Risk Acceptance and Cost-Benefit Criteria Applied in the Maritime Industry in Comparison with Other Transport Modes and Industries

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ABSTRACT

This paper identifies the risk acceptance and cost-benefit criteria of various transport modes and industries, and compares them with those currently applied to the maritime industry.

The current maritime criteria are in general within the range of criteria used in other industries and transport modes, and in most cases in line with good practice elsewhere, so far as this can be determined. In the light of this, the paper considers whether there are any opportunities for improvements of the maritime criteria.

Keywords: *Risk Criteria, Cost-Benefit, Transport*

1. INTRODUCTION

This paper presents results from the third study commissioned by the European Maritime Safety Agency (EMSA) related to the damage stability of passenger ships. The study aims at further investigating the damage stability in a formal safety assessment (FSA) framework in order to cover the knowledge gaps that have been identified after the finalisation of the previous EMSA studies and the GOALDS project. Part of this study focussed on risk acceptance and cost-benefit criteria (DNV GL 2015), and that work is summarised in the present paper.

The objectives of this work were to identify the risk acceptance and cost-benefit criteria of various transport modes and industries, and to compare them with those currently applied to the maritime industry (IMO 2013).

The following transport modes and industries were reviewed:

- Aviation transport (EASA 2013, ICAO 2001, EUROCONTROL 2001, DfT 2007).
- Road transport (SafetyNet 2009a, 2009b, DoT 2013, ACDS 1991, Diernhofer et al 2010, PIARC 2012).
- Rail transport (European Commission 2012, RSSB 2009, LU 2012).
- Nuclear industry (ICRP 1997, EURATOM 1996).
- Onshore process (HSE 2001, BEVI 2004, Duijm 2009, HKPD 2011).
- Offshore oil & gas (ISO 2000).
- Healthcare (USEPA 2010).

The review concentrated on criteria for risks of fatalities, but it also covered criteria for risks of injuries and ill health.

2. DECISION-MAKING IN THE MARITIME INDUSTRY

When designing, managing or regulating ships, decisions sometimes have to be made about questions such as:

- Does the ship have adequate safety to be approved for operation?
- Are restrictions or other safety measures necessary to reduce its risks?
- How much risk reduction is required?
- What level of safety should be achieved by new rules?

To answer questions such as these, the decision-maker must decide when the ship or the maritime operation is safe enough, i.e. when the risks are so low that further safety measures are not necessary. Risk criteria are intended to guide this decision-making process in a systematic way.

In a quantitative risk assessment (QRA), risk criteria can be used to translate numerical risk estimates (e.g. 10-7 per year) into value judgements (e.g. “negligible risk”) which can be set against other value judgements (e.g. “beneficial transport of goods”) in a decision-making process, and presented to the public to justify a decision.

Risk criteria are also useful where risks are to be compared or ranked. Such comparisons are sometimes complicated by the multi-dimensional nature of risk, e.g. rare high-consequence accidents may be exchanged for more likely low-consequence ones. Risk criteria can help the ranking of such options.

Risk assessment is often a qualitative process, based on expert judgement. In this case, risk criteria may be qualitative standards that help decide whether further action is needed.

The risks of accidents on a ship are not the only consideration when making decisions about safety standards. Operational, economic, social, political and environmental factors may be important too. As a result, decisions about safety levels on ships are complex judgements, which cannot be reduced to simple rules or criteria. Nevertheless, it is possible to provide guidance on some of the most critical risk issues, and this is what risk criteria attempt to do.

3. TERMINOLOGY

The term “risk criteria” is defined by ISO (2009) as “terms of reference against which the significance of a risk is evaluated”. Despite the existence of this standard term, different industries use varying terminology for this concept, as shown in Table 1.

