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Risk Acceptance Criteria and Risk Based Damage Stability. Final Report, part 1: Risk Acceptance Criteria

European Maritime Safety Agency

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Abstract:
This report 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.

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PREFACE

This report is a deliverable according to the Framework Service Contract Number EMSA/OP/10/2013. This is the third study commissioned by EMSA related to the damage stability of passenger ships. The previous studies focused on ro-ro passenger ships.

This study aims at further investigating the damage stability in an FSA framework in order to cover the knowledge gaps that have been identified after the finalization of the previous EMSA studies and the GOALDS project.

The project is separated in to 6 studies:

- Identification and evaluation of risk acceptance and cost-benefit criteria and application to risk based collision damage stability
- Evaluation of risk from watertight doors and risk based mitigating measures
- Evaluation of raking damages due to groundings and possible amendments to the damage stability framework
- Assessment of cost effectiveness or previous parts, FSA compilation and recommendations for decision making
- Impact assessment compilation
- Updating of the results obtained from the GOALDS project according to the latest development in IMO.

The project is managed by DNV-GL and is established as a joint project which includes the following organisations:

Shipyards/designer:

Euroyards representing: Meyer Werft, Meyer Turku, STX-France and Fincantieri

Knud E. Hansen AS

Operators:

Royal Caribbean Cruises

Carnival Cruises

Color Line

Stena Line

Universities:

National Technical University of Athens

University of Strathclyde

University of Trieste

Consultants:

Safety at Sea

Software manufacturer:

Napa OY

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EXECUTIVE SUMMARY

This report 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 following transport modes and industries are reviewed:

- Aviation transport
- Road transport
- Rail transport
- Nuclear industry
- Onshore process
- Offshore oil & gas
- Healthcare

The overall conclusion is that each application differs in terms of the types of criteria used, the principles for their development, and the specific values adopted. In the UK, common approaches are used in different industries and transport modes, and these criteria have been adopted in some other countries, 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.

The current maritime criteria include a value of preventing a fatality (VPF) of $3m. Updated calculations in this study indicate the VPF should now be approximately $7m. For sensitivity tests, a range of VPF from $4m to $8m is considered appropriate.

There are very few opportunities for improvement of the maritime criteria, although the following subjects might be considered for future enhancement:

- An element that encourages continuous improvement in societal risk (i.e. a target reduction in the annual numbers of fatalities in the industry as a whole). This would be consistent with road, rail and aviation transport.

- The current societal risk criteria based on FN curves could be treated as guidelines that help encourage reduction of catastrophe risks, rather than rigid rules that define acceptability of societal risks. This would be consistent with the approach in the onshore process industry.

- In cases where non-fatality costs dominate, so that NCAF becomes negative, the net present value (NPV) of a measure would be a better criterion than the net cost of averting a fatality (NCAF). This would be consistent with the approach used in road and rail transport and the nuclear industry.

It is recognised that none of these changes are essential, and that any improved clarity or consistency might be outweighed by confusion caused by the change.

1 INTRODUCTION

1.1 Background

The European Maritime Safety Agency (EMSA) has commissioned a study to assess the acceptable and practicable risk level of passenger ships related to damage stability. The study is being conducted by a consortium led by DNV GL. As part of the development of risk acceptance criteria for the study, EMSA requires an evaluation of appropriate risk acceptance and cost-benefit criteria, based on a comparison of the approaches in other transport modes and industries. This document presents DNV GL's report on this subject.

1.2 Objectives

The objectives of this report are 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.

1.3 Scope

The scope of the report covers criteria that are used by the maritime industry in general. However, it focusses on criteria that are relevant for passenger ships, notably criteria for risks of fatalities. It therefore does not address criteria for accidents involving oil, liquefied gas or other dangerous goods, except where these are part of the criteria also used for fatality risks.

The report concentrates on criteria for risks of fatalities, but it also covers criteria for risks of injuries and ill health.

1.4 Report Structure

Section 2 of the report explains what is meant by the term "risk acceptance criteria", and what the criteria are intended to be used for.

Section 3 describes the main frameworks and principles that have been used to develop criteria for different applications.

The remainder of the report reviews different types of risk criteria in more detail:

- Individual risk criteria - Section 4
- Societal risk criteria - Section 5
- Cost-benefit criteria, including valuation of injury and health risks - Section 6

Appendix A documents the approaches of other transport modes and industries in these areas.

Appendix B estimates historical risks benchmarks for transport in different modes in the European Union.

Appendix C reviews the available literature on the value of preventing a fatality (VPF), and updates the values that are used in current maritime industry criteria.

Appendix D explains and updates the current maritime industry frequency-fatality (FN) criteria.

The report's conclusions regarding possible enhancements to the risk acceptance criteria used in the maritime industry are summarised in Section 7.

2 PURPOSE AND DEFINITIONS

2.1 Decision-Making in the Maritime Industry

Maritime transport, like any other transport mode and industry, inevitably involves risks of accidents. Such accidents may be unlikely, but if they do occur they may cause harm to the ship itself, its cargo or passengers, to port infrastructure or other vessels, to the marine and coastal environment, or to the business performance of its owners and operators. The way ships are designed and operated is intended to minimise the risks of accidents. Risks can usually be reduced, at progressively greater cost, by adding further safety measures or achieving a higher standard of safety-awareness in operation. Nevertheless, it is impossible to eliminate them altogether.

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 shipping 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.

2.2 Definition of Risk

The official technical definition of risk, as recorded by the International Organization for Standardization (ISO), has changed significantly in recent years. For example, ISO (1999) used to define risk as follows:

> **risk**
> Combination of the probability of occurrence of harm and the severity of that harm.

Under this definition, an example of a quantitative risk would be "10^{-6} probability of death due to sinking". Here the "harm" would be loss of life, the "hazard" (i.e. the potential cause of the harm) would be the ship sinking, and the probability is 10^{-6} (i.e. 1 in a million). Risks can also be expressed qualitatively (e.g. "likely to cause injury").

In recent years, the ISO definition has been changed to reflect the focus of financial and business fields on positive outcomes. As a result, the ISO (2009) definition of risk is:

> **risk**
> effect of uncertainty on objectives.
>
> NOTE 1 An effect is a deviation from the expected - positive and/or negative.
> NOTE 2 Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process).
> NOTE 3 Risk is often characterized by reference to potential events and consequences, or a combination of these.
> NOTE 4 Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.
> NOTE 5 Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequence, or likelihood.

This definition ("effect of uncertainty on objectives") is very general and allows positive concepts, such as "possibility of large profit" or "increase in life expectancy", to be considered risks, along with the traditional negative concepts such as "possibility of sinking".

The previous definition is retained (with minor changes in wording) as Note 4 in the current definition, and this previous definition is considered more appropriate for the current study.

2.3 Risk Metrics

Risk is a multi-dimensional concept, and can be measured in many different ways. The following are the most important metrics used by risk criteria for passenger ships:

- Individual risk of fatality - the probability of death experienced by individuals on the ship (such as passengers or crew members) from specified hazards. The main individual risk metrics are:
    - Location-specific individual risk (LSIR) per year. This refers to a hypothetical individual who is always present at a particular location (e.g. in the engine room). This is useful for showing the spatial distribution of risk.
    - Individual-specific individual risk (ISIR) per year. This is the LSIR multiplied by the actual time that a realistic individual is exposed at the location, allowing for time elsewhere, including ashore. This is more realistic for passengers who are rarely exposed, and is useful for comparing with background risks in daily life.
    - Individual risk per hour. This is the annual risk (LSIR or ISIR) divided by the time exposed. It is sometimes expressed as a fatal accident rate (FAR) per 100

million exposed hours. This is the LSIR divided by the number of hours in the year (8760) and multiplied by 10^8, which usually gives a convenient number in the range 1-100. This is commonly used to compare occupational risks, but may be confusing when adding risks from activities of different durations.

  - Individual risk per person km. This is the annual risk (LSIR or ISIR) divided by the distance travelled during the time exposed. This is commonly used for transport risks, but may be misleading when comparing fast and slow transport modes.

- Societal (or group) risk of fatalities - the probability of death experienced by the whole group of people affected by the activity (including all passengers and crew, as well as any people on other ships who may be involved, e.g. in collisions). The main societal risk metrics are:

  - Risk matrix, showing the frequency (or probability) of events and their consequence (or severity). This is able to compare different types of hazards and consequences, including societal risks, but does not usually show the total risk from the activity.

  - FN curve, showing the cumulative frequency per year (F) of events involving N or more fatalities. This is used to illustrate catastrophe risk, but its cumulative form is often found to be confusing.

  - The average number of fatalities per year, known variously as annual fatality rate, potential loss of life (PLL), expectation value or rate of death. This is a useful simple measure of societal risk.

- Injury risks – these may be added to the fatality risks using a weighting to establish the equivalence between different injury severities.

- Health risks – these may be measured as losses of quality-adjusted life-years (QALY). A QALY is a year of life adjusted for its quality, as measured on a health-related quality of life (HRQOL) scale. For example, an illness causing an HRQOL score of 0.8 for 6 months would be equal to the loss of 0.1 QALY. In principle, health benefits from leisure travel could be offset against risks of illness, illustrating a possible positive risk consistent with the ISO (2009) definition.

2.4 Definition of Risk Acceptance Criteria

"Risk criteria" are defined by ISO (2009) as follows:

> **risk criteria**
> Terms of reference against which the significance of a risk is evaluated.

In simple terms, risk criteria help answer questions such as "How safe is safe enough?", or "Which of several different risks is lowest?".

"Risk acceptance criteria" appears to be a slightly more specific term, indicating the standard for evaluating risk that is adopted by a decision-maker. Although widely used, it is not formally defined and is not used in ISO documents on risk management.

The term “risk acceptance” is disliked by regulators in the UK and USA because it implies that the person exposed has consented to receive the risks, and even regards them with favour. The American Institute of Chemical Engineers (CCPS 2009) expressed the view as follows:

> “*The concept of **risk tolerance** or **risk tolerability** is increasingly preferred to **risk acceptance**. The terminology has changed because organizations do not want to imply or create a public perception that risks attributable to their activities or operations are viewed as being acceptable. Rather, recognizing that eliminating all risks is impossible, some organizations prefer to speak of carefully managed residual risks being tolerable*.”

Generalising from the review in Appendix A, Table 2.1 shows the terminology used in other transport modes and industries. The current maritime criteria (IMO 2013) are described as “decision parameters including risk acceptance criteria”.

Table 2.1 Terminology Equivalent to Risk Acceptance 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
Nuclear industry	Dose limits
Onshore process industry	Risk criteria

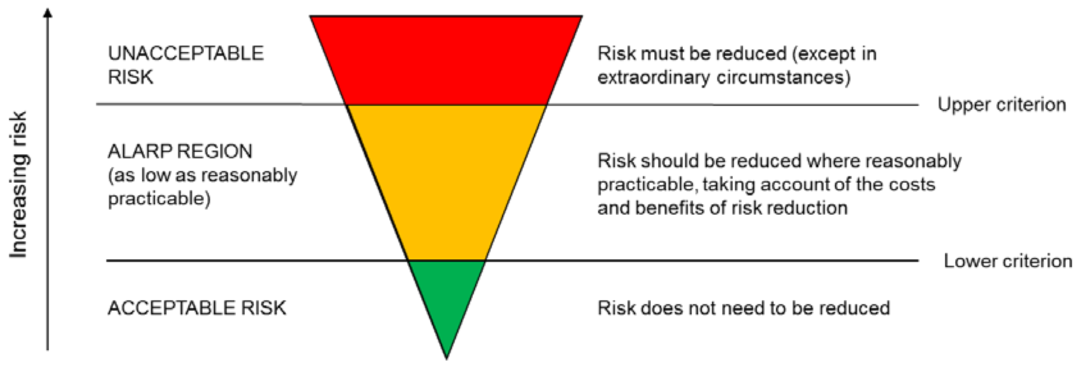
In most cases the alternatives such as “risk criteria”, “risk acceptance criteria”, “acceptability criteria”, “tolerability limit”, “safety target” etc. are interchangeable, and in this report they are all are treated as types of risk criteria.

2.5 Terminology for Risk Regions

It is generally considered impractical to divide risks simply into “acceptable” and “unacceptable”. In reality, there is a spectrum of risks, 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. Unfortunately, different decision-makers often use different terminology.

In many cases, risk criteria are seen as dividing “unacceptable” risks from “acceptable” ones, with an intermediate region where risk reduction is desirable (e.g. see Figure 2.1). However, the terms “tolerable”, “justifiable” and “negligible” are also used, sometimes to refer to different levels of risk and sometimes interchangeably.

Figure 2.1 Three Region Framework for Risk Criteria



Where three regions (i.e. two risk criteria) are used, the intermediate region has been given different names, including “tolerable”, “risk reduction desirable”, “ALARP” (as low as reasonably practicable), “ALARA” (as low as reasonably achievable). In this report, all these terms are treated as broadly equivalent.

In the USA, the phrases “acceptable”, “tolerable” and “negligible” are not used for legal reasons. US criteria use the phrases:

- *De manifestis*, meaning “obvious” or “significant” risk.
- *De minimis*, meaning “small enough to be ignored”. The term is derived from *de minimis non curat lex* - “the law does not concern itself with trifles”.

Overall, the terms can be sorted into the following groups:

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

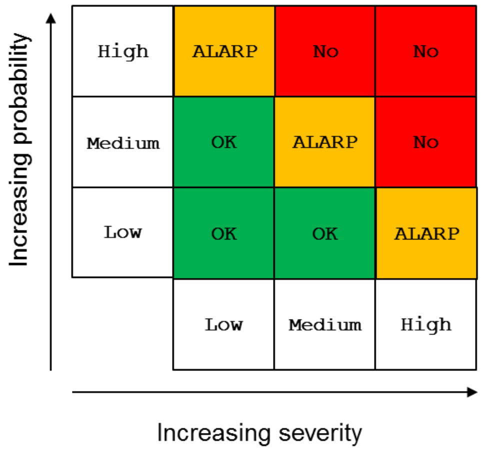
In this report, the terms within each group are treated as interchangeable.

2.6 Types of Risk Criteria

The definitions above are very general, and allow risk criteria to vary widely in form. In fact, for every metric that can be used to describe a risk, there are corresponding risk criteria. For clarity in this report the following types of risk criteria are distinguished:

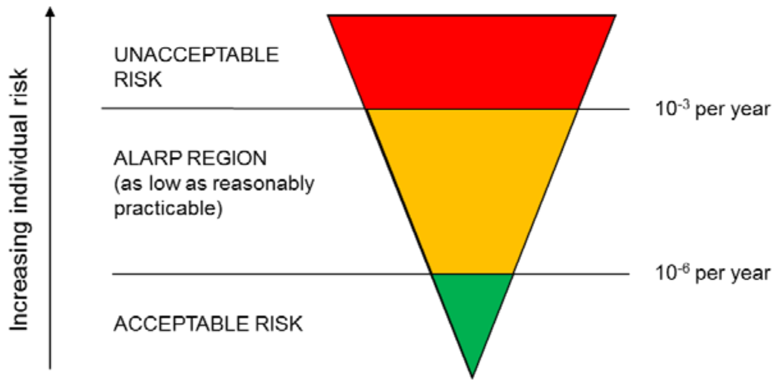
- Risk matrix criteria – showing the acceptable regions on a matrix of accident frequency (or probability) and consequence (or severity) – e.g. Figure 2.2.

Figure 2.2 Risk Matrix Form of Risk Criteria



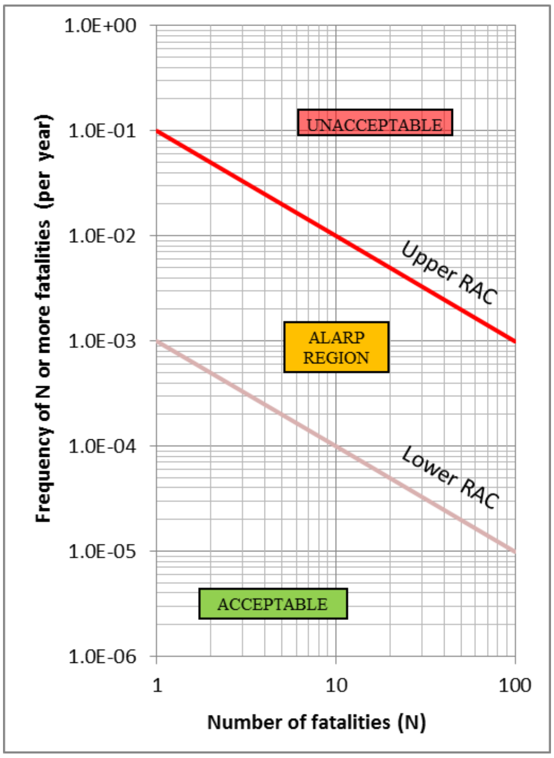
- Individual risk criteria – defining the acceptable level of risk of death to an individual – e.g. Figure 2.3.

Figure 2.3 Individual Risk Form of Risk Criteria



- Societal risk criteria - defining the acceptable level of risk of death to the whole exposed population. These often apply to FN curves – e.g. Figure 2.4.

Figure 2.4 FN Form of Risk Criteria



- Cost-benefit criteria - defining the acceptable 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.

- Qualitative risk criteria – defining the conditions under which a risk is accepted in any qualitative way. These may include following codes and standards; safety management controls; conditions under which risk reduction measures are required, etc. The category of qualitative risk criteria is quite broad and in principle might include all safety requirements. The term “qualitative risk criteria” is therefore only used in this report to acknowledge that qualitative reasoning is a valid form of decision-making on safety questions.

2.7 Application of Risk Criteria in Different Industries

Generalising from the review in Appendix A, Table 2.2 indicates the metrics that are used for risk criteria in other transport modes and industries. Many industries make use of individual and societal risk criteria, and cost-benefit or qualitative criteria defining ALARP. Risk matrix criteria are widely used, but the table shows only those industries using them as their primary metric for decision-making on risk.

Table 2.2 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				√

2.8 Comparison with Maritime Risk Criteria

The current maritime criteria (IMO 2013) apply individual risk, societal risk and cost-benefit criteria. This is in line with the most common approaches in other industries and therefore no enhancement is suggested from this comparison.

3 FRAMEWORKS AND PRINCIPLES

3.1 Introduction

Most risk criteria have developed through a process of expert judgement and political compromise, and consist of elements that may seem arbitrary or inconsistent with other approaches. Before continuing this pragmatic development of existing criteria, it is useful to consider the fundamental principles that could be applied, as this may provide a systematic foundation that helps justify the approach taken.

The following sections therefore consider selected frameworks and sets of principles that have been used in the past for developing risk criteria, drawing on the relatively few sets of criteria that explicitly declare their underlying principles.

3.2 ICRP Principles

One of the earliest general sets of principles for risk criteria was recommended by the International Commission on Radiological Protection (ICRP 1977). The basic principles of their safety policy for occupational exposure to ionising radiation in the nuclear industry are:

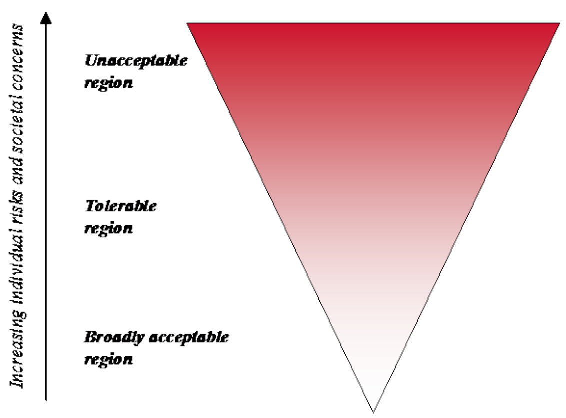
- Justification of practice - no practice shall be adopted unless it has a positive net benefit.
- Optimisation of protection - all exposures shall be kept as low as reasonably achievable (ALARA), taking economic and social factors into account.
- Equity - individual radiation doses shall not exceed specific criteria.

In other words, this consists of a cost-benefit analysis of the activity as a whole, as well as the details of its protection, although in practice these are often largely based on qualitative judgements. In addition there is an upper limit on individual risk, which is evaluated quantitatively.

3.3 HSE Tolerability of Risk Framework

The UK Health and Safety Executive (HSE) uses the framework for the tolerability of risk shown in Figure 3.1. This was originally published for nuclear power stations (HSE 1987), but now applies to all health and safety risks for people at work (HSE 2001).

Figure 3.1 HSE Tolerability of Risk Framework



The framework divides risks into three regions:

- Unacceptable risks – only permitted in exceptional circumstances.
- Tolerable risks – to be made as low as reasonably practicable (ALARP), taking costs and benefits into account.
- Broadly acceptable risks – not normally requiring further reduction.

In this approach, the criteria specify maximum tolerable and broadly acceptable limits on individual risk, in between which cost-benefit balancing would occur, which could be formal CBA or judgemental reasoning. ALARP thus corresponds to the ICRP principle of "optimisation of protection". This approach has been widely used, although the terminology varies (see Section 2.5).

3.4 ACDS Framework

The Advisory Committee on Dangerous Substances of the UK Health & Safety Commission applied the tolerability of risk framework to the transport of dangerous substances (ACDS 1991). This extended the framework in two important ways.

First, it included explicit criteria for both individual and societal risk, acknowledging the importance of societal risk in transport applications. The societal risk criteria were expressed as FN curves, encapsulating a principle of "aversion to catastrophes".

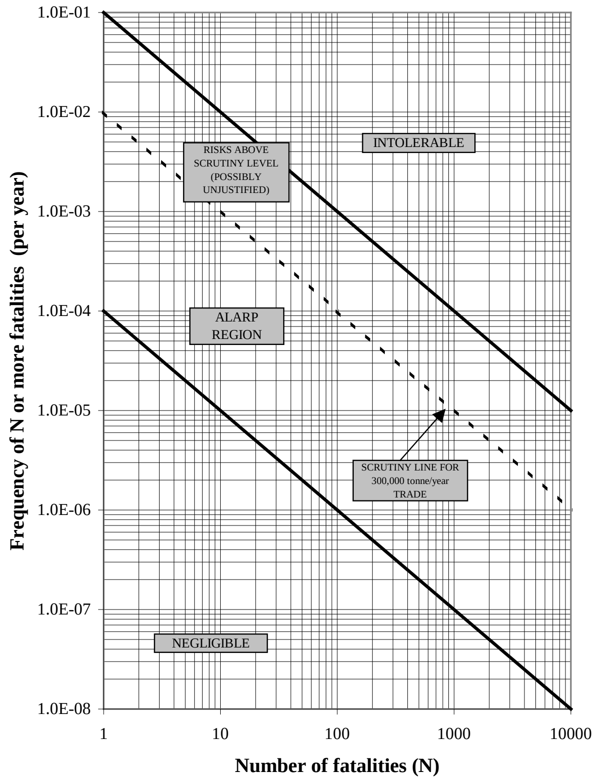
Second, it developed a criterion for societal risks that reflected the size of activity being evaluated. This related risk acceptability to the societal value of the activity, which tends to be greater for larger activities. Societal value is difficult to quantify, and so was approximated by the tonnage of materials transported. This is a version of the ICRP principle of "justification of practice".

The resulting framework divided societal risks into four bands (see Figure 3.2):

- Intolerable risks – above the maximum tolerable risk criteria for local communities.
- Possibly unjustifiable risks – above the scrutiny level. In this region, further examination of the overall risks and benefits of the activity would be required.
- ALARP region – risks considered tolerable provided they were ALARP. In this region, only the marginal costs and benefits of remedial measures would be examined.
- Negligible risks – not requiring further analysis.

