acceptance criteria for environmental risk. Damage to the environment can be expressed at different levels such as organism level, population level, habitat level or complete ecosystem level. However, due to practicality, environmental risk analysis for a complete ecosystem is normally not performed, and the risk is rather assessed in terms of some risk indicators.

With regards to ethics, environmental risk acceptance criteria may equally well be motivated and justified based on teleological and deontological theories. It may easily be argued that a clean and healthy environment has a positive value and contribute to the overall utility of society, but one may also base criteria on the duty to protect the environment from accidental oil pollution, e.g. duties towards affected people (e.g. fishermen, future generations) or towards the affected ecosystem (included fish and sea animals), depending on who is ascribed moral status. Duties towards future generations would also be relevant to consider.

Until recently, environmental risk was not considered to be within the scope of an FSA and no acceptance criteria were proposed. However, recently there have been some proposals, subject to some controversy, for risk acceptance criteria for accidental oil spill at sea, most notably the CATS approach for oil tankers.

Prior to the CATS proposal, Friis-Hansen and Ditlevsen (2003) proposed the Nature Preservation Willingness Index as risk acceptance criteria for pollution of the environment, and several studies had analysed data associated with oil spills (e.g. Etkin, 2000; White and Molloy, 2003). A recent overview is presented in Fingan (2011).

The cost of averting a tonne of oil spilt (CATS) is proposed as a means to establishing cost-effectiveness criteria for accidental oil spills in Vanem et al. (2007b, 2008a, 2008b), with an initial proposed CATS value of US$ 60,000. This approach and the actual proposed value have later become subject to an ongoing debate, both at IMO and in the academic literature (see e.g. Yamada, 2009; Psaraftis, 2008; Kontovas et al., 2010; Psarros et al., 2011), but has already been applied in evaluation of design alternatives (IMO, 2008; Klanac and Varsta, 2011) and safety assessments (Vanem et al., 2007a). Some of the objections are related to CATS being a single value criterion and that this is too simplistic; various non-linear alternatives have been proposed. On the other hand one might argue that the principle of parsimony applies and still opt for a CATS approach.

Notwithstanding, so far no consensus has been reached at IMO or elsewhere on environmental risk acceptance criteria and the debate is currently still on the agenda for the Marine Environment Protection Committee, MEPC, at IMO. Presumably, an agreement on acceptance criteria for oil spill would motivate similar criteria for accidental release of other environmentally harmful substances and would thus be an important contribution to marine environmental risk assessments.

6.3.3. Cost of greenhouse gas emissions

Inspired by the CATS approach for oil spill risk, cost-effectiveness measures for air pollution from ships is proposed in Eide et al. (2009) in terms of the Cost of Averting a Tonne of CO_2-equivalent Heating, CATCH. The results of the study suggest a CATCH-value of US$ 50, i.e. measures to reduce greenhouse gas emission that cost less than 50 US$ per tonne of CO_2 equivalent emissions should be regarded as cost-effective. It is further demonstrated in Longva et al. (2010) how such a cost-effectiveness criterion can be used to derive required levels of an Energy Efficient Design Index or, alternatively, caps on emissions from shipping.

6.3.4. Cost of air pollution

It is believed that similar cost-effectiveness criteria could be suggested for other air pollutants as well, such as nitrogen oxides (NO_X), sulfur dioxide (SO_2) and particulate matter (PM), but the author is not aware of any such proposals to date. However, a re-

Table 3
Possible cost-effectiveness criteria for air pollution.

Pollutant	Cost-effectiveness criteria (USD/t)
NO_X	6200
SO_X	9600
PM	31,500

cent meta-analysis proposes some generic monetary values for such emission to be used in integrated life cycle assessment (Vanem et al., 2011). Even though these were not initially intended for use in risk acceptance criteria, they may be candidates for cost-effectiveness criteria for relevant applications of maritime environmental risk analyses, and the suggested values are presented in Table 3.

7. Summary and conclusions

This paper has presented some general principles for setting risk acceptance criteria when managing risk from safety critical activities on behalf of the general public. It has also been shown that, although some of the principles may seem incompatible at first, they may actually be used to complement each other in one and the same regulatory framework. Furthermore, it is suggested that risk acceptance criteria, which are normative statements of what is deemed acceptable and what is not in a society, are intimately related to ethics, ethical theories and ethical values and norms. It is argued that the principles for establishing risk acceptance criteria, and thereby also the criteria themselves, should be based on ethical considerations and be justifiable by some ethical theory. In spite of the obvious link between ethics and risk management, is it demonstrated that there is no one-to-one correspondence between any ethical theory and principles adopted for establishing risk acceptance criteria. On the contrary, different ethical theories may be used as justification for one and the same principle and on the other hand, one and the same ethical theory can be used to justify contradicting risk acceptance criteria. Notwithstanding, it is argued that there are a close relationship between ethics and risk management, and ethical considerations related to principles for risk acceptance criteria will be meaningful. In particular, this is useful when criteria are subject to debate and should be communicated and justified towards the public.

Finally, some examples of actual risk acceptance criteria from the maritime industries are given along with discussions on how they were derived. It is seen that these actual risk acceptance criteria can be justified based on the principles outlined in this paper, even in cases where they might have been decided upon without a conscious awareness of those principles or any ethical theory. It is noted that some of the risk acceptance criteria examples given herein, most notably those pertaining to environmental risk are still under debate at IMO level and elsewhere, and consensus remains to be reached.

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