Table 1. Terminology Equivalent to Risk Criteria in Different Industries

INDUSTRY	TERMINOLOGY
Aviation transport	Target level of safety
Road transport	Safety targets
Road transport of dangerous goods	Risk criteria
Rail transport	Risk acceptance criteria (RAC)
Nuclear industry	Dose limits
Onshore process industry	Risk criteria
Maritime industry	Risk evaluation criteria

The current guidelines on FSA (IMO 2013) define “risk evaluation criteria” as the term to describe “criteria used to evaluate the acceptability/tolerability of risk”. Despite this, the annex containing the criteria also uses the terms “risk criteria” and “risk acceptance criteria”. It might therefore be appropriate to follow ISO by standardising on the term “risk criteria”. However, the term “risk acceptance criteria” could be considered clearer for people unfamiliar with the ISO definition, and its abbreviation (RAC) is also useful.

It is generally considered impractical to divide risks simply into “acceptable” and "unacceptable". In reality, there is a spectrum, in which higher risks need more stringent control. Risk criteria therefore typically divide the risk spectrum into regions, each calling for different types of response and usually give qualitative terms to each. The different terms used by decision-makers can be sorted into the following groups:

Unacceptable/ Intolerable/*De manifestis*	Highest risk
Tolerable/ Risk reduction desirable/ ALARP/ALARA	Intermediate risk
Acceptable/ Negligible/*De minimis*	Lowest risk

In this paper, the terms within each group are treated as interchangeable.

4. TYPES OF RISK CRITERIA

Risks can be measured in many ways, and for every metric that can be used to describe a risk, there are corresponding risk criteria. In this paper the following types of risk criteria are distinguished:

- Risk matrix criteria – evaluating the regions on a matrix of accident frequency (or probability) and consequence (or severity) – e.g. Figure 1.

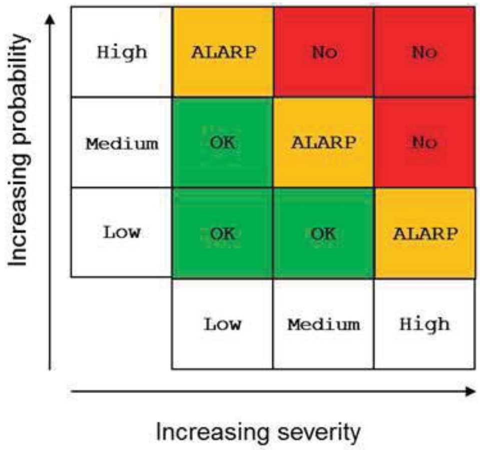

Figure 1 Example Risk Matrix Criteria

- Individual risk criteria – evaluating the risk of death to an individual – e.g. Figure 2.

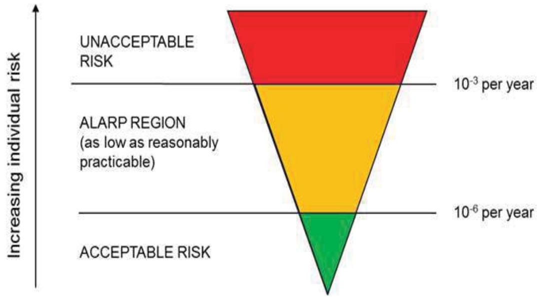

Figure 2 Example Individual Risk Criteria

- Societal risk criteria - evaluating the risk of death to the whole exposed population. These often apply to frequency-fatality (FN) curves – e.g. Figure 3.