In this approach, the criteria specify maximum tolerable and negligible limits on individual and societal risk, as well as the scrutiny level on societal risk. In most cases, cost-benefit balancing would occur, based on formal CBA or judgemental reasoning. For larger activities, the ALARP region is wider. The maximum tolerable societal risk criterion only applies where there is an identifiable community affected by the risk. For the country as a whole, ACDS considered that there was no fundamental limit to the national societal risk, provided the benefits were large and the risks were not unduly concentrated on particular individuals or communities.

Figure 3.2 ACDS Tolerability of Transport Risk Framework



3.5 GAME Safety Principle

In France, regulation of new technology for rail transport is based on the GAME (Globalement au moins équivalent) principle, expressed as follows (Chirac 2000):

> *"Any change to an existing system, and the design and manufacture of a new system, must be carried out in such a way that the resulting global level of safety is at least equivalent to the existing level, or as existing systems which provide comparable services or perform comparable functions."*

This could be described as a principle of "equivalence". However, the implicit aim is to encourage improvement in safety by prohibiting any regression. By referencing a global level of safety, the GAME principle allows flexibility in how the improvement is achieved. The underlying principle is therefore considered to be "continuous improvement". However, it does not guarantee that this is achieved, as it depends on which systems are chosen for the comparison.

3.6 European Railway Safety Framework

The European Railway Safety Directive (European Community 2004) adopted the following objective:

> "*Member States shall ensure that railway safety is generally maintained and, where reasonably practicable, continuously improved.*"

This simple principle of "continuous improvement" is interpreted through accident rate measures, based on historical performance, which in effect keep the individual risk constant (or reducing where cost-effective) but allow societal risk to increase if traffic is growing.

3.7 EUROCONTROL Safety Strategy

The European Organisation for the Safety of Air Navigation (EUROCONTROL 2003) adopted a safety objective for air traffic management (ATM) as follows:

> *"To improve safety levels by ensuring that the numbers of ATM induced accidents and serious or risk bearing incidents do not increase and, where possible, decrease."*

This is a principle of "continuous improvement". Its interpretation is interesting, because aviation is a field where traffic is increasing. It judges that the current of number of accidents in effect defines the maximum tolerable level of societal risk, and hence no increase can be tolerated whatever the increase in traffic. Therefore, as the number of flights increases, the accident risk per flight must *reduce* in proportion to the traffic increase. This ensures that individual risk reduces while societal risk remains constant. This is a very demanding target for a growing industry, especially since collisions tend to grow in proportion to the square of the traffic.

3.8 Summary of Principles

The following proposes a set of principles combining the approaches described above. They are intended to 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 (including multiple-fatality, 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.

It is recognised that, when resources are limited, the principles may be in conflict with each other. For example, reducing catastrophe risks may introduce greater risks from low-consequence accidents (Evans & Verlander 1997). Resolution of such conflicts would require political rather than technical judgement.

Furthermore, it is recognised that the details of the implementation can greatly alter the effect of the principle. For example, the metrics chosen to implement the continuous improvement principle in the rail and aviation industries produce very different safety requirements when traffic increases (see Sections 3.6 and 3.7). The principles must therefore be used to guide development of criteria, but do not determine what the criteria should be.

3.9 Application of Principles in Different Industries

Generalising from the review in Appendix A, Table 3.1 indicates where the principles are applied in other transport modes and industries. The application is inconsistent because most have been developed ad-hoc rather than based on systematic use of principles. However, in most applications where certain principles are not applied, there are valid practical reasons for this omission.

Table 3.1 Application of Principles for Risk Criteria in Different Industries

INDUSTRY	JUSTIFICATION OF ACTIVITY	OPTIMISATION OF PROTECTION	EQUITY	AVERSION TO CATASTROPHES	PROPORTION-ALITY	CONTINUOUS IMPROVEMENT
Aircraft design (EASA)				√		
ATM (EUROCONTROL)						√
Airports (UK)		√	√		√	
Road transport (EU MS)		√				√
Road transport (USA, Norway)		√				
Road transport of DG (ACDS)	√	√	√	√	√	
Road transport of DG (Switzerland)		√		√	√	
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		√				

3.10 Comparison with Maritime Risk Criteria

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.

Industries that make use of the principle of continuous improvement mainly use it to monitor progress and prioritise improvements for further study. Decisions on specific risk reduction measures are usually left to other criteria (often the ALARP approach, represented by the principle of “optimisation of protection”). Therefore, it could be argued that the lack of such a criterion in the maritime industry is not a critical omission. Provided the ALARP approach is applied proactively, continuous improvement will normally result. Nevertheless, a criterion based on the principle of continuous improvement could be a useful addition to promote a continuing search for cost-effective risk reduction measures.

4 INDIVIDUAL RISK CRITERIA

4.1 Purpose

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 as low as reasonably practicable (ALARP), and therefore cost-benefit considerations 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.

4.2 Basis for Individual Risk Criteria

There is no single universal level of acceptable risk. People are prepared to accept a wide variety of risks, depending on their own perceptions of the risks and benefits from the activity. In addition, higher risks are accepted if the individuals consider that they have greater control over them. These factors explain why high risks are commonly accepted in some sports, in driving cars and motorbikes, and in certain hazardous occupations where risk control depends on the individual's own skill (e.g. flying, diving).

When people are exposed to risks over which they have little or no control, they usually expect the appropriate authorities to impose relatively strict control on their behalf. It is these "involuntary" risks which risk criteria attempt to control. An appropriate level for risk criteria would then be substantially below the total accident risks experienced in daily life, but might be similar to risks that are accepted from other involuntary sources.

Hence, individual risk criteria for hazardous activities are often set using the risk levels that have been accepted from other industrial activities. This involves a judgement that the acceptability of individual risks is similar for all activities over whose safety the person exposed has little or no control. Thus, risk criteria for ship's crew could be similar to generally accepted criteria in other industries. This means that risk criteria that have already been developed in other industries can readily be applied to ships.

Crew members on a ship have much longer exposure to the risks than passengers or members of the public near the port. This is balanced by the fact that they earn their living from the ship. Their perception of the risks may be lower, due to familiarity with the hazards of the sea, and their actual risks may be lower due to their knowledge of the ship and its emergency procedures. For these reasons, crew members are usually expected to tolerate higher risks than passengers or other members of the public.

Members of the public (i.e. people on other vessels, or living, working or using recreational facilities near to the port, also known as "third parties") derive little or no benefit from the ship, and hence their risk criteria are set at a lower level.

Passengers on a ship occupy an intermediate position, since they need it for transport, but their exposure is usually much less than the crew. Their risk criteria depend on the specific risk metric used, but are no higher than for crew and no lower than for the public.

4.3 Practical Application

Based on the review in Appendix A, Table 4.1 shows the individual risk criteria that are in use in other transport modes and industries. It shows both the maximum and negligible criteria, where used.

In the UK the individual risk criteria from HSE (2001) are used in all industries, although they are rarely critical. In other European countries, individual risk criteria are sometimes used but often not. CCPS (2009) includes a review of other countries world-wide that use individual risk criteria. When used, the values of the criteria are often different, but 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.

Table 4.1 Individual Risk Criteria in Different Industries

INDUSTRY	MAXIMUM INDIVIDUAL RISK (per year)	NEGLIGIBLE INDIVIDUAL RISK (per year)
Aircraft design (EASA)	-	-
ATM (EUROCONTROL)	-	-
Airports (UK)	10^{-4} (public)	10^{-5}
Road transport (EU MS)	-	-
Road transport (USA, Norway)	-	-
Road transport of DG (ACDS)	10^{-3} (workers),10^{-4} (public)	10^{-6}
Road tunnels (Austria and others)	-	-
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 (France)	-	-
Onshore process (HK)	10^{-5} (public LSIR)	-
Offshore oil & gas (UK)	10^{-3} (workers)	
Healthcare	-	-

4.4 Comparison with Maritime Risk Criteria

The current maritime criteria (IMO 2013) use the HSE individual risk criteria, and so there is no basis for any enhancement of these based on practices in other industries.

5 SOCIETAL RISK CRITERIA

5.1 Purpose

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, although the degree of embedded aversion is subject to debate and is often found to be confusing.

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 major accidents involving many fatalities. These are a particular concern for passenger ships, which have the potential to affect large numbers of people in a single accident, although the likelihood is very low. This tends to produce relatively high risks of high-fatality accidents, although individual risks may be low.

5.2 Problems with Societal Risk Criteria

Attempts to develop societal risk criteria have experienced some significant challenges, which are briefly reviewed as follows.

Societal risks are inevitably larger for larger activities, but this does not necessarily mean that they are less acceptable. For example, a large passenger ship will inevitably have higher potential for high-fatality accidents than a smaller one, but this does not mean that it is less acceptable. If both were given the same risk criteria, this would be too strict for the large ship and too lenient for the small one. Ultimately, this could result in large ships being replaced with several smaller ones, which may increase the total societal risk. Theoretical analyses have shown that FN criteria tend to result in higher fatality risks, when compared to cost-benefit optimisation without this constraint (Evans & Verlander 1997).

In general, societies are prepared to accept risks from technological activities because of the benefits that they bring. In evaluating the acceptability of societal risk from an activity, its overall benefit to society should also be taken into account. This is a major challenge in establishing societal risk criteria, and is considered in more detail in Section 5.3 below. Other than this, there is no fundamental basis for limiting societal risk, unless it affects a single identifiable community (ACDS 1991). Such communities include ports, but it is unlikely that a ship could be considered a community in itself, sufficient to justify applying societal risk criteria.

Public reaction to catastrophic accidents is often interpreted as justifying FN criteria. For example, it is generally considered that a 100-fatality accident provokes greater concern than 100 single-fatality accidents. However, social surveys that address this question directly have found that the public does not support greater weight being given to infrequent multiple-fatality accidents, once confounding factors such as lack of control and culpability have been removed (RSSB 2006).

In contrast to individual risk criteria, it is inappropriate to apply societal risk criteria from one industry in another, since the societal benefits are likely to be different. This was illustrated when the Dutch authorities attempted to apply their FN criteria for industrial installations to the off-site risks from Schiphol airport, and found that it greatly exceeded the criteria. This simply showed that the criteria were inapplicable, not that the airport was unacceptable.

Hence, there has been a movement away from the use of FN criteria, and many such criteria that have been developed are 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.

5.3 Basis for Societal Risk Criteria

To develop more appropriate societal risk criteria, it is desirable to compare the societal risk to the societal benefit from the activity. Possible approaches are now considered.

The standard economic definition of benefit from an activity is the “value added” to the economy by its services. This can be measured as the “revenue generated”, i.e. the earnings during a typical year. Alternatively, it can be measured as the total annualised expenditure on wages, raw materials, other consumables, maintenance and annualised replacement costs (depreciation). This is also its contribution to the gross national product (GNP).

An example of this type of approach was developed by ACDS (1991) for port risks, in which FN criteria were scaled according to the tonnage of bulk hazardous goods shipped, as a convenient representation of value added in such transport (see Figure 3.2). However, when applied to all national trades of bulk hazardous substances, all UK ports were below the scrutiny level, although 4 ports required more detailed analysis to establish this. It may be concluded that economic incentives combined with the ALARP principle are sufficient to ensure that the societal risk is proportionate to societal value, without the need for additional societal risk criteria.

A better approach, which is used by one oil & gas company, is to scale FN criteria according to the asset value. This is typically a multiple of average earnings, and hence is roughly proportionate to value added, but is more easily established as it is not sensitive to market fluctuations.

5.4 Practical Application

Based on the review in Appendix A, Table 5.1 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. In the case of tunnels, these are negligible levels, whereas in the case of railways they are maximum levels. It is apparent that there is no consistency in the range, slope or value of the criteria in different industries, but this is to be expected given the differences in social value. None of the applications had an underlying methodology to take account of societal value, except the ACDS port risk criteria discussed above.

Table 5.1 Societal Risk Criteria in Different Industries

INDUSTRY	RANGE	MAXIMUM FN (per year)	NEGLIGIBLE FN (per year)	FATALITY RATE (per year)
Aircraft design (EASA)	-	-	-	-
ATM (EUROCONTROL)	-	-	-	-
Airports (UK)	-	-	-	-
Road transport (EU MS)	-	-	-	-
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
London Underground	-	-	-	-
Nuclear (ICRP)	-	-	-	-
Onshore process (UK)	-	-	-	-
Onshore process (Netherlands)	≥10	$10^{-3}/N^2$	-	-
Onshore process (Flanders)	10 - 1000	$10^{-2}/N^2$	-	-
Onshore process (France)	-	-	-	-
Onshore process (HK)	1 – 1000	10^{-3}/N	10^{-5}/N	-
Offshore oil & gas	-	-	-	-
Healthcare	-	-	-	-

In summary, despite many attempts, societal risk criteria have proved very difficult to establish, and there are at present no widely accepted societal risk criteria. Explicit societal risk criteria are therefore at present only suitable as guidelines, indicating areas where risk reduction might be cost-effective.

5.5 Comparison with Maritime Risk Criteria

The current maritime criteria (IMO 2013) do have a consistent methodology to take account of societal value. They may therefore be considered more advanced than the criteria in other industries. Nevertheless, given the difficulties problems 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.

The FN criteria have been updated in Appendix D and applied to different sizes of ship for use in the rest of this project. This did not result in a significant change in the criteria, when applied to ships of the same size, but provides a consistent evaluation of ships of different sizes.

6 COST-BENEFIT CRITERIA

6.1 Purpose

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.

Because most ships satisfy other types of risk criteria, the cost-benefit criteria typically form the primary means of decision-making about risk reduction measures.

The present study focusses on quantitative cost-benefit criteria, which can be used in a cost-benefit analysis (CBA). However, qualitative reasoning can also be used to evaluate costs and benefits for an ALARP assessment.

6.2 Valuing Risks to Life

One of the most difficult issues in CBA of safety measures is how to balance costs with risks, when the two are in different units. Usually, the costs of a measure are available in monetary terms, while the benefits are expressed as a reduction in risk - in other words a frequency of preventing an accident whose consequences may involve property damage, environmental pollution, business interruption, and human injury and death. In order to compare costs and benefits, all these must be expressed in common units.

Traditionally the comparison in CBA has used monetary units. Many types of risks can easily be expressed in monetary terms - for example, risks of property damage or business interruption. But risks to life are much more difficult and contentious to value.

The standard approach to CBA of risks to life is to convert them into equivalent costs. The monetary valuation of risks to life is often described as a “value of life”. This phrase is convenient but inaccurate, because CBA evaluates small changes in risks for many people, and does not attempt to value individual lives. The accumulation of risk to many people, which can be expected on average to result in the saving of one fatality, is better described as a “statistical fatality”. For example, a reduction in risk of 10^{-3} per year for each of 100 individuals over a period of 10 years would amount to one statistical fatality. This distinction is important because it is much more reasonable to place a value on small changes in statistical risk than on individually identifiable lives.

Presentation of this difficult concept can be improved by using the term “value of preventing a statistical fatality” (VPF). This emphasises that what is being valued is the reduction in risk to many lives, rather than the actual lives that are at risk of being lost.

6.3 Types of Cost-Benefit Criteria

The VPF can be seen as a type of cost-benefit criterion. In reality it is an input to the CBA, but it is often very critical to the evaluation of the risk reduction measures.

Several other 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. The CAF is a property of a specific risk reduction measure. A measure is normally recommended if its CAF is less than the VPF. Hence the VPF can be seen as a type of cost-benefit criterion, but because it may be adjusted for specific decision-making purposes, it could be described as a "CAF 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 CAF but refers to health risks (see Section 6.8).
- 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. The NPV is often used to express the results of a CBA, but it tends to emphasise measures with high costs or benefits.
- 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. The BCR is useful for ranking measures, although it may be sensitive to effects that are arbitrarily labelled costs or benefit reductions.
- 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 IRR gives the same ranking as BCR but assumes that costs occur first and benefits later.

The CAF is only appropriate to evaluate safety measures, whereas NPV, BCR and IRR are commonly used for commercial investments.

6.4 Basis for Cost-Benefit Criteria

The value of preventing a fatality (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. This may be in terms of gross output (in effect, the lifetime salary) or net output (in effect, the lifetime tax payments). This narrow economic approach is now largely discredited, since it is recognised that people value life for its own sake rather than for its capacity to maintain economic output.
- Willingness-to-pay (WTP) approaches. These estimate the amount that people in society would be prepared to pay to avoid a statistical fatality. There are two main types:
    - The "contingent valuation" or "stated preference" approach uses expressed opinions on hypothetical situations in questionnaires.
    - The "revealed preference" approach uses observed behaviour, such as wage differentials for riskier jobs.
- Life quality approaches. These are based on social indicators of quality of life that reflect life expectancy and 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. This negative impact can arise because safety measures divert expenditure from other uses, which include health care and other expenditure which extend life expectancy by indirect routes. The optimum VPF ensures that safety measures are only recommended when their direct benefit exceeds the lost indirect benefit of the expenditure that they require.

Although VPFs could be based on original research of these types, they are more commonly chosen from the ranges indicated by previous research (see Appendix C).

6.5 Practical Application

Based on the review in Appendix A, Table 6.1 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 VPF values across all industries and transport modes. The variation in VPF is attributable to two main factors:

- Differences in methodology. Some European countries still use human capital approaches, which give low values. The USA uses revealed preference approaches, which give high values. The UK uses stated preference approaches, which give intermediate values.

- Differences in national income. Counties with higher national income (e.g. Norway) would be expected to have higher VPFs than countries with lower income.

Table 6.1 Cost-Benefit Criteria in Different Industries

INDUSTRY	CRITERIA USED	VPF (Original units)	VPF ($m 2012)
Aircraft design (EASA)	-	-	-
ATM (EUROCONTROL)	-	-	-
Airports (UK)	Qualitative	-	-
Road transport (EU MS)	NPV, BCR and IRR	€0.056 to 2.1m	$0.1 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 (ERA)	-	-	-
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 (Flanders)	-	-	-
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	-	-

6.6 Comparison with Maritime Risk Criteria

The current maritime criteria (IMO 2013) include a VPF (or CAF criterion) of $3m based on the life quality approach using data from 1998. New calculations in Appendix C indicate the VPF should now be approximately $7m. This is based on 2012 GDP data and updated life expectancies and fractions of time in economic activity, with the results averaged over all OECD members. For sensitivity tests, a range of VPF from $4m to $8m is considered appropriate.

The maritime criteria are 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. A negative NPV indicates that costs exceed benefits, which is simple to understand. However, NPV is undesirable for safety measures because the valuation of fatalities is hidden in the calculation, and it needs either discounting of future costs and benefits or a finite project lifetime.

In the case of passenger ships, fatalities are a critical issue, and it is appropriate to use CAF (expressed as GCAF or NCAF) as the criterion. However, in cases where non-fatality costs dominate, so that NCAF becomes negative, it may be preferable to express the results as NPV, for which the criterion is NPV>0.

6.7 Valuing Injury Risks

There is no basis for separate criteria for non-fatal injury risks. Instead, injury risks are usually combined with fatality risks and evaluated together. Three methods are in practical use:

- Injuries can be weighted and added to the fatalities to give "equivalent fatality" risks. For example, the rail industry uses a metric of fatalities and weighted serious injuries (FWSI) equal to fatalities + 0.1 x serious injuries.
- Injuries can be valued and added to the fatality costs in a CBA. This is the usual approach in road transport.
- Injuries can be treated as adverse health states in the same way as other health risks (see Section 6.8).

The first two methods require valuations of injuries as equivalent fractions of a fatality. Based on the review in Appendix A, Table 6.2 shows the relative values that are in use in different transport modes and industries. There is no precise consistency, partly because the terminology for injury severity is not standardised.

Table 6.2 Relative Values of Injuries in Different Industries

INDUSTRY	MINOR /FATAL	SERIOUS /FATAL	MAJOR /FATAL
Aircraft design (EASA)	-	-	-
ATM (EUROCONTROL)	-	-	-
Airports (UK)	-	-	-
Road transport (EU MS)	Various	Various	-
Road transport (UK)	0.009	0.112	-
Road transport (USA)	0.003	0.105	0.593
Road transport (Norway)	0.030	0.226	0.683
Road transport of DG (ACDS)	-	-	-
Road tunnels (Austria and others)	-	-	-
Rail transport (ERA)	-	0.1	-
Rail transport (UK)	-	0.1	-
London Underground	-	-	-
Nuclear	-	-	-
Onshore process	-	-	-
Offshore oil & gas	-	-	-
Healthcare	Various	Various	Various

The current maritime approach (IMO 2013) uses relative values of 0.01 for minor and 0.1 for serious injuries, and combines them with occupational accident data on ships, estimating that the costs of injuries and fatalities are approximately equal, which indicates that injury risks are not negligible. The approach then suggests that CAF can be apportioned equally between the fatalities and injuries. This approach is not used in any other industries, and is not evidently superior, so it would be preferable to value injury risks and add to the CBA, following the approaches in the road transport and nuclear industries.

6.8 Valuing Health Risks

When illness is temporary and full health is recovered, illness can be treated in the same way as injuries above. However, because ill health tends to occur later in life, and may last indefinitely, it has characteristics that are different to injuries, and might be treated differently.

Two methods are in practical use for valuing health risks:

- Ill health can be valued using WTP methodology, and added to the fatality costs in a CBA. This is the usual approach for environmental health risks and regulatory economics. This approach has the best theoretical justification, but there is a high cost of valuing many different health states. It is also impossible to transfer to other industries causing different health states.

- Ill health can be measured in quality-adjusted life-years (QALYs), and measures affecting them can be evaluated using a cost-benefit criterion of cost per QALY gained. This is the usual approach for clinical medicine and pharmaceuticals, and has been adopted by the World Health Organization (WHO). This approach appears more rational for allocating expenditure, but is questionable because QALY measurements are not consistent with WTP valuations. However, it is relatively simple to apply and to transfer to other industries.

If the two methods were fully consistent, the WTP valuation of a fatality would be greater than the cost per QALY by the remaining quality-adjusted life-expectancy, which is approximately 35 years for an adult of working age. In reality, a typical WTP of a fatality (approximately $3m) is roughly 100 times greater than a typical cost per QALY (approximately $30,000). The difference arises because human preference for avoiding health risks is complex and not fully represented by either method.

The difference can be important in cases where fatality and health risks are combined, especially when people of different ages are affected. The QALY metric gives greater weight to deaths of young people, whereas WTP gives equal weight to all deaths.

The US Office of Management and Budget, which oversees federal regulation, proposed that regulatory agencies should use both methods to evaluate health and safety rules (Hammitt 2003). A review of economic evaluation techniques in the health sector (Evans & Hurley 1995) concluded that none were better than the others in all situations, and recommended that a full description of the costs and benefits of competing alternatives would be more useful to decision makers than incorporating all possible costs and benefits into a single efficiency ratio.

Apart from healthcare, no other industry or transport mode currently uses a cost-benefit criterion for health risks. The health risks from road transport are typically evaluated using the WTP approach, whose criterion is NPV, BCR or IRR as for fatality risks.

The current maritime approach (IMO 2013) derives a cost per QALY of $42,000 from the CAF criterion in a way that is not fully justified. Since it does not appear to be used in practice, it would be preferable to align this with approaches in other industries.

The treatment of injury and health risks could be changed to one of financial valuation and inclusion in the NPV calculation, as above. This would be consistent with the approach used in road transport and the nuclear industry. However, since IMO is a UN organisation, it would be preferable to adopt the same cost-effectiveness thresholds being developed by WHO.

7 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.

The current maritime criteria include a value of preventing a fatality (VPF) of $3m. Updated calculations in this study indicate the VPF should now be approximately $7m. For sensitivity tests, a range of VPF from $4m to $8m is considered appropriate.