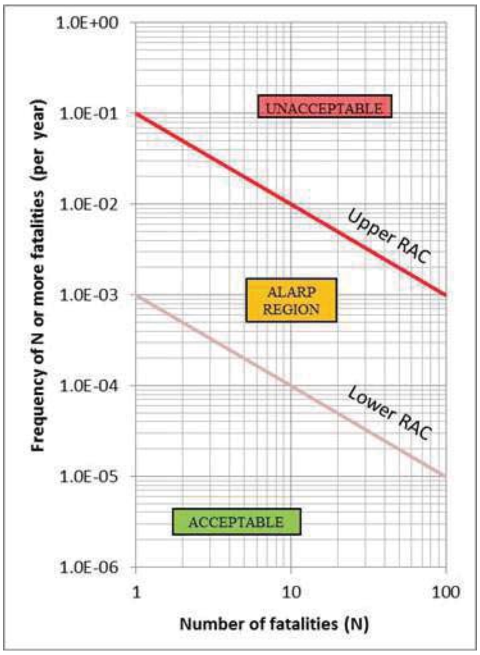

Figure 3 Example Societal Risk Criteria

- Cost-benefit criteria - evaluating the cost of risk reduction measures in a cost-benefit analysis (CBA). Although these do not evaluate the significance of risks directly, and hence are not strictly risk criteria at all, they do evaluate the need for risk reduction, and are closely connected to risk criteria.

Table 2. Application of Types of Risk Criteria in Different Industries

INDUSTRY	RISK MATRIX	INDIVIDUAL RISK	SOCIETAL RISK	ALARP/ COST-BENEFIT
Aircraft design (EASA)	√			
Air Traffic Management (EUROCONTROL)		√		
Airports (UK)		√		
Road transport (EU MS)		√	√	√
Road transport of DG (ACDS)		√	√	√
Road transport of DG (Switzerland)			√	√
Road tunnels (Austria)		√		
Rail transport (ERA)		√	√	
Rail transport/LU (UK)		√	√	√
Nuclear (ICRP)		√		√
Onshore process (UK)		√		√
Onshore process (Netherlands)		√	√	√
Onshore process (Flanders)		√	√	
Onshore process (France)	√			√
Offshore (ISO)	√			
Healthcare				√
Maritime		√	√	√

Table 2 shows the metrics that are used for risk criteria in various transport modes and industries. Many industries make use of individual and societal risk criteria, and cost-benefit or qualitative criteria defining when risks are as low as reasonably practicable (ALARP). Risk matrix criteria are also widely used, but the table shows only those industries using them as their primary metric for decision-making on risk.

5. PRINCIPLES FOR RISK CRITERIA

Most risk criteria have developed through a process of expert judgement and political compromise. Nevertheless, it is worthwhile to consider the fundamental principles that could be used to develop and justify risk criteria.

The following principles have been suggested in different industries, but have been expressed here in a way that would be valid for any activity that involves risks of accidents:

1. Justification of activity – the risks of the activity should be justified by its benefits (in terms of people transported, value of leisure activities, jobs etc) for the society as a whole.
2. Optimisation of protection – the risks should be minimised by appropriate safety measures, taking account of their benefits (in terms of risk reduction) and costs, and also of established good practice.
3. Equity – the risks should not be unduly concentrated on particular individuals or communities.
4. Aversion to catastrophes – the risks of major accidents (involving multiple-fatalities, high cost or widespread impacts) should be a small proportion of the total.
5. Proportionality – the detail in the risk assessment should be proportionate to the level of risk, and negligible risks should be exempted from detailed assessment.
6. Continuous improvement – overall risks should not increase, and preferably should reduce.

Table 3 indicates where these principles are applied in other transport modes and industries.

Table 3. Application of Principles for Risk Criteria in Different Industries

INDUSTRY	JUSTIF-ICATION OF ACTIVITY	OPTIMIS-ATION OF PRO-TECTION	EQUITY	AVERSION TO CATAS-TROPHES	PROPOR-TIONALITY	CONTIN-UOUS IMPROVE-MENT
Aircraft design (EASA)				√		
ATM (EUROCONTROL)						√
Airports (UK)		√	√		√	
Road transport (EU MS)		√				√
Road transport (USA, Norway)		√				
Road transport of DG (ACDS)	√	√	√	√	√	
Road transport of DG (Switz)		√		√	√	
Road tunnels (Austria)		√		√	√	
Rail transport (ERA)			√			√
Rail transport (UK)		√	√			√
Nuclear (ICRP)	√	√	√			
Onshore process (UK)		√	√		√	
Onshore process (Netherlands)		√	√	√		
Onshore process (Flanders)			√	√		
Onshore process (France)		√		√	√	
Onshore process (HK)		√	√	√	√	
Offshore oil & gas		√	√			
Healthcare		√				
Maritime	√	√	√	√	√	

The current maritime criteria (IMO 2013) apply all the principles except continuous improvement. The only enhancement that might be considered, based on the principles used in other industries, might therefore be to include an element to ensure continuous improvement. This could, for example, consist of a requirement that fatality risks or total loss rates in the maritime fleet as a whole, or in the fleets of specific ship types, should decline at a rate no less than that achieved over the previous decade.

6. INDIVIDUAL RISK CRITERIA

Individual risk criteria are intended to ensure that individual people are not exposed to excessive risk. This implements the equity principle, giving all individuals the same protection. Individual risk criteria can also define a negligible risk level, below which further risk reduction is not required. This implements the proportionality principle, allowing simpler assessment for smaller risks.

Individual risks are relatively easy to calculate in a risk analysis, and most approaches to risk criteria include limits on individual risks, so they are sometimes seen as the most important type of risk criteria. However, modern risk assessment practice is typically to use individual risk criteria as outer limits on a process that tries to make the risks ALARP, and therefore cost-benefit criteria (or qualitative equivalents) are usually more important. Furthermore, experience suggests that most ships would comply with standard individual risk criteria. However, individual risk criteria are still important when demonstrating to the public, who may distrust cost-benefit calculations, that acceptable safety levels have been achieved.

Table 4. Individual Risk Criteria in Different Industries

INDUSTRY	MAXIMUM INDIVIDUAL RISK (per year)	NEGLIGIBLE INDIVIDUAL RISK (per year)
Airports (UK)	10^{-4} (public)	10^{-5}
Road transport of DG (ACDS)	10^{-3} (workers), 10^{-4} (public)	10^{-6}
Rail transport (ERA)	Various FWSI per pass km	-
Rail transport (UK)	1.038 FWI per 10^{8} pass km	-
London Underground	10^{-3} (workers), 10^{-4} (public)	10^{-6}
Nuclear (ICRP)	10^{-3} (workers), 10^{-4} (public)	-
Onshore process (UK)	10^{-3} (workers), 10^{-4} (public)	10^{-6}
Onshore process (Netherlands)	10^{-6} (public LSIR)	-
Onshore process (Flanders)	10^{-5} (public LSIR)	10^{-7}
Onshore process (HK)	10^{-5} (public LSIR)	-
Offshore oil & gas (UK)	10^{-3} (workers)	
Maritime	10^{-3} (crew), 10^{-4} (passengers)	10^{-6}

Table 4 shows the individual risk criteria that are in use in other transport modes and industries. In the UK the individual risk criteria from HSE (2001) are used in all industries, and these are also used in the maritime industry criteria. When the values of the criteria are different, this partly reflects the different approaches to ALARP in the national legal systems. In the rail industry, individual risk criteria are expressed as fatalities and weighted serious injuries (FWSI) per passenger km, which cannot be compared to the other metrics

7. SOCIETAL RISK CRITERIA

Societal risk criteria are intended to limit the risks from the ship to the society as a whole, and to local communities who may be affected by it. One purpose is to implement the equity principle, giving all communities the same protection. Societal risk criteria can also define a negligible risk level, below which further risk reduction is not required. This implements the proportionality principle, allowing simpler assessment for smaller risks. Societal risk criteria expressed as FN curves can also implement the principle of aversion to catastrophes.

Societal risk criteria are particularly important for transport activities, which spread their risks over a constantly changing population of passengers and people near to their ports. Compared to fixed installations, this tends to produce relatively high societal risks despite relatively low individual risks.

Societal risk criteria are also important where there is potential for catastrophic accidents. These are a particular concern for passenger ships and liquefied gas carriers, which have the potential to affect large numbers of people in a single accident, although the likelihood is very low.

Table 5 shows the societal risk criteria that are in use in other transport modes and industries. It shows both the maximum and negligible criteria for FN curves, and the applicable range of fatalities (N). Some of the criteria depend on tunnel or road length (L) in km. The table also shows fatality rate criteria where used.