There are very few opportunities for improvement of the maritime criteria, although the following subjects might be considered for future enhancement:

- An element that encourages continuous improvement in societal risk (i.e. a target reduction in the annual numbers of fatalities in the industry as a whole). This would be consistent with road, rail and aviation transport.
- The current societal risk criteria based on FN curves could be treated as guidelines that help encourage reduction of catastrophe risks, rather than rigid rules that define acceptability of societal risks. This would be consistent with the approach in the onshore process industry.
- In cases where non-fatality costs dominate, so that NCAF becomes negative, the net present value (NPV) of a measure would be a better criterion than the net cost of averting a fatality (NCAF). This would be consistent with the approach used in road and rail transport and the nuclear industry.

It is recognised that none of these changes are essential, and that any improved clarity or consistency might be outweighed by confusion caused by the change.

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9 ABBREVIATIONS

ACDS	Advisory Committee on Dangerous Substances
ADN	European Agreement concerning the International Carriage of Dangerous Goods
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
ATM	air traffic management
BCR	benefit/cost ratio
CAF	cost of averting a fatality
CBA	cost-benefit analysis
CSM	common safety method
CST	common safety targets
DG	dangerous goods
EMSA	European Maritime Safety Agency
EU	European Union
FN	frequency-number of fatalities
FSA	formal safety assessment
FWSI	fatalities and weighted serious injuries
GAME	globalement au moins équivalent
GCAF	gross cost of averting a fatality
GDP	gross domestic product
HSE	Health and Safety Executive
ICRP	International Commission on Radiological Protection
IR	individual risk
IRR	internal rate of return
ISIR	individual-specific individual risk
ISO	International Organization for Standardization
LSIR	location-specific individual risk
MS	Member State
NCAF	net cost of averting a fatality
NPV	net present value
QALY	quality-adjusted life-year
QRA	quantitative risk assessment
UK	United Kingdom
UNDP	United Nations Development Programme
USA	United States of America
VPF	value of preventing a fatality
WHO	World Health Organization
WTP	willingness to pay

APPENDIX A

Review of Risk Criteria in Different Industries

Table of contents

A.1 INTRODUCTION

This appendix summarises the approaches to quantitative decision-making criteria used in risk assessment in different transport modes and industries:

- Aviation transport (Section A.2)
- Road transport (Section A.3)
- Rail transport (Section A.4)
- Nuclear industry (Section A.5)
- Onshore process (Section A.6)
- Offshore oil & gas (Section A.7)
- Healthcare (Section A.8)

A.2 AVIATION TRANSPORT

A.2.1 Aircraft Design

A.2.1.1 Origin

The aviation industry was one of the originators of modern techniques of reliability analysis, and acceptability targets were specified as part of this. For example, during World War II the Royal Air Force responded to major losses of aircraft on bombing raids by setting a target for accidents due to engine failure not to exceed 10^{-4} per hour. After further development by civil and military designers, detailed safety targets for civil aviation were published by Lloyd & Tye (1982), and these reliability targets continue to underpin modern aircraft design.

In Europe, safety requirements for aircraft design were developed by the Joint Aviation Authorities (JAA), and specified in the Joint Airworthiness Requirements (JAR-25). In 2008 responsibility was transferred to the newly created European Aviation Safety Agency (EASA) as CS-25. In the USA, the Federal Aviation Administration (FAA) has followed an almost identical approach in the Federal Aviation Regulations (FAR-25).

Aviation safety regulators such as the FAA and the UK Civil Aviation Authority (CAA) have made use of cost-benefit analysis to support decision making on new regulations, although without specific decision-making criteria (Ashford 1991).

A.2.1.2 Current Criteria

EASA criteria for design of large (i.e. turbine-engine) aircraft are specified in qualitative form in Certification Specification CS-25 (EASA 2013). AMC 25.1309 describes acceptable means of compliance, and includes quantitative definitions of the criteria.

The qualitative criteria require the aircraft to be designed so that:

- “Any catastrophic failure condition is extremely improbable and does not result from a single failure.
- Any hazardous failure condition is extremely remote.
- Any major failure condition is remote.”

In the quantitative form, the severity of each failure condition is expressed in terms of its effects on the aircraft and its occupants, and the probability terms are expressed in terms of probabilities per flight hour, as shown in Figure A.2.1. Failures with catastrophic effects (i.e. multiple deaths) must have a frequency less than 10^{-9} per aircraft flying hour. Failures leading to a large reduction in safety margins must have a frequency less than 10^{-7} per aircraft flying hour.

Figure A.2.1 Risk Criteria from AMC-25

Effect on Aeroplane	No effect on operational capabilities or safety	Slight reduction in functional capabilities or safety margins	Significant reduction in functional capabilities or safety margins	Large reduction in functional capabilities or safety margins	Normally with hull loss
Effect on Occupants excluding Flight Crew	Inconvenience	Physical discomfort	Physical distress, possibly including injuries	Serious or fatal injury to a small number of passengers or cabin crew	Multiple fatalities
Effect on Flight Crew	No effect on flight crew	Slight increase in workload	Physical discomfort or a significant increase in workload	Physical distress or excessive workload impairs ability to perform tasks	Fatalities or incapacitation
Allowable Qualitative Probability	No Probability Requirement	<---Probable---->	<----Remote---->	Extremely <-----------------> Remote	Extremely Improbable
Allowable Quantitative Probability: Average Probability per Flight Hour on the Order of:	No Probability Requirement	<-----------------> $<10^{-3}$ Note 1	<-----------------> $<10^{-5}$	<-----------------> $<10^{-7}$	$<10^{-9}$
Classification of Failure Conditions	No Safety Effect	<-----Minor------>	<-----Major------>	<--Hazardous-->	Catastrophic

Note 1: A numerical probability range is provided here as a reference. The applicant is not required to perform a quantitative analysis, nor substantiate by such an analysis, that this numerical criteria has been met for Minor Failure Conditions. Current transport category aeroplane products are regarded as meeting this standard simply by using current commonly-accepted industry practice.

A.2.1.3 Derivation

These criteria were derived from the historical frequency of serious accidents of about 10^{-6} per flight hour, of which about 10% were attributed to aircraft systems, and arbitrarily apportioned equally to about 100 potential failure conditions, giving a criterion of 10^{-9} per flight hour for each failure condition. Less severe effects were given correspondingly higher probabilities.

A.2.1.4 Application

These risk criteria are used inside a comprehensive safety assessment methodology linked to the aircraft and system development cycle. This four stage safety assessment process encompasses:

1. Aircraft and System Functional Hazard Assessment.
2. Aircraft and System Preliminary System Safety Assessments.
3. System Safety Assessments.
4. Common Cause Analysis.

A.2.1.5 Scope Limitations

CS-25 addresses individual safety systems in an aircraft, and does not explicitly address the risk from the aircraft as a whole. This system-based approach is appropriate for aircraft, whose safety depends on various critical systems, which may be designed independently, and which therefore need separate safety targets. No targets have been set for overall aircraft safety, which is dominated by human errors rather than technical failures.

AMC 25.1309 makes clear that it is "intended to provide guidance to supplement the engineering and operational judgement that must form the basis of any compliance demonstration".

A.2.2 Air Traffic Management

A.2.2.1 ICAO

The International Civil Aviation Organisation (ICAO) has specified a target level of safety (TLS) for design of air route structures. The TLS is expressed as a frequency of fatal accidents due to mid-air collisions. In 1966, when considering route spacing over the North Atlantic, the mid-air collision frequency target was 4×10^{-8} fatal accidents per aircraft flying hour (ICAO, 1976). This was reduced as accident performance improved, but has not changed since 1995.

The current TLS as specified by ICAO (2001) is 5×10^{-9} fatal accidents per flight hour per dimension. Since three dimensions are considered, this is in effect 1.5×10^{-8} per hour in total.

In order to use the TLS, it must be apportioned into the various possible failure causes, allowing the route spacing and the technical designs of navigation equipment to proceed independently for vertical, lateral and longitudinal spacing. For example, the safety case developed by Eurocontrol in support of reduced vertical separation minima apportioned 50% of the TLS to technical systems (altimeters etc) and the remainder to other errors (including human error).

The TLS was derived from historical mid-air collision frequencies with a required improvement factor in line with the reducing trend. It was then apportioned equally between the three dimensions.

A.2.2.2 EUROCONTROL

The European organisation for the safety of air navigation, EUROCONTROL, adopted a quantitative safety target for overall performance of air traffic management (ATM), as part of a safety regulatory requirement on risk assessment and mitigation in ATM (EUROCONTROL 2001).

The target sets a maximum tolerable probability of a direct ATM contribution to an accident of 1.55×10^{-8} per flight hour.

The target is to be used when introducing or planning changes to the ATM system. In order to use the target, it must be apportioned into the various parts of the ATM system or individual hazards.

The target was derived from historical aircraft accident frequencies, combined with an estimated ATM contribution. In order to prevent any increase in the annual number of ATM-induced accidents, the target was reduced in proportion to the expected traffic growth. The target of 1.55 x 10^{-8} per flight hour refers to the year 2010, and in principle may be reduced further in the future.

A.2.2.3 SESAR

The Single European Sky ATM Research (SESAR) Consortium adopted a safety target for future ATM (SESAR 2006). This is being used for design of future ATM systems in Europe, although its precise meaning and the appropriate apportionment methodology are still being discussed.

The target is expressed as a high-level goal: "*Improve the safety performance by a factor of 10*". This appears to refer to safety performance measured as the probability of collision given an encounter between a pair of aircraft.

The target is derived from an underlying objective: *"To improve safety levels by ensuring that the numbers of ATM induced accidents and serious or risk bearing incidents (includes those with direct and indirect ATM contribution) do not increase and, where possible, decrease"*. Because air traffic is expected to increase 3-fold by 2020, and encounter frequency is assumed to vary with the square of the traffic, this results in a need to reduce the collision probability given an encounter by a factor of approximately 10.

A.2.3 Airports

A.2.3.1 ICAO

The International Civil Aviation Organisation (ICAO) adopted a risk criterion as part of its design procedure for instrument landing systems (ILS) at airports (ICAO 1980). The criterion is expressed as a probability of collision with obstacles during approach. It does not include collisions with aircraft.

The target, described as a "minimum acceptable risk level" is 1 x 10^{-7} chance per approach of collision with obstacles.

The target was derived from the contemporary obstacle collision frequency with an order of magnitude reduction applied.

A.2.3.2 UK

At civil airports in the United Kingdom (UK), public safety zones (PSZ) are established at runway ends in order to control the risk to the public (known as third-party risk) from aircraft crashes. These were introduced in 1958 based on analysis of accident data. A re-evaluation of the policy (NATS 1997) introduced an approach based on individual risk modelling and constrained cost-benefit analysis.

The current risk criteria are defined by the Department for Transport (DfT 2007). The boundary of the PSZ corresponds to the 10^{-5} per year individual risk contour. Within the PSZ, development restrictions are adopted if their benefits exceed their costs. The maximum tolerable individual risk is considered to be 10^{-4} per year. Within this contour, airport operators are expected to offer to purchase any residences and workplaces so as to empty them.

The criteria were developed using a survey of people living close to airports (NATS 1997). The maximum tolerable individual risk was determined by asking them how much money they would need to be given to accept a certain risk. Where this exceeded the cost of relocation this was deemed to show that the risk was intolerable. A survey of willingness to pay for reduction in third party risk showed no difference to the contemporary valuation of preventing a fatality (VPF) for road accidents of £0.74m (1993 prices). FN criteria were considered and rejected, following the view that concern about major accidents could only be converted into policy on a judgmental basis at present.

A.2.3.3 Netherlands

Following a fatal accident in Amsterdam in 1992, the Netherlands government investigated applying its criteria for external risks from hazardous industrial activities to Schiphol airport. When it became clear that the airport exceeded the societal risk criteria by more than 10-fold, and that compliance would prevent an airport expansion deemed essential to the national economy, the criteria were declared advisory rather than mandatory (CCPS 2009).

A.2.3.4 USA

The Federal Aviation Administration (FAA) developed criteria for the establishment and discontinuance of airport traffic control towers (FAA 1990). The same methodology has also been used in Australia, New Zealand and Canada.

The approach is a cost-benefit analysis, comparing the benefits of a tower to its costs. The VPF was $1.5m (1990 prices).

A.3 ROAD TRANSPORT

A.3.1 General Road Transport

A.3.1.1 Origin

Road transport is one of the main causes of fatalities in the developed world, and as a result has an ample statistical record for decision-making. It has used the monetary valuation of human life for cost-benefit analyses of road safety improvements since the 1950s. Early applications used the “human capital” approach to valuing statistical fatalities averted, i.e. the net or gross output forgone as a result of an accident. Some countries still use this approach, but most have now that have adopted the “willingness to pay” approach.

Finland was the first European country to set a national target for road fatality reduction. In 1973 it set a target of 50% reduction in deaths, which was met by the end of the 1970s. A second target of a further 50% reduction was set in 1989 and was also successfully achieved. A third target of a further 50% reduction was set in 1997, but after a poor start the target achievement date was revised from 2005 to 2010 (SafetyNet 2009a). In 2003 the European Commission adopted a common target, and encourages Member States to contribute to its achievement through their own national road strategies.

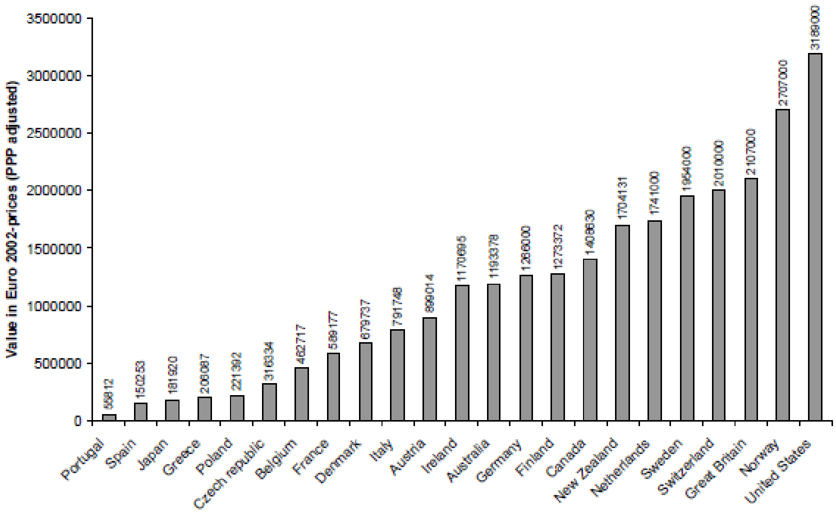
A.3.1.2 Current EU Criteria

Most EU countries have set quantitative road safety targets, typically aiming to reduce the annual number of fatalities by 40 to 50% within 5 to 15 years (ETSC 2003). Some countries are pursuing the long-term outcome of the elimination of deaths, with interim target reductions. The European Commission’s common target is “halving the overall number of road deaths in the EU by 2020 starting from 2010” (European Commission 2010).

Some countries also use intermediate outcome targets, e.g. reductions in average speed or increases in seat belt use. Some set output targets for their institutional service delivery, e.g. numbers of random breath tests or speed checks.

Many countries use CBA to help select appropriate programmes to reduce road accidents. One of the key elements is the monetary valuation of road accident fatality risks. Figure A.3.1 shows the official monetary valuation of preventing a fatality (VPF) in road accidents in different countries (SafetyNet 2009b). The median value is €1.2m (2002 prices), but the most notable aspect is the wide variation from €0.056 to 2.1m (approximately $0.1 to 4.3m in 2012 prices). Some of this variation is due to differences in methodology for estimating VPF. Another important difference is that wealthier countries (i.e. those with higher gross national income per capita) tend to use larger VPFs and also tend to have lower accident risks (measured in fatalities per person or per unit traffic).

Figure A.3.1 Official Road Accident VPF in Selected Countries



Harmonised valuations of fatalities and injuries have been proposed (HEATCO 2006), based on a common value of €1.5m adjusted in proportion to real per capita income at purchasing power parity exchange rates for each country, but these are only proposed when no national study of willingness-to-pay is available, and do not appear to be used in practice. A fully harmonised VPF (i.e. the same value used in all MS) is not adopted, because it would fail to take account of their ability to pay for risk reduction.

Evans (2005) indicates that, due to funding restrictions, the ICAF of road safety measures actually implemented in the UK is approximately 10 times lower than the official VPF.

A.3.1.3 Application

Different countries use different decision criteria in their cost-benefit analyses. The most common ones are (HEATCO 2006):

- 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. The NPV is often used to express the results of a CBA, but it tends to emphasise measures with high costs or benefits.
- 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. The BCR is useful for ranking measures, although it may be sensitive to effects that are arbitrarily labelled costs or benefit reductions.
- 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 IRR gives the same ranking as BCR but assumes that costs occur first and benefits later.

A.3.1.4 United Kingdom

In the UK, the Department for Transport (and its predecessors) used values of preventing statistical fatalities for appraisal of road transport projects based on the human capital approach since 1952. In 1988, it switched to a willingness-to-pay approach, based on surveys of public preferences, adopting a value of £0.5m (1987 prices). This was subsequently uprated in line with increases in per capita national income. In 1997, following methodological improvements, the VPF reached £1m.

The most recent published value is £1.59m (2009 prices), intended to be uprated in line with growth in GDP per capita (DfT 2011). The value for 2012 was estimated as £1.76m (RSSB 2012) equivalent to $2.8m. Injury costs are shown in Table A.3.1.

Table A.3.1 Relative Injury Costs in UK Road Transport CBAs

SEVERITY	COST (£ m)	FRACTION OF VPF
Slight	0.014	0.009
Serious	0.178	0.112
Fatal	1.585	1.000

A.3.1.5 United States

In the USA, in 1972 the White House Office of Science and Technology estimated that the average cost of a road accident fatality was $0.14m based on the human capital approach. This was used as an input to a decision to reject under-ride guards on trucks.

In 2003 the Office of Management and Budget endorsed values in the range $1m to $10m.

The Department for Transportation adopted a “value of life” for economic evaluations of $2.5m in 1993. This was renamed a “value of statistical life” (VSL) and revised to $5.8m in 2008, based on willingness-to-pay surveys (DoT 2011).

The most recent published value is $9.1m (2012 prices). This is based on a review of wage differential studies, and is intended to be uprated in line with income growth (DoT 2013). Injury costs are expressed as fractions of VSL, based on quality-adjusted life-year (QALY) research for various abbreviated injury scale (AIS) levels, as shown in Table A.3.2.

Table A.3.2 Injury Costs in US Transport CBAs

AIS LEVEL	SEVERITY	FRACTION OF VSL
AIS 1	Minor	0.003
AIS 2	Moderate	0.047
AIS 3	Serious	0.105
AIS 4	Severe	0.266
AIS 5	Critical	0.593
AIS 6	Fatal	1.000

A.3.1.6 Norway

In Norway, the VPF was NOK 26.5m (2005 prices) (Statens vegvesen 2006), equivalent to $4.5m. Injury costs are shown in Table A.3.3.

Table A.3.3 Injury Costs in Norwegian Transport CBAs

SEVERITY	COST (NOK m)	FRACTION OF VPF
Slight	0.8	0.030
Serious	6.0	0.226
Most serious	18.1	0.683
Fatal	26.5	1.000

A.3.2 Transport of Dangerous Goods

A.3.2.1 ACDS

In the UK risk criteria for transport of dangerous goods were developed by the Advisory Committee on Dangerous Substances (ACDS 1991). It adopted the HSE individual risk and cost-benefit criteria (see Appendix A.6.2).

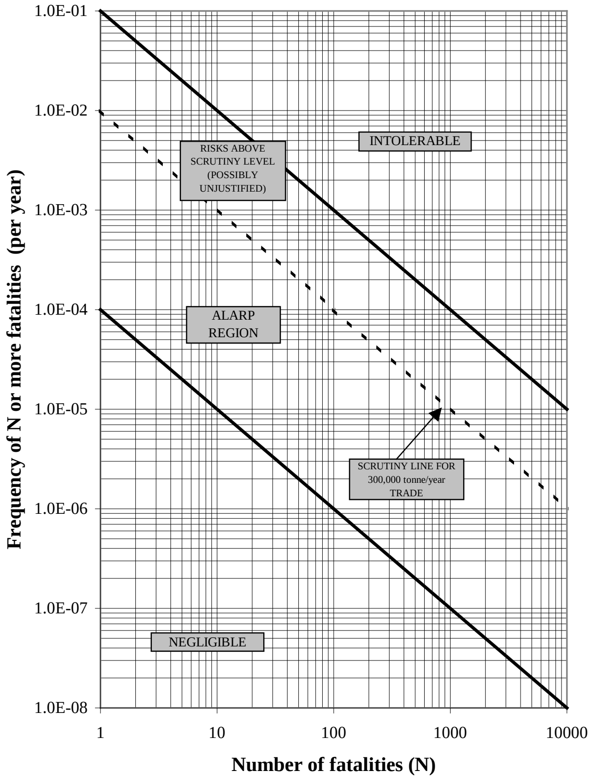
ACDS also developed societal risk criteria for communities affected by the transport of dangerous goods, including people living near roads, railways and ports.

- Intolerable risk $F>0.1/N$
- Negligible risk $F<10^{-4}/N$

The upper criterion was based on the estimated risk levels at the Canvey Island industrial complex (HSE 1981), which were considered just tolerable. The lower criterion was obtained by using the VPF to value the corresponding fatality rate, and showing that this would not even justify the cost of a cursory risk study and brief committee discussion.

For port risks, ACDS used a “scrutiny level” to indicate the justifiable societal risk in small trades and also in the overall national traffic in bulk dangerous goods. This was scaled from the tolerable line at Canvey Island, according to the annual tonnage of dangerous goods shipped. The intercept of this line with N=1 was 3.2 x 10^{-8} per tonne/year, within the range 10^{-4} to 10^{-1} per year. This is illustrated in Figure A.3.2 for an example port (or a single trade in a port) handling 300,000 tonnes per year of dangerous goods.

Figure A.3.2 ACDS Tolerability of Transport Risk Framework



For ports that exceeded the scrutiny level, a fundamental assessment was required, to see whether the risks were justified by the benefits of the trade. Below it, in the ALARP region, only marginal costs and benefits of risk reduction measures were examined. A cost of £2m per fatality averted was used to indicate where risk reduction measures were "reasonably practicable" (approximately $5.3m at 2012 prices). The ACDS approach was used to evaluate all major ports in Great Britain, but has not been used since.

A.3.2.2 Switzerland

In Switzerland, the Ordinance on Protection Against Major Accidents, implemented in 1991, requires assessment of risks to the public and the environment from fixed installations and dangerous goods transport, including railway installations, transit roads and the Rhine (when used to transport or trans-ship dangerous goods). The Swiss Federal Office for the Environment has published societal risk criteria (PIARC 2012):

- Upper criterion: $F=10^{-3}/N^2$ for $10 \le N \le 10{,}000$ fatalities
- Lower criterion: $F=10^{-5}/N^2$ for $10 \le N \le 1000$ fatalities

For risks between these, the ALARP principle is applied, with safety measures adopted where cost-effective. The same criteria are applied to fixed installations and to 100m sections of road tunnels.

A.3.3 Road Tunnels

A.3.3.1 Origin

Following a fatal accident in the Gleinalmtunnel in Austria in 2001, a method of rationalising decisions on tunnel safety using quantitative risk assessment (QRA) was developed by the World Road Association (PIARC), and is widely used in Europe. This does not specify risk criteria, but several countries have developed their own.

A.3.3.2 Austria

In Austria, the Federal Ministry for Transport, Innovation and Technology (BMVIT) has defined a 3-stage procedure for risk assessment of dangerous goods in road tunnels (Diernhofer et al 2010). The same approach is used by Slovenia for tunnels between the two countries.

Stage 1 of the procedure is based on an expected value of 1 x 10^{-3} fatalities per year for the tunnel. This is used to populate a matrix that screens out tunnels requiring no further analysis.

Stage 2 compares the estimated FN curve of the tunnel to a societal risk criterion, defined as $F=0.1\ L^{0.5}/N^2$. This is only applied in the region N>10 fatalities. It takes account of the tunnel length (L in km), but is less than proportional to it. If any part of the FN curve exceeds this line, additional risk reducing measures are investigated. It is not clear on what basis these measures are selected, but it is presumed to be expert judgement. Previous suggestions by the Austrian Commission for Tunnel Safety (Knoflacher & Pfaffenbichler 2004), consisting of two societal risk criteria, dividing risks into non-tolerable, ALARP and tolerable regions, and extending to N=1, have apparently been abandoned.

Stage 3 considers alternative routes for dangerous goods transport where the tunnel risks are considered intolerable. In general, an existing transport activity is allowed to follow the route with the lowest risk.

A.3.3.3 Czech Republic

In the Czech Republic the following criteria have been recommended for road tunnels (PIARC 2012), although there is no legal requirement:

- Upper criterion: $F=0.1/N$ for $1 \le N \le 1000$ fatalities
- Lower criterion: $F=10^{-4}/N$ for $1 \le N \le 1000$ fatalities

For risks between these, the ALARP principle is applied, with safety measures adopted where cost-effective. The criteria are for a 1km long tunnel, and in effect are proportional to tunnel length. They apply to the overall risk from all the traffic using it.

A.3.3.4 Denmark

Risk criteria were used to help manage the risks on the Øresund Link tunnel and bridge connecting Denmark and Sweden (PIARC 2010). The risk policy required the average individual risks for users to be comparable to Danish/Swedish motorways/railways having similar length and traffic intensity. This covered overall risk from all the traffic using the Link. The main criteria were for individual risk:

- For road: 33 fatalities per billion passages of the Link
- For rail: 4 fatalities per billion passages of the Link

In addition, the following FN criteria were applied with an ALARP region in-between:

- Upper criterion: $F=0.4/N^2$
- Lower criterion: $F=0.004/N^2$

Since the Link opened in 2000 the risk profile has exceeded the upper FN RAC and the rail individual RAC. It appears the RAC were used to guide risk reduction effort rather than to determine acceptability.

A.3.3.5 France

In France, a 2-stage methodology is used for the evaluation of dangerous goods transport in road tunnels (PIARC 2012)[1].

Stage 1 is based on an expected value of 1.0×10^{-3} fatalities per year for the tunnel, used to screen out tunnels for which no restrictions are required.

Stage 2 compares the risks for the tunnel with various safety measures and alternative routes, but no specific criteria are prescribed.

A.3.3.6 Germany

In Germany, a methodology for the evaluation of dangerous goods transport in road tunnels was developed in a research project by the Federal Highway Research Institute (PIARC 2012), but this is not legally binding.

Stage 1 of the procedure is based on an expected value of 6.2×10^{-3} fatalities per year per kilometre of tunnel. This is also split into different accident scenarios. It is used to screen out tunnels for which no dangerous goods restrictions are required.

Stage 2 compares the estimated FN curve of the tunnel to a societal risk criterion, defined as $F=0.01\ L/N^2$. This is only applied in the region $10<N<1000$ fatalities. It takes account of the tunnel length (L) by normalising to a 1 km length. If any part of the FN curve exceeds this line, additional risk reducing measures are investigated. Otherwise no dangerous goods restrictions are required.

Stage 3 considers alternative routes and other safety measures, and evaluates them using cost-benefit analysis in order to determine appropriate measures.

A.3.3.7 Italy

In Italy, the government-owned motorway company ANAS uses an Italian Risk Analysis Method (IRAM) for road tunnel safety (PIARC 2012). This includes societal risk criteria:

- Upper criterion: $F=0.1/N$ for $N\geq 1$ fatality
- Lower criterion: $F=10^{-3}/N$ for $N\geq 1$ fatality

For risks between these, the ALARP principle is applied, with safety measures adopted where cost-effective. For risks above the upper criterion, safety measures must be implemented regardless of cost.

[1] PIARC, "Current Practice for Risk Evaluation for Road Tunnels", 2012.

A.3.3.8 The Netherlands

In the Netherlands, the Ministry of Infrastructure and the Environment has defined criteria for tunnel users based on an individual risk of 1×10^{-7} per person-kilometre and a societal risk of $0.1/N^2$ per year per kilometre (PIARC 2012). This is only applied in the region $N>10$ fatalities. It is used as a target value, and may be exceeded if sufficient arguments are applied.

A.4 RAIL TRANSPORT

A.4.1 European Common Safety Targets

A.4.1.1 Origin

The European Railway Safety Directive (European Commission 2004) adopted the principle that "*Member States shall ensure that railway safety is generally maintained and, where reasonably practicable, continuously improved*".

To implement this principle, the European Railway Agency (ERA) developed Common Safety Targets (CSTs), for the purpose of harmonising the evaluation of changes to the railway system across Europe and ensuring that the current safety performance of the railway system is not reduced in any Member State. CSTs were first adopted in 2009, and revised in 2012 (European Commission 2012).

A.4.1.2 Current Criteria

The CSTs address the following risk categories:

- Risk to passengers, measured in units of passenger fatalities and weighted serious injuries (FWSI) per passenger train-km, and passenger FWSI per passenger-km.
- Risk to employees, measured in units of employee FWSIs per train-km.
- Risk to level crossing users, measured in terms of level-crossing user FWSI per train-km (since data for more relevant metrics is not yet available).
- Risk to other people, measured in units of other FWSI per train-km.
- Risk to unauthorised persons on railway premises, measured in units of unauthorised person FWSI per train-km.
- Risk to the whole society, measured in units of FWSI per train-km.

At present the applicable targets are National Reference Values (NRVs) for 25 Member States (MS) in the same risk categories. The CSTs are equal to the highest of the NRVs amongst the MS. In the future the CSTs will be revised so as to progressively achieve harmonisation.

A.4.1.3 Derivation

The development of CSTs aimed to harmonise safety levels across the EU, which at present vary widely. In order to avoid compromising safety in MS with low risks, or creating impractical targets for MS with high risks, the applicable targets are the National Reference Values (NRVs), or the CSTs if these are lower. The NRVs were calculated from accident experience in each MS (or in adjacent larger MS) during the period 2004-09 (European Commission 2009).

The CST is defined as the NRV that is highest amongst the MS, or a value equal to 10 times the European average value, if this is lower. At present, the spread of NRVs is such that the CSTs are equal to the highest of the NRVs amongst the MS. Hence at present the applicable criterion is always the NRV.

A.4.1.4 Application

The CSTs are used in the Common Safety Method (CSM) to evaluate significant changes to the railway system. The CSM acknowledges three alternative risk acceptance principles:

- Application of codes of practice
- Comparison with similar (reference) systems
- Explicit risk estimation. This is the only case that require the CSTs.

CSTs only relate to significant accidents associated with rolling stock in motion.

A.4.2 UK Railways

A.4.2.1 Origin

In the UK, British Railways (BR) adopted risk assessment and cost-benefit analysis in order to prioritise safety projects following the 1988 Clapham Junction accident. BR adopted the individual risk criteria and ALARP principle of the HSE risk criteria, and also set a target for risks to regular commuters of 10^{-5} per year (HSE 1995). At first the VPF for rail fatalities was based on the UK roads value, which was £0.715 in 1992 prices. This was applied to single-fatality accidents, but a higher value of £2m was adopted for train accidents, in the belief that people would be willing to pay more for them (Evans 2005).

After the privatisation of British Railways, the infrastructure controller, Railtrack, and the train and station operating companies (collectively known as the Railway Group) were required to produce Safety Cases, including some form of risk assessment. Railtrack's safety responsibilities were subsequently taken over by the Rail Safety and Standards Board (RSSB). The Railway Group Safety Plan stated industry safety objectives, which were used in the Safety Cases.

The VPF for CBA demonstration of ALARP was based on the UK roads value, cited as £0.75m (1995 prices) per equivalent fatality averted (including injuries as fractions of fatalities). Values up to £2m would be considered "where schemes address risks that are near the upper limit of tolerability; where accidents may involve many fatalities; or where other factors may influence the public's perception and acceptance of risks" (Railtrack 1995). Subsequently the VPFs increased in line with the roads value, reaching £1.3m (2003 prices) for prevention of single fatalities, and £3.64m for "prevention of multiple fatalities or where risks are close to intolerable" (RSSB 2003). This was despite research indicating no greater willingness-to-pay for avoiding train accidents compared to road accidents. The implementation of TPWS at this time indicates an ICAF that is much higher in practice (Evans 2005). Since then the VPF has been reduced to the roads value for all accident types.

The Railway Group Safety Plan also set short-term targets, based on continuous improvement of recent performance. For example, in 2003/04 these included (RSSB 2003):

- The *overall* risk of accidental fatalities should be less than 1.9×10^{-7} per train km. This target was introduced in 1999.
- The risk of accidental death to *passengers* other than in train accidents should be less than 7.5×10^{-9} per passenger journey. These targets have been progressively reduced since 1995.

- The frequency of *precursors* to catastrophic events should be reduced by 10% per year. This numerical target was introduced in 2003.
- The risk of accidental death to *members of the public* should be less than 7 x 10^{-7} per year.
- The fatality risk targets for *trackside workers* was previously 10^{-4} per year (Railtrack 1995), but had been removed by 2003.

These have since been replaced by the NRVs from the European Common Safety Targets.

A.4.2.2 Current Criteria

The Railways Act 2005 requires the Department for Transport to set High Level Output Specifications (HLOS) for the rail industry. The HLOS for safety requires the passenger risk per km travelled and the rail worker risk per hour worked to reduce by 3% during the period 2009-14 (DfT 2007). Injuries are to be included using the metric of fatalities and weighted injuries (FWI). These are interpreted as 1.038 passenger FWI per billion passenger km and 0.130 worker FWI per million workforce hours for 2014 (RSSB 2009a).

The NRVs from the European Common Safety Targets also apply. They refer to other risk categories and cover slightly different types of accidents, but are considered complementary.

As for any employer in Great Britain, the Health and Safety at Work Act 1974 imposes a duty to ensure the safety of people affected by the undertaking so far as is reasonably practicable (SFAIRP). This may involve reference to established good practice, a qualitative judgement balancing safety against costs, or cost-benefit analysis (CBA). Where CBA is used, fatality risks are quantified using the road VPF, which is currently £1.65m (DfT 2012). Individual risk criteria are no longer considered mandatory (RSSB 2009b), but the HSE (2001) criteria are used as guidelines, and indicate that most population groups are in the tolerable if ALARP range.

A.4.2.3 Derivation

The HLOS and NRVs are both based on a Safety Risk Model (SRM) for the rail industry, which combines accident statistics to produce consistent measures of risk and trends.

A.4.3 Transport of Dangerous Goods

The first use of risk assessment for railways was in connection with the transport of dangerous goods. Starting in the 1980s, techniques that had been used to assess the risks of process plants were applied to multi-modal transport operations including railways, notably in the Netherlands, and subsequently in many industrialised nations.

Rail transport of dangerous goods typically produces low individual risks near to the transport route, but large societal risks spread over the length of the route. They readily satisfy the individual risk criteria developed for the process industry, but it has proved difficult to develop societal risk criteria that give rational evaluation of transport alternatives.

In the UK risk criteria for transport of dangerous goods were developed by the Advisory Committee on Dangerous Substances (ACDS 1991), using the same approaches for road and rail (see Section A.3.2), consisting of individual risk and cost-benefit criteria. FN criteria for risks to communities were also used, but did not impact decisions because all activities were found to be in the tolerable range.

A.4.4 London Underground

A.4.4.1 Origin

The London Underground (LU) first adopted risk assessment in around 1990 after safety measures recommended by the Fennel Inquiry into the Kings Cross fire were found to cost over £10m per fatality averted. The design of equipment for the Jubilee Line extension project used a form of risk assessment to identify and minimise hazards. This was extended to form a network wide QRA and Safety Case.

LU has maintained an approved Railway Safety Case since 1995 in accordance with the Railways (Safety Case) Regulations. Since 2007 it has been known as the Safety Certificate and Safety Authorisation Document. The LU safety objective is to make system risk ALARP and within tolerable limits (LU 2004). This is based on structured qualitative evaluation, informed by CBA where appropriate.

LU's decision-making criteria for passenger transport criteria were at first based on a VPF of £2m per fatality averted, although "projects would be examined up to at least £5m per fatality averted before they are rejected on safety cost-benefit grounds" (Rose 1994). The reference VPF was 3 times higher than the then value for roads of £0.63m.

In 1999, based on further research, the reference VPF was reduced to £1.4m, which was 50% higher than for roads. "If existing risk levels are towards the upper end of the tolerable region, the reference value is multiplied by a factor of 3" (LU 2004).

Criteria for tolerability were at first based on the ACDS criteria (see Section A.3.2), i.e.:

	Intercept with N=1	Slope
Negligible criterion	10^{-4} per year	-1
Local scrutiny level	10^{-2} per year	-1
Local intolerable criterion	10^{-1} per year	-1
National scrutiny level	6 per year	-1

The interpretation of these criteria was as follows (Rose 1994):

- In the negligible region (below the negligible criterion) there is no concern for safety and no requirement or justification for safety improvements.
- In the ALARP region (up to the local scrutiny line) the HSE ALARP principle applies.
- In the local unjustifiable region (up to the local intolerable line) local systems are subject to additional scrutiny, in addition to the ALARP requirement, and may be considered unjustifiable by the HSE. National risks in this region are only subject to the ALARP requirement.
- In the local intolerable region (up to the national scrutiny level), local systems would be unacceptable. National risks in this region are only subject to the ALARP requirement.
- In the national unjustifiable region (above the national scrutiny level), national risks would be subject to additional scrutiny, in addition to the ALARP requirement, and may be considered unjustifiable by the HSE. Local systems in this region would be unacceptable.

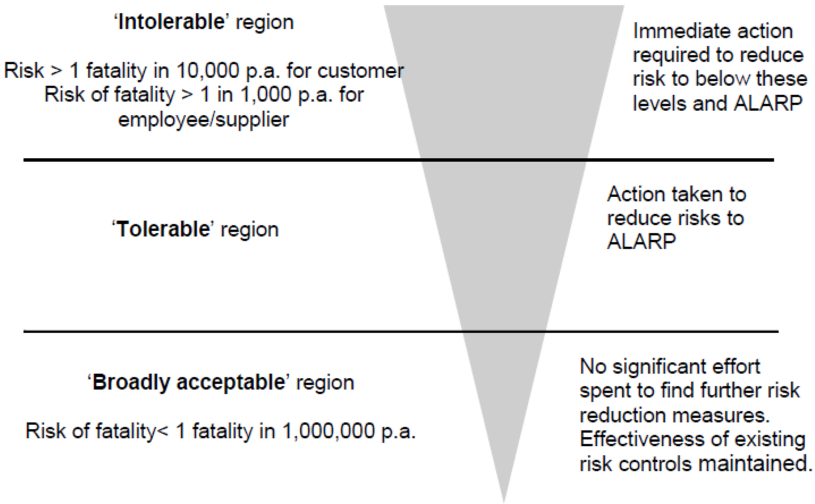
In about 1999 these were abandoned, and the HSE individual risk criteria were adopted instead.

A.4.4.2 Current Criteria

Under the Health and Safety at Work Act, LU has a duty to ensure the risks arising from its operations are as low as reasonably practicable (ALARP). LU's approach to ALARP demonstration begins with application of best practice. Where best practice is unachievable, a qualitative judgement is made as to whether improvement options are reasonably practicable. Where major costs are involved or the issue has high safety significance, LU supports the qualitative assessment with a quantitative assessment.

LU follows the individual risks criteria from the HSE (Section A.6.2), as expressed in Figure A.4.1 (LU 2012).

Figure A.4.1 London Underground Tolerability of Risk Framework



A.5 NUCLEAR INDUSTRY

In the nuclear industry, the International Commission on Radiological Protection (ICRP) makes recommendations on safety of workers and the public. In Europe these are adopted by the European Atomic Energy Community (EURATOM). They are implemented in Member States through national legislation.

The basic principles of the safety policy for occupational exposure to ionising radiation were introduced in 1977 (ICRP 1977):

- No practice shall be adopted unless it has a positive net benefit.
- All exposures shall be kept as low as reasonably achievable (ALARA), taking economic and social factors into account.
- Individual radiation doses shall not exceed specific criteria.

The principles remain substantially unchanged, now expressed as (ICRP 2007):

- The principle of justification: Any decision that alters the radiation exposure situation should do more good than harm.
- The principle of optimisation of protection: the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.
- The principle of application of dose limits: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the Commission.

ICRP do not use explicit criteria for the risk of death, but base their approach on radiation doses measured in milli-Sieverts (mSv). At small doses, the risk of a fatal cancer or genetic defects in future generations is believed to be proportional to the dose without any threshold effect. It can be converted to an individual risk of death using a risk factor (i.e. individual fatality risk per unit dose), which is currently estimated to be 5 x 10^{-5} per mSv (ICRP 2007).

The individual dose limits are (EURATOM 1996):

For workers	50 mSv per year
For members of the public	5 mSv per year

At the time the dose limits were set, the risk factor was 2 x 10^{-5} per mSv (NRPB 1986). Hence the individual risk limits are equivalent to:

For workers	1 x 10^{-3} per year
For members of the public	1 x 10^{-4} per year

The EURATOM directives allow Member States to specify alternative dose limits in some cases. For example, the UK dose limit is 20 mSv per year for any worker (HSC 1999). Using the current risk factor this is still an individual risk of 10^{-3} per year.

Once these criteria are met, ICRP recommends cost-benefit analysis to help optimise radiation protection using the ALARA principle. In the UK, NRPB (1986) have recommended costs of collective doses which reflect aversion to high individual risks. The baseline cost is £3 per person mSv for individual doses in the region of 0.01 mSv, rising to about £45,000 at 1000 mSv. At that time the baseline value was equivalent to a cost of $0.15m per statistical fatality, but it has since been brought into line with the Department of Transport’s value for road transport (see Section A.3.1).

A.6 ONSHORE PROCESS INDUSTRY

A.6.1 European Union

The Seveso Directive is the main European legislation governing the safety of industrial activities involving dangerous goods. It only applies to fixed installations, which exceed threshold quantities of various substances. It explicitly excludes transport.

The Directive requires a Safety Report, which describes the probabilities and consequences of major accident scenarios, but does not need explicit risk measures or risk criteria. It requires measures to limit the consequences of major accidents, and requires Member States to adopt land-use planning to maintain appropriate safety distances around establishments. Different countries have adopted different methods of setting distance requirements (JRC 2008):

- Risk-orientated quantitative approach, with individual or societal risk criteria for various land-use categories.
- Semi-quantitative approach, with risk matrix criteria representing the compatibility of frequency and consequence combinations with land-use categories.
- Consequence-oriented approach, with damage effect criteria defining the required separation from land-use categories.

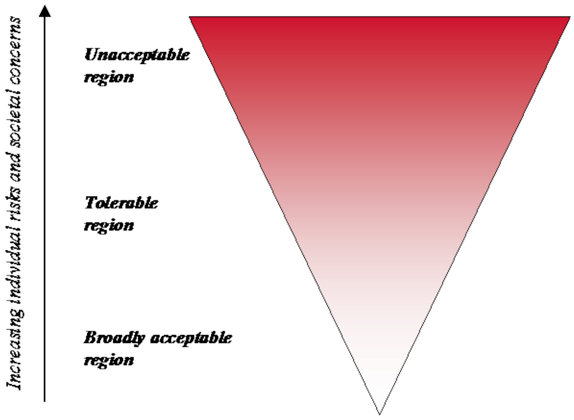
The approaches in selected countries are described below.

A.6.2 United Kingdom

The Health & Safety Executive (HSE) is responsible for industrial safety in Great Britain. Its decision-making on safety issues is based on a tolerability of risk (TOR) framework (Figure A.6.1). This applies to risk in a broad sense, including not just the risks of harm (individual and societal risks), but also the perception of hazards and associated ethical and social considerations ("societal concerns"), such as aversion to multiple-fatality accidents. It divides risk into 3 zones:

- Unacceptable - risks regarded as unacceptable except in extraordinary circumstances (such as wartime), whatever their benefits. Activities causing such risks would be prohibited, or would have to reduce the risks whatever the cost.
- Tolerable - risks that are tolerated in order to secure benefits. In this region, risks are kept as low as reasonably practicable (ALARP), by adopting reduction measures unless their cost is grossly disproportionate to the reduction in risk that they achieve.
- Broadly acceptable - risks that most people regard as insignificant. Further action to reduce such risks is not normally required.

Figure A.6.1 Tolerability of Risk Framework (HSE 2001)



HSE has specified risk criteria (or "tolerability limits") to indicate the boundaries between the zones for hazards involving the risk of single or multiple fatalities. These are considered to be guidelines, not rigid criteria to be complied with in all cases, and may be adapted to take account of societal concerns. The individual risk criteria are (HSE 2001):

Maximum tolerable risk for workers	10^{-3} per year
Maximum tolerable risk for the public	10^{-4} per year
Broadly acceptable risk	10^{-6} per year

The criterion for workers refers to "any substantial category of workers for any large part of a working life", and hence might be exceeded by "fairly exceptional groups". The criterion for workers is based on the highest risk experienced by substantial groups of workers, such as fishing vessel crew (HSE 1987).

Legal precedent established that, in order to make risks ALARP, risk reduction measures should be adopted unless their cost is "grossly disproportionate" to the benefit gained. To value risk reductions in risks to life, HSE uses £1m per statistical fatality averted as a "benchmark", but "regard higher values as being appropriate for risks for which people appear to have a high aversion" (HSE 2001 p36).

HSE suggested a societal risk criterion for major industrial installations, such as an existing chemical plant near to a housing estate, as a maximum tolerable frequency of 2 x 10^{-4} per year for accidents causing 50 fatalities or more. This applies to "a single major industrial activity from which risk is assessed as a whole, such as all chemical manufacturing and storage units within the control of one company in one location or within a site boundary, a cross-country pipeline, or a railway line along which dangerous goods are transported" (HSE 2001 p47). This RAC does not appear to be used in practice, and subsequent efforts to develop societal risk criteria have not reached agreement.

A.6.3 The Netherlands

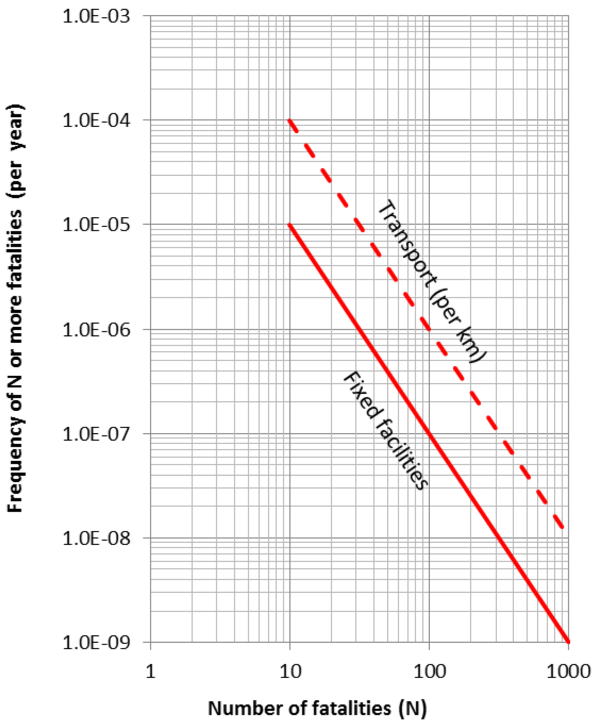
The Government of the Netherlands was among the first national authorities to use numerical risk criteria to assess the safety of industrial plants against major accidents. The 1984 LPG Integral study established acceptability criteria based on individual and societal risk, and became the basis of Dutch external safety policy. In 1993 the acceptability criteria for were adjusted to remove the criteria for negligible risks (Bottelberghs 1995). In 2004 they were further adjusted to avoid application to societal risk below 10 fatalities.