Despite their attractiveness, there are many theoretical and practical challenges in understanding and using FN criteria, especially when comparing activities with different societal benefits (such as ships whose size or cargo is much larger than average).

Table 5. Societal Risk Criteria in Different Industries

INDUSTRY	RANGE	MAXIMUM FN (per year)	NEGLIGIBLE FN (per year)	FATALITY RATE (per year)
Road transport of DG (ACDS)	≥1	0.1/N	10^{-4}/N	-
Road transport of DG (NL)	≥10	$10^{-2}L/N^2$	-	-
Road tunnels (Austria)	≥10	-	$0.1L^{0.5}/N^2$	10^{-3} per tunnel year
Road tunnels (Czech Republic)	1 - 1000	0.1/N	10^{-4}/N	-
Road tunnels (Denmark)	≥1	$0.4/N^2$	$0.004/N^2$	-
Road tunnels (France)	-	-	-	10^{-3} per tunnel year
Road tunnels (Germany)	10 - 1000	-	$0.01L/N^2$	6.2 x 10^{-3} per tunnel km per year
Road tunnels (Italy)	≥1	0.1/N	10^{-3}/N	-
Rail transport (ERA)	-	-	-	Value per train km for each MS
Rail transport (UK)	-	-	-	1.9 x 10^{-7} per train km
Onshore process (Netherlands)	≥10	$10^{-3}/N^2$	-	-
Onshore process (Flanders)	10 - 1000	$10^{-2}/N^2$	-	-
Onshore process (HK)	1 – 1000	10^{-3}/N	10^{-5}/N	-
Maritime (tanker)	≥1	0.02/N	2 x 10^{-4}/N	
Maritime (dry cargo)	≥1	0.01/N	10^{-4}/N	
Maritime (passenger ro/ro)	≥1	0.1/N	0.001/N	

As a result, there are at present no widely accepted societal risk criteria, and FN criteria that have been developed are often not used in practice, or are treated as guidelines that indicate where risk reduction might be cost-effective. Because cost-benefit criteria make use of integrated measures of fatality risk, some authorities consider these automatically take account of quantifiable societal risks. Societal concerns, including concern about catastrophe risks, are better addressed through qualitative decision making rather than embedded in the risk criteria.

The current maritime criteria are unusual in having a consistent methodology to take account of societal benefit (Norway 2000). They may therefore be considered more advanced than the criteria in other industries. Nevertheless, given the difficulties with societal risk criteria, it is recommended that they are treated as guidelines rather than rigid rules. If exceeded, they indicate opportunities for risk reduction, and should not be considered to demonstrate that risks are unacceptable.

8. COST-BENEFIT CRITERIA

Cost-benefit criteria define the point at which the benefits of a risk reduction measure just outweigh its costs. This implements the principle of optimisation of protection. By systematically evaluating a range of measures, it is possible to show whether the risks are ALARP.

One of the most important issues in a cost-benefit analysis (CBA) of safety measures is the value assigned to reductions in fatality risks. The critical parameter is the “value of preventing a fatality” (VPF). It should be emphasised that this does not refer to any individual fatality, but to a small change in risk to many lives, equivalent to a single statistical fatality. The VPF is an input to the CBA, but it is often very critical to the evaluation of safety measures.

Several types of cost-benefit criteria are in use:

- Cost of averting a fatality (CAF) - the cost of a measure divided by the expected number of fatalities averted. A measure is normally recommended if its CAF is less the VPF Hence the VPF can be seen as a type of cost-benefit criterion.
- Cost per quality-adjusted life year (QALY) - the cost of a measure divided by the life-years saved, standardised to equivalent years of healthy life. This is similar to the VPF but refers to health risks.
- Net present value (NPV) - the difference between the discounted benefits and the discounted costs of a measure. A measure is normally recommended if its NPV is positive.
- Benefit/cost ratio (BCR) - the discounted benefits of a measure divided by the discounted costs. A measure is normally recommended if its BCR is greater than 1.
- Internal rate of return (IRR) - the discount rate that makes the discounted benefits of a measure equal to the discounted costs, and hence would make its NPV equal to zero. A measure is recommended if its IRR is greater than the usual discount rate.