The current criteria are set by the Ministry of Housing, Physical Planning and Environment (VROM) in the Decree on External Safety of Installations (BEVI 2004).

The maximum acceptable individual risk is 10^{-6} per year. This is a statutory limit for “vulnerable objects” (i.e. housing, hospitals, schools etc), and a target to be achieved as far as possible for “less vulnerable objects” (i.e. shops, offices, recreational facilities). This applies equally to risks from fixed installations and TDG. It is calculated for an unprotected person (i.e. outdoors) present all year at specific locations. Individual risks up to 10^{-5} were previously accepted in existing situations. This is no longer stated as a criterion, but it is recognised that in some cases a balancing of interests may lead to acceptance of a risk higher than 10^{-6} per year. There is also a requirement for risks to be made as low as reasonably achievable (ALARA) in addition to meeting the individual risk criteria.

The societal risk criteria for fixed installations are expressed on an FN diagram as 10^{-5} per year for 10-fatalities, with $F=10^{-3}/N^2$ for higher fatalities (see Figure A.6.2). The criteria do not apply for fewer than 10 fatalities. The calculation of societal risk takes account of occupancy patterns and protection through being indoors. The societal risk criteria apply to both new and existing situations, but the authorities may choose to accept situations which exceed them, provided that a thorough balancing of interests has taken place (Bottelberghs 1995).

Figure A.6.2 Netherlands Societal Risk Criteria



The corresponding societal risk criteria for transport are expressed on an FN diagram as 10^{-4} per year for 10-fatalities, with $F=0.01/N^2$ for higher fatalities. This includes all people involved in the accident (i.e. road/railway/waterway users and nearby residents and workers) but does not include the workers involved in the activity (i.e. vehicle/train/barge crew). It refers to a single kilometre of route, which implies that 100m of transport route is given the same risk criterion as a fixed installation. It is applied to all transport modes (road, rail, inland waterway and pipeline). In order to minimise risk calculations, it is applied only to the highest-risk kilometre of each route, which is identified in a simplified way using the consequence area and the surrounding population density.

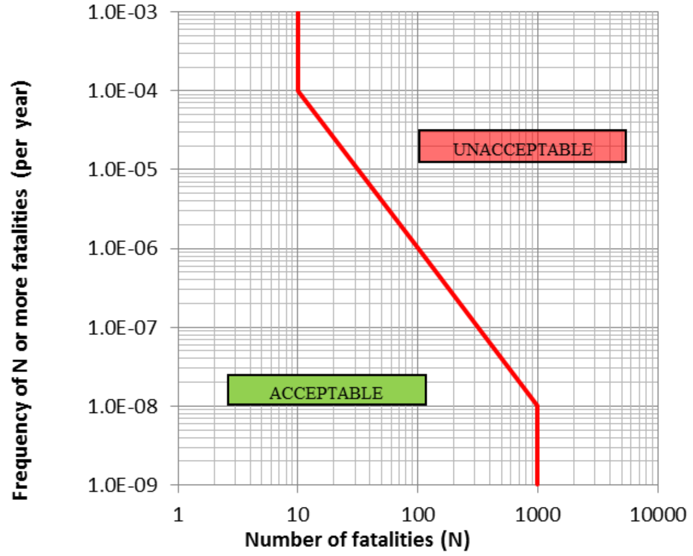
A.6.4 Belgium

The Government of the Flemish Region of Belgium has established risk criteria for its implementation of the Seveso Directive (Duijm 2009).

For individual risks, where the 10^{-5} risk contour passes outside the boundary of the establishment, a safety information plan is required to exchange information about risks with other establishments in the area. For risks in the range 10^{-7} to 10^{-5}, various land uses are permitted. Risks below 10^{-7} are in effect treated as negligible.

The maximum acceptable societal risk for installations is expressed on an FN diagram as $F=0.01/N^2$ for $10 \le N \le 1000$ fatalities (see Figure A.6.3). No societal risk criteria apply for N<10 fatalities. No accidents are permitted with N>1000 fatalities. This excludes people working at the establishment itself.

Figure A.6.3 Flanders Societal Risk Criteria



The Walloon Region of Belgium has also established criteria for its implementation of the Seveso Directive (Beaudoint 2012). The 10^{-6} risk contour defines a consultation zone, within which certain types of buildings (e.g. schools, hospitals and nurseries) are not permitted. Houses are not permitted within the 10^{-5} risk contour. Societal risk is not taken into account.

A.6.5 France

France has adopted a semi-quantitative approach to managing the risk from hazardous installations. The risk from each hazard is described by its probability of occurrence and the number of people exposed to lethal or irreversible effects. The criteria are expressed in a matrix where each combination of probability and consequence is characterised as acceptable or not. The matrix for fixed installations, shown in Figure A.6.4 (Duijm 2009), includes an ALARA region in which plants can be approved once all practicable safety measures are implemented.

Figure A.6.4 Risk Matrix Criteria in France

Seriousness / Frequency class	Moderate	Serious	Major	Very major	Disastrous
A	ALARA	No	No	No	No
B	OK	ALARA	No	No	No
C	OK	ALARA	ALARA	No	No
D	OK	OK	ALARA	ALARA	No
E	OK	OK	ALARA	ALARA	No

A.6.6 Germany

Germany has adopted the consequence-oriented approach to managing hazardous installations (Duijm 2009). The approach is based on consequence calculations in specific release scenarios, with damage effect criteria including thermal radiation of 1.6kW/m^2, overpressure of 0.1 bar, and toxic concentrations equal to the Emergency Response Planning Guidelines EPRG-2 value for the substance. When detailed consequence calculations are not available, standard separation distances are specified for individual substances.

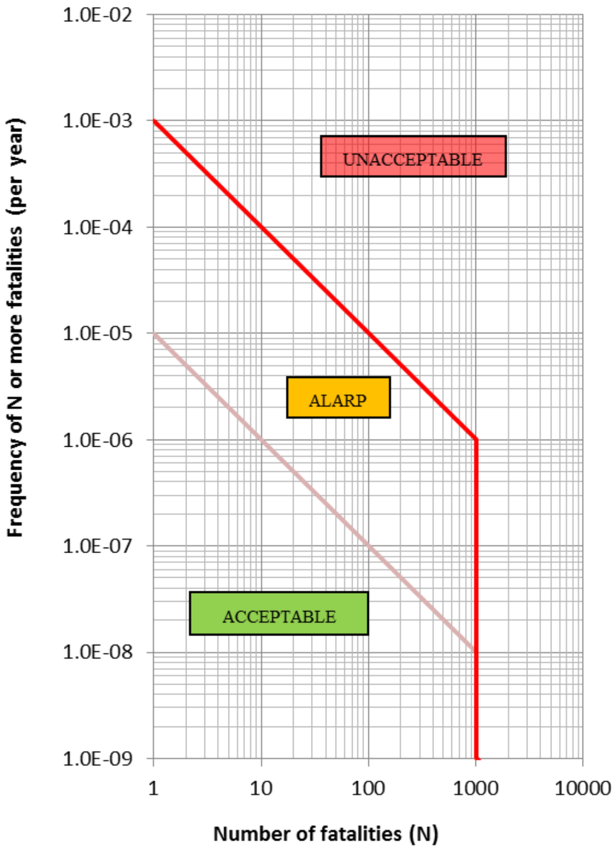
A.6.7 Hong Kong

Risk guidelines for potentially-hazardous installations (PHIs) in Hong Kong are set by an Inter-Departmental Coordinating Committee (CCPHI). Interim guidelines were introduced in 1988 and revised into the current form in 1992. The guidelines are published in the Hong Kong Planning Standards and Guidelines (HKPD 2011), and in a Technical Memorandum on the Environmental Impact Assessment Ordinance (HKEPD 1997).

For individual risks, the maximum risk of death to any individual not involved in the hazardous activity should be less than 10^{-5} per year.

For societal risks, the FN curve of off-site fatality risks should comply with the FN diagram shown in Figure A.6.5. The maximum acceptable risk is $F=10^{-3}/N$ for $1 \leq N \leq 1000$. Risks in a band 2 orders of magnitude below this maximum acceptable line should have their risks reduced to as low as reasonably practicable (ALARP) before they are considered acceptable. Accidents involving more than 1000 fatalities are unacceptable, unless their frequency is less than 10^{-9} per year.

Figure A.6.5 Hong Kong Societal Risk Criteria



A.7 OFFSHORE OIL & GAS INDUSTRY

A.7.1 Norwegian Petroleum Directorate

Numerical risk criteria to evaluate the results of risk assessments in the offshore industry were first used by the Norwegian Petroleum Directorate (NPD) as part of their Guidelines for Safety Evaluation of Platform Conceptual Design, which were issued in 1981. Although these guidelines were withdrawn in 1990 in order to encourage operators to develop their own risk criteria, the approach continues to be widely used.

The NPD Guidelines required the frequency of each of 9 categories of events impairing any of 3 types of safety functions (escape ways, shelter areas and main support structure) to be less than 10^{-4} per platform year. The Guidelines state that this is meant to indicate the magnitude to be aimed for, as accurate calculations of the frequencies are not expected to be possible. NPD therefore applied the criterion with flexibility.

A.7.2 Health & Safety Executive

Although the NPD Guidelines were withdrawn in 1990, the CSE approach clearly influenced the Cullen Report into the *Piper Alpha* accident, which recommended that offshore safety management should be demonstrated to the UK regulatory authority (HSE) through a safety case. Cullen recommended that the survivability of the Temporary Refuge (TR) should be a central feature of the safety case, and that the operator should specify appropriate acceptance criteria, although initially the main criterion for frequency of loss of the TR should be set by the regulatory body.

The resulting HSE impairment frequency criterion appears in the general guidance on the content of safety cases accompanying the Safety Case Regulations (HSE 1992 para 117). It states that "*HSE will look for a demonstration that the frequency with which accidental events will result in a loss of integrity of the temporary refuge within the minimum endurance time stated in the safety case, does not exceed the order of 1 in 1,000 per year. Risk should be reduced to a lower level wherever this is reasonably practicable; where the risk is close to 1 in 1,000 a year, there should be convincing arguments presented that it is not practicable to reduce it further*". In effect, this is a maximum tolerable criterion of around 10^{-3} per year, with ALARP considerations applied below this level.

In the 2005 revision of the Safety Case Regulations, the above guidance was removed, to make the duty holder responsible for setting their own criteria. The Safety Case is required to show that "*all major accident risks have been evaluated and measures have been, or will be, taken to control those risks to ensure that the relevant statutory provisions will be complied with*." The statutory provisions include the Health and Safety at Work Act, which in effect requires the risk to be made ALARP. The guidance to the Safety Case Regulations requires the evidence should also show that the duty holder's risk acceptance criteria are appropriate. HSE guidance on risk assessment (HSE 2006) simply states that "*an individual risk of death of 10^{-3} per year has typically been used within the offshore industry as the maximum tolerable risk*".

The criterion for temporary refuge impairment frequency (TRIF) is no longer specified, and HSE guidance on risk assessment (HSE 2006) explained that it added little value provided the TR was specified so that impairment will not occur so far as reasonably practicable (SFAIRP), which is equivalent to ALARP.

A.7.3 Individual Operators

The safety regimes in the UK and Norway require operators to use risk assessment to help manage the risks in their operations, and part of this is defining their own safety objectives. Although some operators use the earlier NPD and HSE impairment criteria, others have adopted criteria from onshore industries or developed their own. Most such criteria cover individual risks to workers, and set a value on statistical fatalities averted for evaluating risk reduction measures.

An example of a risk matrix that is commonly used for qualitative risk evaluation in the offshore industry is included in the international standard for risk assessment methodology in offshore production (ISO 2000), as shown in Figure A.7.1.

Figure A.7.1 Risk Matrix Criteria in ISO 17776

Consequence					Increasing probability			
Severity rating	People	Assets	Environ-ment	Reputation	A	B	C	D
					Has occurred in E&P industry	Has occurred in operating company	Occurred several times a year in operating company	Occurred several times a year in location
0	Zero injury	Zero damage	Zero effect	Zero impact				
1	Slight injury	Slight damage	Slight effect	Slight impact	**Manage for continued improvement**			
2	Minor injury	Minor damage	Minor effect	Limited impact				
3	Major injury	Local damage	Local effect	Considerable impact				
4	Single fatality	Major damage	Major effect	Major national impact	**Incorporate risk-reducing measures**		**Fail to meet screening criteria**	
5	Multiple fatalities	Extensive damage	Massive effect	Major international impact				

Statoil used an FAR of 10 for employees and a maximum individual risk for third parties of 10^{-5} per year (Tveit 1995). In addition, FN criteria were applied to third-party societal risk with an ALARP region in-between:

- Not acceptable: $F>0.01/N$
- Acceptable: $F<10^{-4}/N$

VPFs for decision-making purposes have been in the range £1m - 10m, although few have been published:

- BP used a range of values of £0.6m to 6m (Beaumont 1995). Risk reduction measures costing less than £0.6m per life saved would proceed without question; between £0.6m and £6m a measure would only proceed if no better alternative were available.
- Shell adopted guidelines in the form of costs to avert a fatality that were linked to the individual risk levels. In general, risk reduction measures costing less than £5m per life saved were presented to management for consideration (Kennedy 1993).

Most operators no longer publish their risk criteria, and those that were previously published may no longer be valid.

A.8 HEALTHCARE

A.8.1 WHO

The World Health Organization (WHO) project CHOICE (Choosing Interventions that are Cost-Effective) was developed in 1998, and since 2005 has provided cost-effectiveness thresholds based on GDP per capita, which automatically update and adjust to different countries.

The current thresholds for the value of a statistical life year (VSLY) are (WHO 2014):

- Highly cost-effective – less than GDP per capita
- Cost-effective – between 1 and 3 times GDP per capita
- Not cost-effective – more than 3 times GDP per capita

Based on a current OECD average GDP per capita of $40,000, this implies a VSLY up to $120,000 per life-year.

A.8.2 United States

The US Environmental Protection Agency uses benefit-cost analysis of new environmental policies affecting risks of dying from adverse health conditions that may be caused by environmental pollution.

EPA has estimated a value of statistical life (VSL) since approximately 1984. In its benefit-cost analysis of the Clean Air Act (USEPA 1999), EPA reviewed 26 wage-risk and stated preference studies, obtaining a central estimate VSL of $4.8m with a standard deviation of $3.2m (1990 prices). It also used an alternative approach based on life-years, which was derived from the VSL estimate using a 35-year remaining life expectancy and discounting future lost years at 5%, obtaining a central estimate of $293,000 per life year.

EPA currently recommends a central VSL of $7.4m (2006 prices), updated to the year of the analysis, be used in all benefits analyses that quantify mortality risk reduction benefits (USEPA 2010). This is applied regardless of the age, income, or other characteristics of the affected population. It is based mainly on wage differential studies. It would be $8.5 million in 2012 prices or €6.4m.

EPA's preferred method of valuing morbidity is willingness-to-pay, including stated preference, revealed preference and cost of illness studies.

The US Food and Drug Administration (FDA) has used a VSL of $5m since approximately 2003, and this has not been updated (Robinson 2007). It has also used VSLY estimates in the range £100,000 to $500,000 per life-year.

A review of cost-effectiveness analyses in medical therapies (Owens 1998) indicated that most US decision makers conclude that interventions that cost less than $50,000 to $60,000 per QALY gained are reasonably efficient, whereas few conclude that interventions that cost more than $175,000 per QALY are justifiable.

A.8.3 United Kingdom

The UK National Institute for Health and Care Excellence (NICE) uses the quality-adjusted life-year (QALY) to compare different drugs and measure their clinical effectiveness. In general, if a treatment costs more than £20,000-30,000 per QALY, then it would not be considered cost effective (NICE 2010). This guidance has been unchanged since 2004.

A.8.4 Spain

In Spain a commonly used threshold for economic evaluation of health technologies is €30,000 per QALY (Rodríguez Barrios 2012). This threshold has been used since 2003.

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APPENDIX B

Historical Transport Risks

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B.1 INTRODUCTION

This appendix provides estimates of historical risks in different transport modes. It makes use of data covering the EU as a whole.

The aim is to show how travelling by RoPax or Cruise vessels compares to equivalent travel by car, bus or train.

In making this comparison, “equivalent travel” could be interpreted as the same distance, the same journey time, the same number of journeys or the same contribution to the economy. In the case of freight transport, the comparison might be with the same number of tonne-km. Since the results may be sensitive to the benchmark chosen, all the following metrics all are provided where available:

- Fatalities per billion passenger km
- Fatalities per billion passenger hours
- Fatalities per billion passenger journeys
- Fatalities per billion € revenue
- Fatalities per billion tonne-km

These risks are estimated for the following transport modes:

- Road transport, including car and bus (Section B.1)
- Rail transport (Section B.2)
- Air transport (Section B.3)
- Sea transport (Section B.4)

The best results for the different modes are compared in Section B.5.

B.2 ROAD TRANSPORT

The European Transport Safety Council (ETSC 2003) estimated the fatality rate in road transport in 15 European Union countries as 9.5 per billion person km in 2001/02, with the breakdown by vehicle type as shown in Table B.2.1. This was based on 38,935 fatalities, but the precise source for each mode was not stated. The conversion between the metrics corresponds to an average speed of 35 km/hour for cars and 30 km/hour for bus/coach.

Table B.2.1 Road Accident Fatality Rates EU-15, 2001

VEHICLE TYPE	FATALITY RATE (per 10^9 person km)	FATALITY RATE (per 10^9 person hours)
Pedestrian	64	250
Pedal cycle	54	750
Motorcycle	138	4400
Passenger car	7	250
Bus/coach	0.7	20
Total	9.5	280

Koornstra (2008) updated these to 2007 using a 5.3% annual reduction, obtaining an average rate of 7.7 per billion person km. It also distinguished between fatalities to the vehicle user (i.e. drivers and passengers) and others (i.e. pedestrians) as shown in Table B.2.2.

Table B.2.2 Estimated Road Accident Fatality Rates EU-15, 2007

VEHICLE TYPE	VEHICLE USER FATALITY RATE (per 10^9 person km)	OTHER FATALITY RATE (per 10^9 person km)	TOTAL FATALITY RATE (per 10^9 person km)
Pedestrian	52	-	52
Pedal cycle	44	2	46
Motorcycle	111	82	193
Passenger car	5.7	6.6	12.3
Bus/coach	0.6	6	6.6
Lorry/truck	3.5	46	49.5
Total	7.7		

The estimated passenger fatality rate in road transport in the EU-27 in 2011 is 6.1 per billion passenger km (EC 2013 p102). A breakdown by vehicle type has not been published, possibly due to concerns about data completeness and consistency in the enlarged EU. The available data is reviewed as follows.

Table B.2.3 gives the fatalities in road accidents recorded in the EU-27 in 2012 for the latest available year (mainly 2012 but in some countries as old as 2009), broken down by vehicle type (EC 2012). The results may be under-estimated because pedestrian fatalities were mainly not allocated to a vehicle type, and in many other cases the vehicle type was unknown. If these were distributed in the same way as driver and passenger fatalities where the vehicle type was known, the total for each vehicle type would be 30% higher than shown.

Table B.2.4 gives the passenger transport exposure in the EU-27 in 2011, broken down by vehicle type (EC 2013 p46). It is assumed that in this case “passenger” includes drivers. Table B.2.4 also combines these with the accidents from above to estimate current fatality rates. The numbers of fatalities have all been adjusted to include pedestrians and cases where the vehicle type was unknown, assuming these were distributed in proportion to the other fatalities.

Table B.2.3 Road Accident Fatalities in EU-27, 2012

VEHICLE TYPE	DRIVER FATALITIES	PASSENGER FATALITIES	PEDESTRIAN FATALITIES	TOTAL FATALITIES
Pedestrian	2	0	6081	6083
Passenger car	9224	4207	1	13432
Motorcycle <125cc	51	0	0	51
Motorcycle >125cc	388	16	0	404
Motorcycle not specified	3670	219	0	3890
Moped	934	59	0	992
Two-wheel motor vehicle	30	0	0	30
Pedal cycle	2079	7	0	2086
Bus	22	63	0	85
Minibus	1	0	0	1
Coach	0	0	0	0
Bus/minibus/coach/trolley	1	14	0	15
Goods vehicle <3.5t mgw	537	163	0	700
Goods vehicle >3.5t mgw	271	48	0	319
Goods vehicle	182	58	0	240
Road tractor	105	14	0	119
Agricultural tractor	159	32	0	191
Other motor vehicle	60	27	0	87
Other non-motor vehicle	55	19	0	74
Ridden animal	10	2	0	12
Unknown				906
Total	17781	4948	6082	29717

Table B.2.4 Estimated Road Accident Fatality Rates in EU-27, 2012

VEHICLE TYPE	PASSENGER EXPOSURE (10^9 passenger km)	DRIVER FATALITY RATE (per 10^9 passenger km)	PASSENGER FATALITY RATE (per 10^9 passenger km)	PEDESTRIAN FATALITY RATE (per 10^9 passenger km)	TOTAL FATALITY RATE (per 10^9 passenger km)
Passenger cars	4822	2.0	0.9	0.7	3.6
Powered two-wheel vehicles	123	42.9	2.5	11.7	57
Bus/coach	512	0.0	0.2	0.1	0.3

These results are much lower than the previous estimates in Table B2.2, and cannot be explained by improvements in road safety. Given concerns about possible under-reporting, and the fact that the accident and exposure datasets have not been combined in official EU publications, it is desirable to validate them by comparing with an independent source. Data for the UK is chosen for this purpose, since it provides 13% of EU exposure for passenger cars, and is considered to be comprehensively reported. Table B.2.5 shows the passenger fatality rates for road accidents in Great Britain in 2012 (DfT 2013). Cars, vans and motorcycles include driver fatalities. These are broadly consistent with the estimated current EU values, and hence are considered to justify use of the EU values, although the previous estimates could still be used as a more pessimistic sensitivity test.

Table B.2.5 Road Accident Fatality Rates in Great Britain, 2012

VEHICLE TYPE	PASSENGER FATALITY RATE (per 10^9 passenger km)
Pedestrian	23
Pedal cycle	24
Motorcycle	67
Passenger car	1.3
Bus/coach	0.2
Van	0.4

The turnover of road transport in the EU-27 in 2010 was €104 billion for passenger transport and €294 billion for freight transport (EC 2013 p26). The corresponding numbers of fatalities in bus/coach and goods vehicle accidents were 101 and 1259. Increasing these by 30% to include pedestrians and cases where the vehicle type was unknown, the fatality rates can be estimated as 1.3 per billion $ revenue in passenger transport and 5.6 per billion € revenue in goods transport. The value added by personal transport is not known, and therefore no comparable metric can be estimated for passenger cars.

The quantity of road freight transport in the EU-27 in 2011 was 1734 billion tonne-km (EC 2013 p36). The corresponding number of fatalities in goods vehicle accidents was 1259. Increasing this by 30% to include pedestrians and cases where the vehicle type was unknown, the fatality rate can be estimated as 0.94 per billion tonne-km.

B.3 RAIL TRANSPORT

ETSC (2003) estimated the fatality rate in rail transport in EU-15 countries as 0.35 per billion passenger km (or 20 per billion passenger hours) in 2001. This was based on the trend over the period 1970 to 2000, since the annual values had fluctuated due to the occasional occurrence of major accidents. The conversion between the metrics corresponds to an average speed of 60 km/hour.

Koornstra (2008) updated these to 2007 by continuing the historical 5.5% annual reduction, obtaining an average rate of 0.27 per billion passenger km. This refers to passengers alone. Including fatalities to others (i.e. train employees, track workers, trespassers and other third party fatalities), the total was 2.2 per billion passenger km.

The average number of passenger fatalities in the EU-27 during the period 2006-11 was 63 per year (EC 2013 p106). The average exposure in the same period was 402 billion passenger km (EC 2013 p 46). Hence the average passenger fatality rate was 0.16 per billion passenger km. This may be affected by under-reporting of fatalities.

The turnover of rail transport (including passenger and goods transport) in the EU-27 was €74.8 billion in 2010 (EC 2013 p26). Hence the fatality rate is estimated as 0.84 per billion € revenue.

The quantity of rail freight transport in the EU-27 during the period 2006-11 was 416 billion tonne-km (EC 2013 p36). Hence the fatality rate is estimated as 0.15 per billion tonne-km. However, many of these fatalities were not associated with freight transport, so this measure is not suitable to predict the risks from additional freight transport.

B.4 AIR TRANSPORT

ETSC (2003) estimated the fatality rate in civil aviation in EU-15 as 0.35 per billion passenger km (or 160 per billion passenger hours) in 2001. This was based on the trend for domestic and continental flights within the EU over the period 1980 to 2001, since the annual values had fluctuated due to the occasional occurrence of major accidents. The conversion between metrics was based on an average flight length of 720 km and 1.6 hours, i.e. an average speed of 450 km/hour (240 knots).

Koornstra (2008) updated these to 2007 using an 8% annual reduction, obtaining an average rate of 0.2 per billion passenger km. This refers to crew and passengers alone, but including fatalities to others (i.e. people on the ground) makes only a 10% increase. Adjusting to refer to flights under 200km a value of 0.4 per billion passenger km was selected.

The average number of fatalities on commercial transport and business aircraft over 5700kg over the EU-27 during the period 2000-12 was 51 per year (EC 2013 p107). The average exposure in the same period was 512 billion passenger km (EC 2013 p 46). Hence the average passenger fatality rate was 0.10 per billion passenger km.

The turnover of air transport (including passenger and goods transport) in the EU-27 was €122 billion in 2010 (EC 2013 p26). Hence the fatality rate is estimated as 0.42 per billion € revenue.

The quantity of air freight transport in the EU-27 during the period 2000-11 was 2.6 billion tonne-km (EC 2013 p36). Hence the fatality rate is estimated as 20 per billion tonne-km. However, most of these fatalities were on flights carrying only small amounts of cargo, so this measure is not suitable to predict the risks from additional freight transport.

B.5 SEA TRANSPORT

The North West European Project on Safety of Passenger/Ro-Ro Vessels (DNV Technica 1996) estimated the fatality rate in ferry transport in North-West Europe as 5.7 per billion passenger km (or 180 per billion passenger hours, or 520 per billion passenger journeys). This was based an average of 75 fatalities per year during 1978-94. The data period included the *Estonia* accident, and accident risks are considered to have reduced since then. The conversion between the metrics was based on an average journey length of 93 km and 3.3 hours, i.e. an average speed of 28 km/hour (15 knots).

ETSC (2003) estimated the fatality rate in ferry transport in European waters as 2.5 per billion passenger km (or 80 per billion passenger hours). This was based on an average of 141 fatalities per year during 1984-2001. This is higher than above because it included all European waters. The conversion between the metrics corresponds to an average speed of 32 km/hour (17 knots).

Koornstra (2008) updated these to 2007 using a 7% annual reduction to represent the improvement since the *Estonia* accident, obtaining an average rate of 1.4 per billion passenger km. This includes fatalities to crew and passengers.

EMSA (2011) reported an average of 6.8 fatalities per year on passenger ships in EU waters during 2007-10. However, this may under-estimate the contribution of irregular major accidents, since there were 32 deaths on the *Costa Concordia* in 2012. Assuming that major accidents give a similar long-term average contribution to accidents occurring each year, the fatality rate could be estimated as 6.8 x 2 = 13.6 per year. The average exposure in the same period was 40 billion passenger km (EC 2013 p 46). Hence the average passenger fatality rate was 0.34 per billion passenger km.

The turnover of sea transport (including passenger and goods transport) in the EU-27 was €101 billion in 2010 (EC 2013 p26). This must be compared with the fatalities on cargo ships as well as passenger ships. Including all types of ships, EMSA (2011) reported an average of 69 fatalities per year during 2007-10. Hence the fatality rate is estimated as 0.68 per billion € revenue.

The quantity of sea freight transport in the EU-27 during the period 2007-11 was 1438 billion tonne-km (EC 2013 p36). This should be compared with the fatalities on cargo ships excluding passenger ships. From above, this is estimated as approximately 69-13.6 = 55.4 fatalities per year. Hence the fatality rate is estimated as 0.04 per billion tonne-km.

B.6 COMPARISON OF TRANSPORT MODES

There are some concerns that the latest fatality rate data for the EU may be under-reported, and therefore the following tables present both these and previous estimates (based mainly on Koornstra 2008). The latter also address the total fatality rate including estimates of risk to non-passengers who may be affected by the transport. Although they may be over-estimates, as they do not reflect recent safety improvements, they indicate the large uncertainty in the latest estimates.

Table B.6.1 summarises the estimated risks in each transport mode in terms of fatalities per billion passenger km. By this metric, air transport has the lowest risk. The ranking of sea transport depends on the dataset used.

Table B.6.1 Transport Accident Fatality Rates per Billion Passenger Km

TRANSPORT TYPE	LATEST PASSENGER FATALITY RATE (per 10^9 passenger km)	PREVIOUS ESTIMATE OF TOTAL FATALITY RATE (per 10^9 passenger km)
Passenger car	0.9	12.3
Bus/coach	0.2	6.6
Rail	0.16	2.2
Air	0.10	0.4
Sea	0.34	1.4

Table B.6.2 assumes a representative average speed for each transport mode, and converts the risks into fatalities per billion passenger hours. By this metric, sea or bus transport have the lowest risk, depending on the dataset selected.

Table B.6.2 Transport Accident Fatality Rates per Billion Passenger Hours

TRANSPORT TYPE	AVERAGE SPEED (km/hour)	LATEST PASSENGER FATALITY RATE (per 10^9 passenger hour)	PREVIOUS ESTIMATE OF TOTAL FATALITY RATE (per 10^9 passenger hour)
Passenger car	35	32	430
Bus/coach	30	6	200
Rail	60	10	130
Air	450	45	180
Sea	28	10	40

Table B.6.3 assumes a representative journey length for each transport mode, and converts the risks into fatalities per billion passenger journeys. By this metric, bus transport has the lowest risk. In contrast, sea and air transport have risks similar to or higher than car transport, depending on the dataset used.

Table B.6.3 Transport Accident Fatality Rates per Billion Passenger Journeys

TRANSPORT TYPE	AVERAGE JOURNEY LENGTH (km)	LATEST PASSENGER FATALITY RATE (per 10^9 passenger journeys)	PREVIOUS ESTIMATE OF TOTAL FATALITY RATE (per 10^9 passenger journeys)
Passenger car	20	18	250
Bus/coach	8	1.6	50
Rail	30	4.8	70
Air	720	72	290
Sea	93	32	130

Table B.6.4 expresses the risks as fatalities per billion € revenue. It also compares to previous estimates based on UK data (DNV 2002). By this metric, air transport has the lowest risk.

Table B.6.4 Transport Accident Fatality Rates per Billion € Revenue

TRANSPORT TYPE	LATEST PASSENGER FATALITY RATE (per 10^9 € revenue)	PREVIOUS ESTIMATE OF TOTAL FATALITY RATE (per 10^9 \$ revenue)
Passenger car	-	-
Bus/coach	1.3	2.16
Goods vehicle (road)	5.6	11.06
Rail	0.84	3.35
Air	0.42	1.64
Sea	0.68	2.46

Table B.6.5 expresses the risks as fatalities per billion tonne-km. This aims to compare deaths associated with the cargo transport, but in the case of aviation it is impractical to separate passenger and cargo transport. By this metric, sea transport has the lowest risk.

Table B.6.5 Transport Accident Fatality Rates per Billion Tonne-km

TRANSPORT TYPE	LATEST PASSENGER FATALITY RATE (per 10^9 tonne-km)
Passenger car	-
Bus/coach	-
Goods vehicle (road)	0.94
Rail	0.15
Air	20
Sea	0.04

Overall, it can be concluded that the risks from sea travel are broadly similar to those from bus, train or air travel, and the precise ranking depends on the dataset and the metric used.

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APPENDIX C
Review and update of VPF

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C.1. INTRODUCTION

This appendix includes an explanation of the terms VSL (Value of Statistical Life) and VPF (Value of Preventing a Fatality) and how they should be understood.

The various techniques to set the values of VSL and VPF are described in section C.3. Generally there are 3 approaches that are used:

- Human capital approaches
- Willingness to pay (WTP) approaches
- Life quality approaches.

The use of the method included in the IMO FSA guidelines is described in section C.4 and finally section C.5 provides an overview of published VSL/VPF for different countries and organisations.

C.2. VALUE OF PREVENTING A FATALITY

The cost of averting fatalities or value of statistical lives relates to considerations that are made to decide on reducing relatively small probabilities of fatalities to even lower probabilities. A “statistical life” reflects the aggregation of small changes in risks across individuals. For example, a 1 in 1,000 probability reduction that affects 1,000 individuals can be expressed as a statistical life (1/1,000 probability x 1,000 people = 1 statistical life). To understand the type of risk that are subject to cost effectiveness criteria reference is made to the criteria for individual risk. The ALARP criterion for individual risk is referring to risks above 10-^{3} as intolerable and risks less than 10^{-6} as negligible. The VSL criterion for annual individual risk therefor only applies to individual risk in the range [10^{-6}, 10^{-3}].

The VPF in practice reflects society’s willingness to pay for small reductions in risk of mortality, multiplied across population. For example, a $7 million VPF results if each member of a society of 10,000 is willing to pay $700 on average for a one in 10,000 decrease in individual annual risk of dying ($700 x 10,000 people = $7 million). The VPF concept is frequently misunderstood; it is not the value of saving a particular individual’s life, it is not the compensation paid by the insurer if the insured person dies, etc.

The variation between different studies can in many cases be explained by the method used or the issue addressed

- Studies of individual preferences or societies preferences
- Type of risk: uncontrollable, involuntary, dreaded, or ambiguous risks etc.
- Risk affecting young, middle age or aging people
- Immediate or delayed death following the accident
- Safety issue or Security issue
- Morbidity period prior to death or not
- Etc.

C.3. TECHNIQUES OF SETTING THE VPF/VSL

The value of preventing a fatality (VPF) or Value of a Statistical Life (VSL) criterion can be set through different techniques. The most common techniques are:

- Human capital approaches. These estimate the VPF/VSL in terms of the future economic output that is lost when a person is killed. This may be in terms of gross output (in effect, the lifetime salary) or net output (in effect, the lifetime tax payments). The approach was largely promoted by economists, and for example the World Bank used this approach. This narrow economic approach is now largely discredited, since it is recognised that people value life for its own sake rather than for its capacity to maintain economic output. Also the World Bank is no longer using this technique. It typically gives values less than half as high as other approaches.

- Willingness-to-pay (WTP) approaches. These estimate the amount that people in society would be prepared to pay to avoid a statistical fatality. There are two main types:

  - The "contingent valuation" or "stated preference" approach uses expressed opinions on hypothetical situations in questionnaires. This approach is widely used, and many regulators base their VPF/VSL values on meta-analysis of such studies. The use of such approaches result in relatively large variation in results, partly because the hypothetical questions in the questionnaires are varying, and because the questions are difficult to relate to. Stated preference methods involve asking respondents how they would behave in a hypothetical market, allowing researchers to investigate individual WTP for nonmarket goods. They include surveys, which ask respondents to report their WTP for risk reductions associated with specific scenarios, and conjoint analyses (or choice experiments), which disaggregate the attributes of the scenarios and explore related trade-offs.

  - The "revealed preference" approach uses observed behaviour, such as wage differentials for riskier jobs. This approach is preferred in the USA, and the recommended VSL values in the US results from meta-studies of what is perceived as high-quality revealed preference studies. Revealed preference methods use data from observed behaviour to estimate the value of related goods. Wage-risk studies (also referred to as compensating wage differential or hedonic wage studies) are a type of revealed preference research that is commonly used. In these studies, researchers compare earnings across workers in different occupations or industries who face varying levels of on-the-job risks, using statistical methods to control for the effects of other factors (such as education or nonfatal job risks) on their wages.

  - A variant of "revealed preferences" is when decisions made by regulators to implement or not implement safety measures are studied by risk analysis. Tengs et al.(1995) is a much quoted reference for this type of studies. For maritime, similar study is available in Skjong et al. (2005).

- Life quality approaches. These are based on social indicators of quality of life that reflect life expectancy and 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. This negative impact can arise because safety measures divert expenditure from other uses, which include health care and other expenditure which extend life expectancy by indirect routes. The optimum VPF ensures that safety measures are only recommended when their direct benefit exceeds the lost indirect benefit of the expenditure that they require. The IMO FSA Guidelines (IMO, 2013) refers to this approach. There are currently two different types of life quality approaches: Life Quality Index and J-value (Judgement – value). The literature about the two approaches is extensive, and a reference list is included for Life Quality Index and J-Value, respectively.

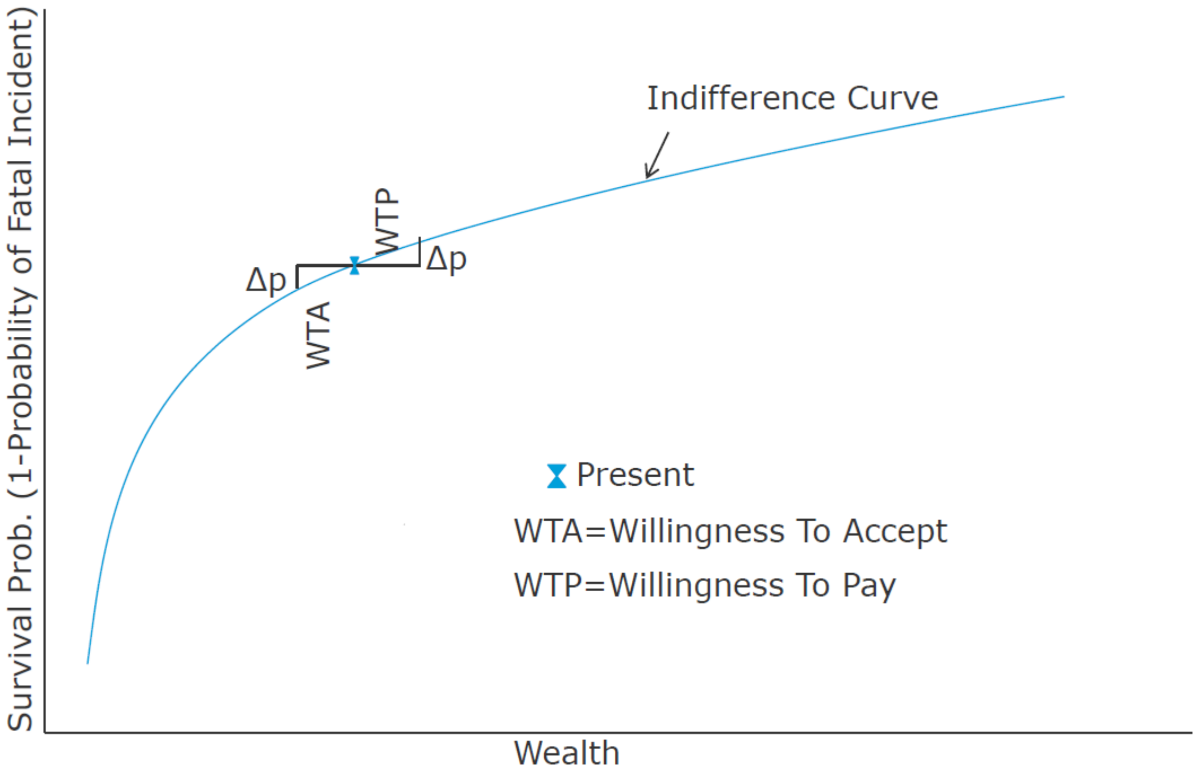

Figure 3-1: Illustration of Willingness To Pay (for risk reduction) and Willingness to Accept (risk increases)

There is also a variant of WTP (for risk reduction), which use willingness to accept WTA risk increases. The VPF/VSL concept is illustrated more formally in Figure 3-1. Wealth is plotted along the horizontal axis, and the probability ("p") of survival is plotted along the vertical axis. The curved line represents an individual's indifference curve; i.e., the set of points (combinations of wealth and survival probabilities) which is considered equivalent (The individual would consider to be equally well-off at each point along this curve.) For each change in survival probability ("Δp"), WTP or WTA is measured by the horizontal distance between the two points on the indifference curve. Because the VSL is the value of a "statistical" case; i.e., sums the values for small changes in risk, it can be calculated as the individual's average WTP or WTA divided by the change in survival probability.

$$\text{VPF/VSL} \approx \text{WTA}/\Delta p \approx \text{WTP}/\Delta p$$

The classical methods to establish VSL are revealed preferences or stated preferences described above.

The method used to establish a VPF/VSL number for decision making vary widely between countries, and even between different agencies within a country. The main difference is the reliance on Revealed Preference methods in terms of wage risk studies in the United States (where most such studies have been conducted), while Europe, Canada and Australia rely more on Stated Preference (SP) methods, eliciting people's willingness-to-pay (WTP) or willingness to accept (WTA) for changes in mortality risks.

In particular the stated preference methods have been subject to criticism, as stated preferences may become unrealistic, and may be subject to perception biases. The main drawback of the stated preference methods is that it is hypothetical, so that the amounts people say they are willing to pay may be different from what they actually would have been willing to pay, if faced with the given situation.

Although VPFs could be based on original research of these types, they are more commonly chosen from the ranges indicates by previous research and meta-studies.

C.4. IMO FSA RECOMMENDED METHODOLOGY

The IMO FSA Guidelines, MSC-MEPC.2/Circ.12, Appendix 7, paragraph 3.2 specifies the following:

The proposed values for NCAF and GCAF in table 2 were derived by considering societal indicators (refer to document MSC 72/16, UNDP 1990, Lind 1996). They are provided for illustrative purposes only. The specific values selected as appropriate and used in an FSA study should be explicitly defined. These criteria given in table 2 are not static, but should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on LQI (Nathwani et al. (1996), Skjong and Ronold (1998, 2002), Rackwitz (2002 a,b).

The referenced Table 2, is based on MSC72/16, and refers to VPF value of $3million, which was used in all FSA studies from 2000 to 2012.

In SLF.55/INF.9, Section 3.7 the FSA Guidelines was followed strictly, and the VPF was updated:

The criterion used for recommendations based on NCAF and GCAF can be found in the consolidated version of the FSA Guidelines (MSC83/INF.2, page 54). The criterion that has been used for all FSAs submitted to IMO so far has been at $3million/fatality, see Table 2, page 54 of MSC83/INF.2. However, it is stated in the FSA Guidelines that the proposed values for NCAF and GCAF have been derived by considering societal indicators, (UNDP 1990, Lind 1996). They are provided for illustrative purposes only. The specific values selected as appropriate and used in an FSA study should be explicitly defined. This criterion is not static, but should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on the Life Quality Index (LQI).
It is noted that the $3million is in reality derived from 1998 statistics. If adjusted for US inflation rates until 2010, this figure should be updated to $4.14 million (2010). If adjusted for a 5% risk free rate of return the figure should be $5,39million (2010), and if a full update based on LQI is carried out the result is $7,45million.

The LQI formula used is g × e/4 × (1-w)/w)

- *g is gross domestic product per capita (Statistics from world bank used)*
- *e is life expectancy at birth (statistics from CIA fact-book used)*
- *w is the portion of life spent in economic production (statistics from OECD used)*

As for the $3 million (1998) figures, the derived criterion is an OECD average. The main changes are due to the following:

- *The number of OECD countries has increased,*
- *Gross Domestic Product per Capita has increased,*
- *Life expectancy at birth has increased and we spend less time in economic activity (now about 1/10 rather than the 1/7 in the nineties).*

In addition the US$ has decreased its value against most other currencies.
In this report the $7,45million criterion is used to indicate when an RCO is considered cost effective.

The required statistics for updating the VPF according to the approach according to the FSA Guidelines is provided in Table 4-1. In addition to life expectancy at birth, the table contains the HALE (Health Adjusted Life Expectancy), and the resulting VPF if it was assumed that a fatality on average occurred at HALE/2 rather than e/2.

Table 4-1 Statistics OECD Countries

Country	GDP (2012)	e	HALE	w	VPF $million (2012)	VPF(HALE) $million (2012)
AUSTRALIA	43324	81,5	72	0,09	8,909	7,8705
AUSTRIA	44462	80,5	74	0,09	8,685	7,9838
BELGIUM	38884	79,5	72	0,07	9,996	9,0526
CANADA	42693	80,6	73	0,10	8,010	7,2543
CHILE	22655	78,5	70	0,15	2,471	2,2035
CZECH REPUBLIC	26426	77,5	70	0,10	4,724	4,2669
DENMARK	41388	78,9	72	0,09	8,070	7,3645
ESTONIA	23024	75,6	66	0,11	3,360	2,9330
FINLAND	38230	80,1	72	0,09	7,758	6,9783
FRANCE	35845	80,9	73	0,07	9,716	8,7670
GERMANY	40394	80,2	73	0,08	9,176	8,3578
GREECE	24667	79,6	72	0,09	5,053	4,5702
HUNGARY	21570	74,4	66	0,10	3,547	3,1463
ICELAND	37533	82,2	74	0,09	8,147	7,3341
IRELAND	42662	79,9	73	0,09	9,136	8,3468
ISRAEL	28809	81,1	73	0,09	6,138	5,5285
ITALY	32513	81,4	74	0,08	7,455	6,7771
JAPAN	35204	82,6	76	0,09	7,323	6,7377
KOREA	30722	79,6	71	0,12	4,596	4,0992
LUXEMBOURG	88318	80,1	73	0,13	11,379	10,3705
MEXICO	16676	75,5	67	0,11	2,646	2,3501
NETHERLANDS	42938	80,6	73	0,08	9,868	8,9429
NEW ZEALAND	31499	80,7	73	0,10	5,873	5,3164
NORWAY	62767	80,8	73	0,10	11,982	10,8256
POLAND	21903	76,3	67	0,10	3,673	3,2251
PORTUGAL	25307	79,3	71	0,11	4,116	3,6853
SLOVAK REPUBLIC	24896	75,4	67	0,09	4,929	4,3825
SLOVENIA	26801	79,2	71	0,08	5,899	5,2883
SPAIN	32129	81,3	74	0,08	7,947	7,2331
SWEDEN	42217	81,4	74	0,09	8,846	8,0464
SWITZERLAND	52063	82,1	75	0,12	7,824	7,1476
TURKEY	18348	74,5	66	0,09	3,340	2,9610
UNITED KINGDOM	35819	79,9	72	0,08	8,184	7,3796
UNITED STATES	49965	78,2	70	0,09	9,859	8,8249
Average	35960	79,4	72	0,095	7,019	6,340

It is seen that the resulting VPF value for OECD Countries is at $7.01 million. As sensitivity, the table has included the VPF if it is assumed that an accident on average happens at HALE/2 rather than at e/2. This is a reasonable assumption, but the assumption has not been verified, simply because very limited statistics exists.