The VPF can be set through techniques such as:

- Human capital approaches. These estimate the VPF in terms of the future economic output that is lost when a person is killed.
- Willingness to pay (WTP) approaches. These estimate the amount that people in society would be prepared to pay to avoid a statistical fatality.
- Life quality approaches. These are based on social indicators of quality of life that reflect life expectancy and gross domestic product (GDP). By relating the costs of a measure to the GDP and the risk benefits to life expectancy, it is possible to identify the point at which further safety measures have a negative overall impact on the quality of life.

Table 6 shows the cost-benefit criteria that are in use in other transport modes and industries. Some industries do not use CBA at all. Some countries, notably the UK, have standardised on VPFs across all industries and transport modes. Others vary because of differences in national income and the VPF setting technique used.

The VPF of $3m in the maritime criteria (IMO 2013) was derived from 1998 statistics. New calculations in the present study (DNV GL 2015) indicate an appropriate VPF would be approximately $7m. This uses the life quality approach, based on 2012 GDP data and updated life expectancies and fractions of time in economic activity, with the results averaged over all OECD members.

The maritime criteria are unique in taking account of injuries by adjusting the criterion for studies that do not model injury costs explicitly. It would be clearer to value injury risks separately following approaches in the road and nuclear industries. For sensitivity tests, a range of VPF from $4m to $8m is considered appropriate.

The maritime criteria are also unique in distinguishing gross and net costs of averting a fatality (GCAF and NCAF). The need for this arises because decisions on risk reduction measures can sometimes be sensitive to the inclusion of non-fatality economic benefits. The two separate criteria make clear whether this is so, but because both are compared to the same criterion, GCAF appears redundant since NCAF is always lower. However, GCAF is simpler to calculate, and NCAF sometimes becomes negative, which has no clear meaning. The distinction is logical but somewhat confusing. Other industries address this issue by using the criterion of NPV instead, and it may be possible to do the same in future developments of the maritime criteria.

Table 6. Cost-Benefit Criteria in Different Industries

INDUSTRY	CRITERIA USED	VPF (Original units)	VPF ($m 2012)
Airports (UK)	Qualitative	-	-
Road transport (EU MS)	NPV, BCR and IRR	€0.056 to 2.1m	$0.1m to $4.3m
Road transport (UK)	NPV, BCR	£1.7m	$2.8m
Road transport (USA)	NPV	$9.1m	$9.1m
Road transport (Norway)	NPV	NOK26.5m	$4.5m
Road transport of DG (ACDS)	CAF	£2m	$5.3m
Road tunnels (Austria and others)	Qualitative	-	-
Rail transport (UK)	NPV	£1.7m	$2.8m
London Underground	Qualitative	-	-
Nuclear (UK)	NPV	£1.7m	$2.8m
Onshore process (UK)	Qualitative	-	-
Onshore process (Netherlands)	Qualitative	-	-
Onshore process (France/HK)	Qualitative	-	-
Offshore oil & gas	CAF	Various	Various
Healthcare (USA)	NPV	$7.4m	$7.4m
Healthcare (WHO/UK/Spain)	Cost per QALY	-	-
Maritime	GCAF and NCAF	$3m	$4m to $8m

9. CONCLUSIONS

The overall conclusion from the review of risk criteria used in different industries and transport modes is that each application differs in terms of the types of criteria used, the principles for their development, and the specific values adopted. In some countries, the same approaches are used in different industries and transport modes, but overall the pattern is one of difference rather than commonality.

The current maritime criteria are in general within the range of criteria used in other industries and transport modes, and in most cases are in line with good practice elsewhere, so far as this can be determined. Only a few minor improvements have been suggested.

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