The essentials of the statistics, the VPF, are also displayed in Figure 4-1. It may be noticed that the VPF value based on LQI is almost exactly the same as EPA, Office of Ground Water and Drinking Water (EPA, 2005).
The use of OECD averages may obviously be debated. When this was proposed Norway (2000), statistics of world trade indicated that 95% of the trade world involved OECD countries. If the statistics was developed based on OECD+BRIC (Brazil, Russia, India, China) the VPF would be $6.46 million (2012).
The VPF value for EU is $6.31 million (on average EU is not quite as wealthy as average OECD).

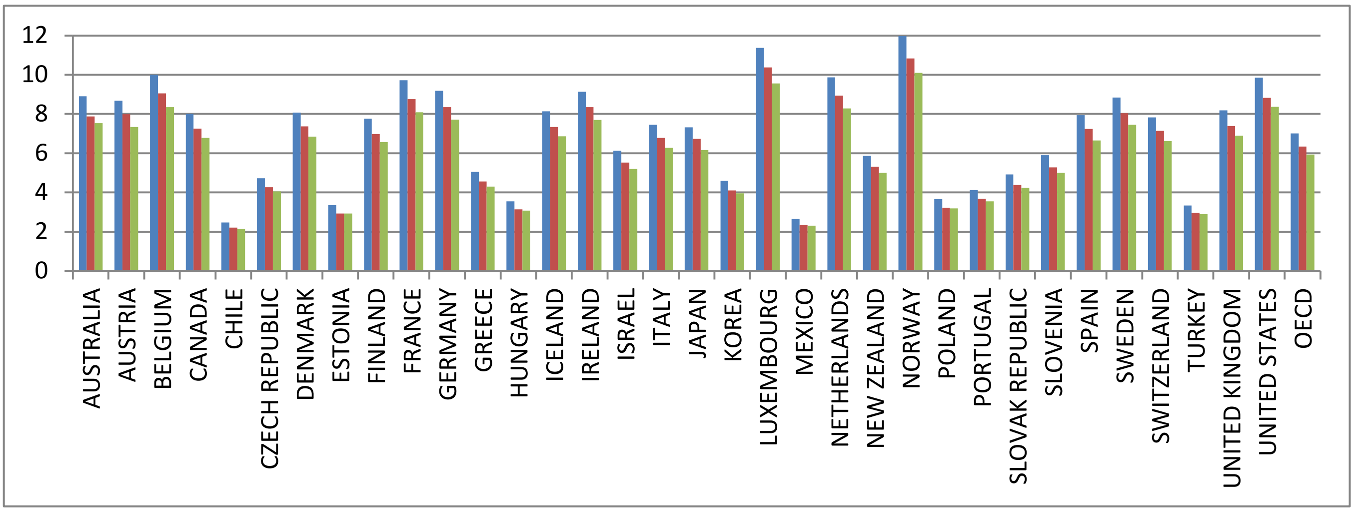

Figure 4-1: VPF values ($m)

The blue columns correspond to the method used in Skjong & Ronold (1998, 2002), referenced in MSC72/16, but with 2012 data. If it is assumed that loss of life corresponds to HALE/2 rather than e/2, the red column results. If, as advocated by Rackwitz (2002), a reference given in the FSA Guidelines (IMO, 2013) it is assumed that going to and from work is work and not enjoying life, the result is the green column (Loss of life is e/2 and it is assumed that for each 8 hours of work there will be 1 hour of travel). The resulting OECD averages are: $7.02, $6.34 and $5.94 million, respectively.

It may be worth noting that the high value for Norwegian GDP may be unrealistic in the LQI context because more than 10% is directly transferred to the 'Oil Fund' for investments abroad. These resources are not invested in Norway for safety, and not for any other purpose. This is to avoid overheating the economy, and for saving the oil fortune for future generations.

The description of the LQI approach also applies to the J-Value approach (Judgement-Value approach). Both methods for deriving a VPF rests on a prior trade-off between free-time and fraction and income, made at a societal level. In the J-Value case it is assumed that the percentage increase in life expectancy has the same value as a similar percentage increase in total expected free-time. In many ways it may be stated that the J-value approach confirms the LQI approach by linking it classical economic theory, like the Cobb-Douglas (1928) production function. In Thomas et al (2010) it is demonstrated that the exponent in the LQI is equal to both the modulus of the elasticity of expected future free-time with respect to income and the modulus of elasticity of life expectancy with respect to income. The formula derived is:

$$VPF = \Theta\ ge/2\ (1-w)/w$$

where Θ is the share of the wages in the GDP. In Thomas et al. (2010) it is estimated that Θ = 0.546. It may be noted that the LQI formula and the J-Value formula would be identical if Θ= 0.5.

The resulting VPF for OECD countries are provided in Figure 4-2. Blue columns are VPF corresponds to e/2 and red corresponding to VPF for HALE/2. The OECD averages are $7.66 million and $6.92million, respectively (2012 US$)

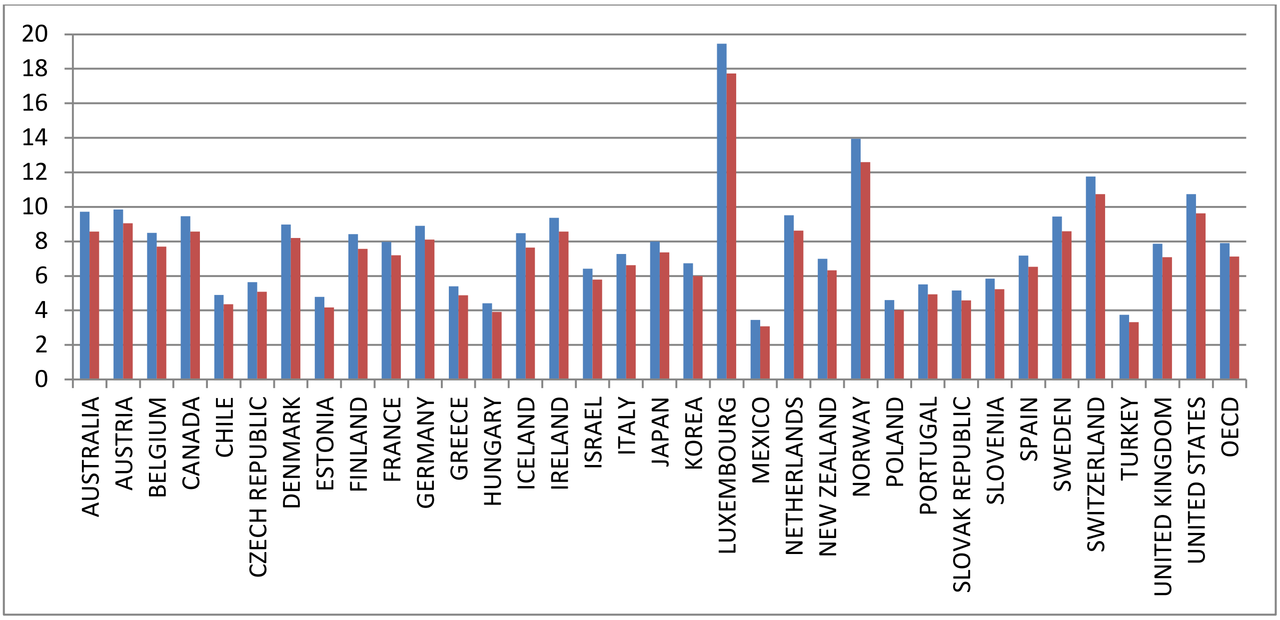

Figure 4-2: **VPF values ($m) by J-value criteria.**

Some limitation on application

There are cases where VPF criterion cannot be used directly. For example when it involves risk transfer from one group of people to another. For shipping, it is well known that VPF values are used in various impact assessments to calculate the social costs of NOx, SOx, PM etc. from shipping. Here the affected population is largely onshore. Although the total societal cost for switching to LNG as fuel is very favourable for LNG, the increased risks to seafarers are not immediately acceptable. This is reflected in the IGF code, which states that LNG should be as safe as conventional fuel (for the crew and passengers on-board).

C.5. VPF/VSL SETTING IN VARIOUS COUNTRIES AND ORGANISATIONS

US

In the US, under Executive Order 12866, Regulatory Planning and Review (EOP 1993, as amended by Executive Orders 13258 (2002) and 13422 (2007)), Federal agencies are required to assess the costs, benefits, and other impacts of major regulations. These analyses are required for regulations that are economically significant; i.e., that have a predicted annual impact on the economy of $100 million or more or other significant effects. Since benefits of safety and regulations relates to reduced risk of fatalities, injuries and ill health these Executive order lead to a need to derive criteria for Value of Statistical Life (VSL)/ VPF, or Value Of Life Year (VOLY).

Robinson and Robinson (2008) gives a good overview of the basis for recommending Values of Statistical Lives in monetary terms (VPF), which in principle is the same as in the IMO FSA Guidelines is referred to as Cost of Averting a Fatality criterion (CAF, or Net and Gross Cost of Averting a Fatality, NCAF, GCAF). The paper states that: 'The U.S. Office of Management and Budget (OMB) is responsible for reviewing economically significant regulations and developing guidance for the supporting analyses. Its most recent guidance, published in 2003, suggests that the VPF ranges from roughly $1 million to $10 million based on available research'.

Robinson and Robinson (2008) refer to studies providing estimates that reflect newer data and improved analytic models.

Dr. Joseph E. Aldy and Dr. W. Kip Viscusi conducted a series of studies that examine the wage or salary premium received by workers who accept riskier jobs, using statistical methods to separate the effects of other factors (such as education and nonfatal job risks) on wages. The most recent reference to this work in Robinson and Robinson(2008) was Viscusi(2004) suggesting that the mean VPF in the U.S. is approximately $6.87 million (when inflated to 2013 dollars).

According to Robinson & Robinson (2008) EPA's original approach to VPF criterion was based on research conducted by Viscusi (1992, 1993), from which it identified 26 VPF estimates suitable for use in its analyses. These estimates were derived from data collected largely in the late 1960s through early 1980s. The meta-analysis contained 26 estimates. The mean VPF estimates ranged from $0.6 million to $13.5 million in each study, with an overall mean of $4.8 million across studies (1990 dollars). This corresponds to US$ $_{2013}$ 8.58 million.

One of the studies involved Japanese manufacturing workers (Kneisner and Leeth ;1991) and corresponds to a VPF criterion of USD $_{2013}$ 13.58 million. Kneisner and Leeth (1991) also related to Australian workers and correspond to a criterion of USD $_{2013}$ 5.9 million. Another of the referenced studies related to Canadian workers (Cousineau, Lecroix, and Girard;1992) and corresponds to a VPF criterion of USD $_{2013}$ 6.43 million. Miller and Guria (1991) related to Zew Zeeland residents and correspond to a criterion of USD $_{2013}$ 2.14 million.

Robinson & Robinson (2008) also refer to researchers that had completed several meta-analyses that use statistical methods to combine data from various studies, including analyses by Mrozek and Taylor (2002), Viscusi and Aldy (2003), and Kochi et al. (2006). Each group of researchers uses a somewhat different approach and reports different ranges of estimates. Mrozek and Taylor report a best estimate of $2.15 million to $3.585 million (Converted to 2013 dollars); Viscusi and Aldy report means ranging from $7.46 million to $10.31 million (2013 dollars); and Kochi et al. (2006) report a mean of $7.32 million (2013 dollars) with a standard deviation of $3.25 million. Only the Kochi et al. analysis includes stated preference research; the other two studies rely on data from wage-risk studies. These meta-analyses are discussed in great detail in Chapter 3 of Robinson & Robinson (2008).

US FDA generally relies on a VSL estimate of $5 million (without specifying a dollar year). Since this is based on meta-analysis from about 2004, this may represent about USD $_{2013}$ 6.18 million.

The US Occupational Safety and Health Administration (OSHA), in assessing a rule that addressed lung cancer and other risks from exposure to hexavalent chromium (OSHA, 2006), OSHA adopted an approach similar to EPA's. OSHA used a base VSL of $6.9 million (2003 dollars) then adjusted it for latency and for changes in real income over time, and added the value of averted medical costs. US$$_{2003}$6.9 million corresponds to US$ $_{2013}$ 8.76 million.
The 2013 VSL used by US Ministry is clearly stated here:

http://www.dot.gov/regulations/economic-values-used-in-analysis

The value is US$$_{2012}$ 9.1 million, which corresponds to US$$_{2013}$ of 9.21 million. A sensitivity should be carried out using the values US$$_{2012}$ 5.9 million, which corresponds to US$$_{2013}$ of 6.0 million and US$$_{2012}$ 12.9 million, which corresponds to US$$_{2013}$ of 13.12 million. It is also stated that this value is expected to increase by 1.07% annually.

The EPA recommended VSL is also stated explicitly here:

http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/MortalityRiskValuation.html

EPA recommends that the central estimate of $7.4 million ($2006), updated to the year of the analysis (US$$_{2013}$ 8.57 million), be used in all benefits analyses that seek to quantify mortality risk reduction benefits regardless of the age, income, or other population characteristics of the affected population until revised guidance becomes available. This approach was vetted and endorsed by the Agency when the 2000 Guidelines for Preparing Economic Analyses were drafted.

The US Department of transport VSL recommendations are based on the mean value of 5 studies Table 5-1. The VSL estimates are at $5.8 million, with sensitivity analyses using estimates of $3.2 million and $8.4 million (2007 dollars). This is corresponding to $6.53, $3.6, $9.46 million (2013)

Table 5-1 DOT used Studies

Authors	2007 US$ million	2013 US$ million
Mrozek and Taylor (2002)	2.6	2.93
Miller (2000)	5.2	5.86
Viscusi (2004)	6.1	6.87
Kochi et al. (2006)	6.6	7.43
Viscusi and Aldy (2003)	8.5	9.57

Some previously published VSL/VPF numbers are provided in Table 5-2.

Table 5-2 Summary US Regulators

Agency	Regulation	Mean, Range, US$ year	US$ 2013
EPA, Office of Air and Radiation	National Ambient Air Quality Standards for Particle Pollution (EPA 2006)	$5.5 million ($1.0 million – $10 million, 1999 dollars)	$7.71 million
EPA, Office of Ground Water and Drinking Water	Stage 2 Disinfectants and Disinfection Byproducts Rule (EPA 2005)	$7.8 million ($1.2 million – $17.9 million, 2003 dollars)	$9.9 million
HHS, Food and Drug Administration	Performance Standard for Diagnostic X-Ray Systems (FDA 2005)	$5 million (none, no dollar year reported – Assume 2005)	$5.98 million
DOT, National Highway Traffic Safety Administration	Electronic Stability Control Systems (NHTSA 2007)	$3 million ($1.0 million – $10 million,2005 dollars)	$3.59 million
DOL, Occupational Safety and Health Administration	Occupational Exposure to Hexavalent Chromium (OSHA 2006)	$6.9 million (none, 2003 dollars)	$8.76 million
DHS, Customs and Border Protection	Western Hemisphere Travel Initiative Rule For International Land Travelers (IEc, 2007)	$3 million, $6 million (2005 dollars)	$3.59, $7.18 million

Norway

In Norway, the first guide within this area was drafted under the direction of the Ministry of Finance in 1978, under the name of “Programme Analysis”. New technical reports were prepared in 1990s by the “Cost Calculation Committee”, whose work resulted in the NOU 1997: 27 Green Paper; Cost-Benefit Analysis, and the NOU 1998: 16 Green Paper; Guidance on Using Profitability Assessments in the Public Sector. The guide to cost-benefit analysis by the Ministry of Finance was published in 2000 on the basis of such reports. It is important that the framework is updated. The Ministry of Finance revised its guidelines on cost-benefit analysis in 2005. Key elements of such revision were modifications to the guidelines for determining the discount rate, presentation of more examples, as well as making the guide more pedagogic and user friendly.

In Norway a group of experts delivered a recommendation to the ministry of economics October 10th, 2012 (NOU (2012)). In the Terms of Reference for the expert group realised the need to update previous Guidelines. It is stated that ' *The cost-benefit analysis guide of the Ministry of Finance does not explicitly address the fact that analysis parameters may change over time, for example that the value of time and time savings may be assumed to increase in line with real wage growth in the economy. Correspondingly, the willingness to pay for environmental goods may change over time, whilst technological progress may change future costs. This type of considerations may have a major impact of the assessment of costs and benefits in long-term projects, like for example infrastructure investments within the transportation sector. The Expert Committee shall examine whether and, if applicable, how changes in parameter values over time may be included in the cost-benefit calculations*.' The recommended VPF value was NOK 30 Million (2012). This corresponds to $US\$_{2013}$ 4.94 million. It is also recommended that both VPF and VOLY is adjusted proportional to the change in GDP per capita. Higher values are generally debated in the health sector, typically about NOK 0.5 million per QALY gained, for example as described in Norwegian Knowledge Centre for the Health Services (2009). (About USD $\$_{2013}$ 80,000, or USD_{2013} 28 million for 35 QALY (=1 VPF)). Whilst such numbers and the QALY concept are used, there appear not to be any consensus on the criteria.

EU

In EC DG Environment (2001) the European Commission's VSL estimate of EUR 1.4 million at 2000 prices for accidents (where the average age at death is about 40 years), and a somewhat lower value of EUR 1 million at 2000 prices for a case of environmentally-related premature death (where the average age of fatalities is considerably higher).
The $€_{2000}$ 1.4 million, corresponds to $UD\$_{2013}$ 2.54 million.

A project funded by the European Commission, Directorate-General for Transport and Energy, reviews the use of cost-benefit analysis, as a specific method of analysis, in the evaluation of traffic safety measures (SafetyNet, 2009). The report compares the valuations of a statistical life in various countries, see Figure 5-1

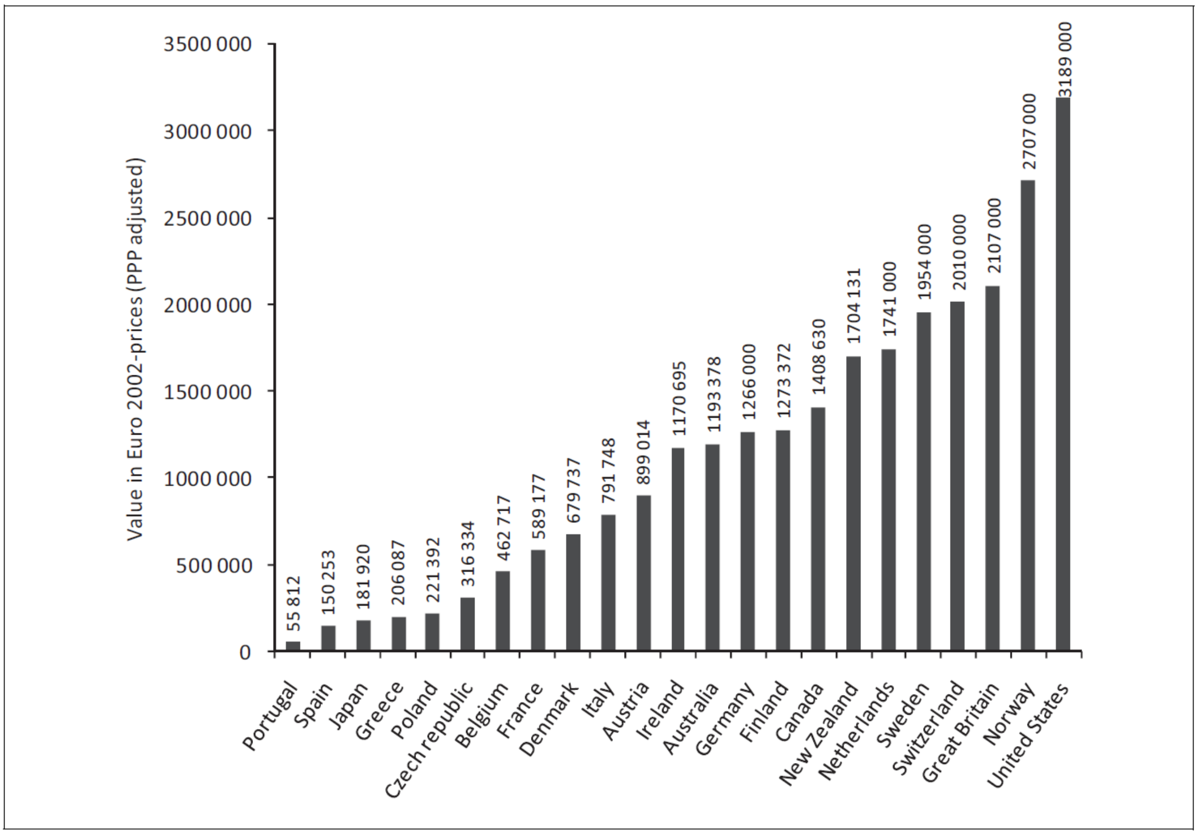

Figure 5-1: Estimates for the value of a statistical life in the traffic sector in selected countries. Unit: Euros at 2002 prices (Purchasing Power Parity-adjusted). Source: SafetyNet (2009).

UK

The United Kingdom has a long tradition for stated preference surveys of VSL/VPF, and the WTP results from these studies have been used in the Cost-benefit Analysis guidelines for the transport sector since 1993 to establish VSL estimates in order to value both fatal and non-fatal accidents. The UK Department of Transport 2009 uses the midpoint from a range of GBP 750 000 to GBP 1 250 000 (1997-GBP) produced by the most recent UK stated preference study to establish a VSL/VPF mid-point value of GBP 1 million. They then update this to 2007-GBP, yielding a central VSL/VPF estimate of GBP 1 080 760. Then they add lost output/productivity loss of GBP 555 660 and medical and ambulance costs of GBP 970 to get the estimate currently used for the social benefits of preventing a fatality GBP 1 638 390. The GDP growth of UK since 2009 is about 3% resulting in GDP $_{2013}$ of 1, 688 million, or US$$_{2013}$ 2.760 million.

Table 5-3: Cost to society per case - average appraisal value estimates (£ in 2011 prices), from HSE (2012)

	Non-Financial Human Costs (rounded)	Financial Costs (rounded)	Total Costs (rounded)
Workplace fatal injuries*	1,112,000	464,000	1,576,000
Reportable injuries*	15,600	7,800	23,500
Non-reportable injuries*	340	350	700
Ill Health+	9,100	7,600	16,700

Table 5-4: Average value of prevention of road accidents by severity and element of cost (2010 values and prices), UK Ministry of transport (2014)

Accident severity	Cost Element						TOTAL
	Casualty related costs			Accident related costs			
	Lost output	Human costs	Medical & ambulance	Police cost	Damage to property	Insurance & admin	
Fatal	613,609	1,204,968	5,341	17,235	11,028	302	1,852,483
Serious	24,301	165,522	14,581	2,014	4,981	188	211,587
Slight	3,056	14,559	1,296	524	2,993	114	22,542
All injury	12,972	49,621	3,249	925	3,369	127	70,263
Damage only	-	-	-	34	1,890	54	1,978

Australia

Australia (2008) concludes as follows in their executive summary:

The literature review was undertaken in conjunction with the DEEWR library. The search protocol included all journal articles and reports in the period 2005 to June 2007 with 'value of a statistical life' in the title of the document, and an internet search. Seminal studies from earlier periods were also retrieved and reviewed, and stakeholders provided other relevant material.

VSL estimates were identified from 244 'western' studies (17 Australian and 227 international studies) between 1973 and June 2007, although these contained only 19 explicit VSLY estimates (nine Australian and ten international studies). Estimates were converted to 2006 Australian dollars and analysed by:

- *sector – health, occupational safety, transport, environment, 'other';*
- *country – Australia's VSL was 5th (lowest) of 14 economies included;*
- *broad methodology – stated preference, revealed preference, mixed, other/unknown;*

- *age of the study.*

Where needed, a discount rate of 3% was considered appropriate for healthy life years, which aligns generally with the literature and the current practice of the Australian Institute of Health and Welfare (AIHW).

Simple analysis of all these data (regardless of study quality) showed:

- *a mean VSL of $9.4 million for all countries and a median of $6.6 million;*
- *a mean VSL for Australia of $5.7 million and a median (taking into account a large number of implicit valuation estimates based on past policy decisions) of $2.9 million;*
- *a mean VSLY of A$433,437 and a median of A$119,589 (also influenced by the skew towards Australian estimates used in previous policy-making);*
- *revealed preference estimates were slightly lower than stated preference estimates; but*
- *lower estimates for older studies; and*
- *significant differences by sector in means/medians: health ($4.0/$3.7 million), transport ($7.9/$5.4 million), 'other' (consumer choice, crime and fire safety – $8.5/$6.0 million), environment ($11.2/$8.1 million) and occupational safety ($11.1/$7.4 million).*
- *A random effects meta-analysis was performed, using MIX software, of the higher quality studies (ie, studies from 1980 on that had either a midpoint and standard deviation or other minimum-maximum range, and were not outliers). This eliminated many of the implicit evaluation studies (which helps to remove the circularity effect of future policy being based on speculative past policy).*
- *The meta-analysis yielded an average VSL of $6.0 million in 2006 Australian dollars with a range of $5.0 million to $7.1 million based on exclusion sensitivity analysis.*
- *No publication bias was evident from the funnel plot and the meta-analysis was also robust in relation to exclusion sensitivity analysis.*
- *However, because of the greater variability shown across all the source studies, particularly across sectors, the suggested range for sensitivity analysis is based on the 'raw' study median values, which ranged from $3.7 million in the health sector to $8.1 million in the environment sector.*

Data constraints prevented analysis of some items of interest such as the average age of the study group (which it is expected may account for a great deal of variation in VSL estimates), the base level of risk/wellbeing and whether the individual's valuation is for their own or another's life. However, these factors were accounted for by using a random effects meta-analysis technique, which is designed to allow for other underlying variables.

Based on international and Australian research, Australia (2009) concludes that a credible estimate of the VSL is AUD 3.5 million. The GDP growth in Australia since 2009 is about 12.5% AUD_{2013} 3.544 million or $US\$_{2013}$ 3.13 million.

World Health Organization and QALY

The QALY concept is largely used in the Health Sector, as correctly referenced from the IMO FSA Guidelines. The World Health Organisation (WHO, 2012) proposes GDP per capita as a basis for grading the cost-effectiveness of health measures. Measures with a cost per QALY gained of less than GDP per capita are thus classified as "very cost effective". Measures with a cost per QALY gained of between one and three times GDP per capita are categorised as "cost effective", whilst measures with a cost per QALY gained of more than three times GDP per capita are categorised by the WHO (2012) as "not cost effective". The average OECD GDP is about USD$$_{2013}$ 40,000, implying that health interventions are consider cost effective up to USD$$_{2013}$ 120,000. If this is transferred to VSL by multiplying with e/2 (40 years), the VSL criterion is USD$$_{2013}$ 5.8 million. The factor of 3 GDP may be compared to the factor 3.5 derived based on LQI in Skjong and Ronold (2002).

OECD

OECD (2012) proposes a range for the average adult VSL for OECD countries of USD (2005-USD) 1.5 million – 4.5 million, with a base value of USD 3 million. For EU-27, the corresponding range is USD 1.8 million – 5.4 million (2005-USD), with a base value of USD 3.6 million. These base values and ranges should be updated as new VSL primary studies are conducted. It is recommended to update the VSL by the GDP per capita. The GDP growth in OECD since 2005 is totally 10%, resulting in US$$_{2013}$ 3.3 million and US$$_{2013}$ 3.96 for OECD and EU respectively.

Selected Research Papers

Miller (2000) provides a review of many research publications, sorted by countries on VSL values. The main results are provided in Table 5-5. The last two columns has been updated to US$$_{2013}$ based on US$ inflation, and the GDP per capita growth in the respective counties.

Table 5-5 Value of Statistical Lives – Research publications

COUNTRY				1000 US$	Corrected
Authors	Method	Range	Chosen	Inflated	GDP/capita
AUSTRALIA		US$ 1995 million	US$ 1995 thousand	US$ 2013 thousand	US$ 2013 thousand
Kneisner & Leeth(1991)	Wage-Risk	2.671-2.796	2 781	4255	3972
AUSTRIA					
Weiss et al. (1986)	Wage-Risk	4.494	4494	6876	6196
Maier et al, (1991)	Contingent Value	3.207-4.031	3451	5280	4758
CANADA					
Cousineau(1992)	Wage-Risk	4.014-4.146	4014	6141	5733
Marinello & Meng (1992)	Wage-Risk	6.063	6063	9276	8659
Meng (1989)	Wage-Risk	3.482-4.145	3563	5451	5089
Meng & Smith (1990)	Wage-Risk	1.043-8.995	5669	8674	8097
Vodden et al.(1993)	Wage-Risk	1.083-4.624	3495	5347	4992
DENMARK					
Kidholm (1995)	Contingent Value	2.461-18.945	3764	5759	4834
FRANCE					
Desaigiues & Rabi (1995)	Contingent Value	0.689-21.562	3435	5256	4258
JAPAN					
Kneisner & Leeth(1991)	Wage-Risk	0-10.829	10829	16568	12278
NEW ZEELAND					
Miller & Guria (1991)	Wage-Risk	1.082-1.663	1371	2098	1890
Miller & Guria (1991)	Behaviour	1.403	1403	2147	1934
Guria et.al. (1999)	Contingent Value	1.800-2.400	2100	3213	2895
SOUTH KOREA					
Kim (1985)	Wage-Risk	0.872-1.745	872	1334	1797
Kim & Fishback (1999)	Wage-Risk	0.678	678	1037	1397
SWEDEN					
Johanneson et al (1997)	Contingent Value	3.474-6.904	3764	5759	5569
Persson & Cedervall (1991)	Contingent Value	1.300-2.200	2030	3106	3003
Persson et al.(1995)	Contingent Value	4.300-4.910	4605	7046	6813
Søderquist (1994)	Contingent Value	0.288-2.670	1107	1694	1638
SWITSERLAND					
Schwab-Christie (1995)	Contingent Value	7.525-16.205	7525	11513	8842
TAIWAN					
Hsush & Wang (1987)	Wage-Risk	1.157-1.874	1515	2318	2579
UK					
Ghosh et al. (1975)	Behaviour	1.704	1704	2607	2611
Jones-Lee et al (1983)	Contingent Value	3.355-6.128	3568	5459	5468
Jones-Lee et al (1995)	Contingent Value	2.172-3.413	2691	4117	4124
Maclean (1985)	Contingent Value	1.924-3.114	2446	3742	3748
Marin & Psacharopoulos(1982)	Wage-Risk	3.728-4.251	2497	3820	3827
Melinek (1974)	Wage-Risk	1.457	1457	2229	2233
Melinek (1974)	Behaviour	1.608	1608	2460	2464
Average of All				4986	4541

Miller (2000) also concluded that the elasticity estimates in the country and individual-study models are extremely close, varying from 0.92 to 1.00 in the country-level regressions, and from 0.85 to 0.96 in the individual-study regressions.

Andersson and Treich (2008) give another overview in Table 5-6.

Table 5-6 Empirical estimates of the value of a statistical life in road traffic, in US$2005 (*1000)a

Table 1: Empirical estimates of the value of a statistical life in road traffic, in US$ 2005 (× 1000)a						
Year of da			Range of VSL estimates			
Authors	Country	Study type	estimates b	Single	Lowest	Highest
Andersson (2005a)	Sweden	1998, RP	1	1,425		
Andersson (2007)	Sweden	1998, SP	8		3,017	15,297
Atkinson and Halvorsen (1990)	US	1986, RP	1	5,521		
Beattie et al. (1998)	UK	1996, SP	4		1,51	17,06
Bhattacharya et al. (2007)	India	2005, SP	1	150		
Blomquist (1979)	US	1972, RP	1	1,832		
Blomquist et al. (1996)	US	1991, RP	4		1,434	7,17
Carthy et al. (1999)	UK	1997, SP	4		4,528	5,893
Corso et al. (2001)	US	1999, SP	2		3,517	4,69
Desaigues and Rabl (1995)	France	1994, SP	6		1,031	23,984
Dreyfus and Viscusi (1995)	US	1987, RP	1	4,935		
Ghosh et al. (1975)	UK	1973, RP	1	1,901		
Hakes and Viscusi (2007)	US	1998, SP	5		2,396	6,404
	US	1998, RP	6		2,288	10,016
Hojman et al. (2005)	Chile	2005, SP	1	541		
Hultkrantz et al. (2006)	Sweden	2004, SP	2		2,192	5,781
Iragu¨en and Ortu´zar (2004)	Chile	2002, SP	1	261		
Jara-Diaz et al. (2000)	Chile	1999, SP	1	4,555		
Jenkins et al. (2001)	US	1997, RP	9		1,35	4,867
Johannesson et al. (1996)	Sweden	1995, SP	4		5,798	6,981
Jones-Lee et al. (1985)	UK	1982, SP	1	4,981		
Kidholm (1995)	Denmark	1993, SP	3		898	1,338
Lanoie et al. (1995)	Canada	1986, SP	2		1,989	3,558
Maier et al. (1989)	Australia	1989, SP	6		1,853	5,114
McDaniels (1992)	US	1986, SP	3		10,131	36,418
Melinek (1974)	UK	1974c , RP	1	881		
Persson et al. (2001)	Sweden	1998, SP	1	2,551		
Rizzi and Ortu´zar (2003)	Chile	2000, SP	1	486		
Schwab Christe (1995)	Switzerland	1993, SP	1	1,094		
Vassanadumrongdee and Matsuoka (2005)	Thailand	2003, SP	2		3,208	5,458
Viscusi et al. (1990)	US	1991, SP	1	11,091		
Winston and Mannering (1984)	US	1980, RP	1	2,315		
VSL estimates in US$ 2005. Values transformed using purchasing pow er parities (PPP) and consumer price indices (CPI)						
from http://stats.oecd.org, 09/02/07. (For Chile and Thailand PPP and CPI from http://w w w .imf.org/external/data.htm w ere used.)						
a : Many of the VSL estimates are from de Blaeij et al. (2003).						
b : Several studies contain more estimates than stated here. When available, "preferred" values have been used.						
Refers to year of study rather than data, since the latter not available.						

Yet another meta-study by Abelson (2010) provides the following summary shown in Table 5-7. The Value Of Statistical Life (VOSL) is used for VSL/VPF.

Table 5-7 Summary table VOSL

Report	Year	Original studies	Estimated VOSL (US $s)
Kneisner and Leith	1991	Wage risk study, Australia	About $2.2m in 2000 prices
Viscusi	1993	24 wage-risk studies, 4 CV studies[a]	Most estimates in $3m-$7m range Range 1.2m-$9.7m
Jones-Lee	1994	13 wage-risk studies, 7 other revealed preference studies, 8 CV studies	$1.9m-2.2m are the median and mean for most reliable results
Jones-Lee et al	1995	CV study in UK	$2.7m
Schwab-Christe	1995	CV study in Switzerland	$7.5m
Desaigues and Rabl	1995	CV study in France	$3.4m
Van den Burgh et al.	1997	10 US and 1 UK wage-risk studies	$3.9m 'most reliable estimate'
Johannesson et al.	1997	CV study in Sweden	$3.8m in 1995 prices
Desvouges et al.	1998	28 wage-risk studies and 1 CV study, US	VOSL of $3.6m, with confidence interval of $0.4m-$6.8m
Day	1999	16 wage-risk studies, 10 US, 2 Canada, 4 UK	$5.6m is best estimate
Guria et al.	1999	CV study in New Zealand	$2.1m
Krupnick et al	2000	CV study in Canada	$0.5m - $2.0m
Mrozek and Taylor	2001	40 wage-risk studies	Approximately $2.0m

It was explained above that the World Bank used to advocate the use of the Human Capital Approach to derive VSL/VPF. This is no longer the case. Wang (2009) published a study on the VSL/VPF in China based on the contingent valuation method internally in the World Bank. VSL/VPFs were calculated based upon the WTP information and the cancer morbidity and mortality data. Instead of asking people to evaluate the abstract probability reduction, as done in conventional risk valuation studies, which is usually difficult for the respondents to understand, this study elicits people's willingness to pay for a cancer vaccine that can be easily understood and is similar to a market transaction. The average value of the lower bound VSL/VPF was ¥0.89 million (2000). This would correspond to about ¥ 5.1 million if corrected for GDP growth. This correspond to about $0.85 million (2013), which again is close to half of the resulting LQI value ($1.9 million)

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APPENDIX D
Updated FN Criteria

Table of contents

D.1 INTRODUCTION

This appendix updates the FN criteria for passenger ships that were derived for the current maritime approach (Norway 2000).

Section D.2 explains the methodology, Section D.3 provides the data used in the original implementation, and Section D.4 provides the update.

D.2 METHODOLOGY

The FN criteria are based on two key principles:

- The acceptable risk should reflect the economic value of the vessel being evaluated. Larger economic contributions, which typically arise from larger vessels, are allowed to impose greater societal risks.
- The frequency of large accidents should be inversely related to the number of fatalities involved.

The method used to set the criteria is as follows.

An appropriate generic benchmark (q) for fatality risk is the number of fatalities per unit contribution to Gross National Product (GNP). The contribution to GNP is a standard measure of economic value. In the case of a ship, it may be estimated as the revenue it generates.

Suitable benchmarks are obtained from historical data in other industries. Passenger ship accidents are not used because the potential for occasional large accidents makes it difficult to obtain a long-term average risk. FN curves are also not used directly, because the other industries are not comparable to ships in terms of multiple-fatality potential or economic value. Therefore the chosen benchmark is the expected annual fatality rate divided by the annual contribution to GNP.

In the original study (DNV 1999), two benchmarks were distinguished:

- Occupational fatalities per unit GNP
- Passenger fatalities per unit transport contribution to GNP

The two benchmarks gave similar results. In the update, only the second one is used.

The generic benchmark is converted to a specific benchmark for an individual vessel by multiplying by the revenue generated by the vessel (R). This gives a benchmark for the annual fatality rate on the ship, which is also known as the potential loss of life (PLL). This is considered an acceptable average for all vessels of this type:

$$PLL_A = q\ R$$

Because revenue data is rarely available and subject to market fluctuations, it is preferable to define an average revenue per passenger (t), so that the benchmark can be obtained from the number of passengers (N_p):

$$PLL_A = q\ t\ N_p$$

This is then converted into a benchmark FN criterion, consisting of the acceptable frequency (F) per ship year of accident exceeding N fatalities:

$$F(N) = F_A\ N^{-b}$$

The FN criterion slope (b) is assumed to be 1. The maximum number of people on board is equal to the total number of passengers and crew (N_T). If the FN curve follows the criterion line up to the maximum value, the intercept with the N=1 axis is expressed as:

$$F_A = k\ PLL_A$$

The constant k can be shown to be (Norway 2000):

$$k = \frac{1}{\sum_{N=1}^{N_T} \frac{1}{N}}$$

This can be approximated analytically as:

$$k = \frac{1}{0.577 + ln(N_T + 1)}$$

The resulting variation with number of people (N_T) is small compared to the uncertainty in deriving the criteria, so the number of passengers (N_p) can also be used, or a k value can be chosen.

The final step is introducing an ALARP region two orders-of-magnitude wide, centred on the above benchmark. This results in two criteria:

- Upper criterion (intolerable risk) $F(N) > 10\ F_A\ N^{-1}$
- Lower criterion (negligible risk) $F(N) < 0.1\ F_A\ N^{-1}$

D.3 ORIGINAL IMPLEMENTATION

The following presents the data and results from the original implementation of the above method, reported by Norway (2000). Calculations were made for RoPax ships, distinguishing crew and passengers. The basis currency for economic value was 1990 £, which was converted at the rate £1=$1.67=NOK11.8.

D.3.1 Occupational Risk for Crew

The generic benchmark for occupational fatality risk per unit GNP contribution (q) was 1.5 fatalities per £billion (Norway 2000), equivalent to 0.9 fatalities per $billion. This was based on the number of work-related fatalities compared to the total GNP in Norway and the USA during 1992-97 (DNV 1999). It was an average fatality rate across all sectors of the economy.

Revenue data was gathered for 7 Norwegian RoPax ships during 1995-96. The average total operating revenue was NOK317m per ship year (derived from DNV 1999), which was then equivalent to $45m, and later rounded to $50m (Norway 2000).

The constant k was not stated in the calculations, but it appears to have been based on the number of crew, which averaged 132 in the 7 ships. This results in k = 0.18.

The benchmark intercept with the N=1 axis was then:

$$F_A = k\ q\ R = 0.18 \times 0.9 \times 45/1000 = 7.3 \times 10^{-3} \text{ per ship year}$$

This was rounded to 10^{-2} per ship year, which resulted in the same criteria as previously recommended by DNV Technica (1996).

D.3.2 Transport Risk for Passengers

The generic benchmark for passenger fatality risk per unit GNP contribution (q, but denoted r is the original study) was 8.6 fatalities per £billion (Norway 2000), equivalent to 5.1 fatalities per $billion. This was based on the number of fatalities in aircraft accidents compared to the total passenger operating revenue world-wide during 1990-94 (ICAO 1995). Aviation was used as a benchmark because of its high safety standards and open reporting.

Ticket revenue data (i.e. excluding on-board sales) was gathered for 7 Norwegian RoPax ships during 1995-96. The average was NOK98m per ship year (derived from DNV 1999), which was then equivalent to $14m. Since the number of passengers averaged 1700 in the 7 ships, this is equivalent to $8200 per passenger year. This is consistent with the ticket revenue of $16m that was quoted for a representative 1900 passenger vessel (Norway 2000).

The constant k was not stated in the calculations, but it appears to have been based on the number of passengers, which averaged 1700. This results in k = 0.125.

The benchmark intercept with the N=1 axis was then:

$$F_A = k\ q\ R = 0.125 \times 5.1 \times 14/1000 = 8.9 \times 10^{-3} \text{ per ship year}$$

This was consistent with the rounded value for crew of 10^{-2} per ship year.

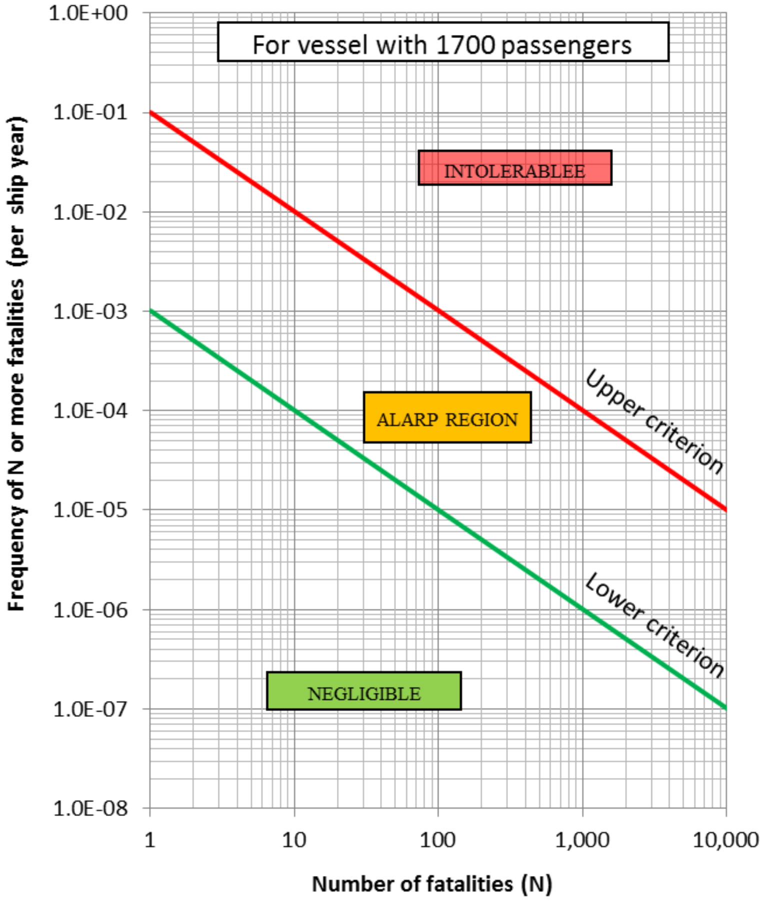
D.3.3 Original Criteria

The combined criteria from the original implementation, for a typical RoPax ship with 1700 passengers (although the same criteria would apply to any ship with the same number of passengers), were:

- Upper criterion (intolerable risk) $F(N) > 0.1\ N^{-1}$
- Lower criterion (negligible risk) $F(N) < 10^{-3}\ N^{-1}$

They are shown in Figure D.3.1.

Figure D.3.1 FN Criteria for 1700-Passenger Vessel (Original Implementation)



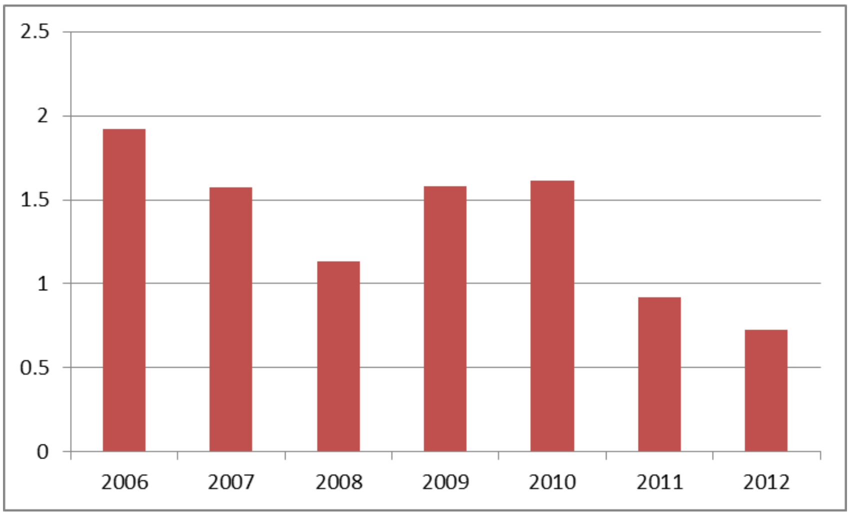
D.4 UPDATED IMPLEMENTATION

The following presents the data and results from the update of the above method. Calculations were made for RoPax ships, following the second of the two approaches used in the previous study. The basis currency for economic value is 2012 $.

D.4.1 Transport Risk for Passengers

The generic benchmark for passenger fatality risk per unit GNP contribution (q) is now 0.73 fatalities per $billion. This is based on the 414 fatalities in aircraft accidents world-wide in 2012 compared to the total airline revenue of $638bn (IATA 2013). Based on data from previous years, revenue is reduced by 12% to eliminate the contribution from freight. The substantial reduction from the original value is due to the reduced fatality risk and greatly increased airline revenue. Figure D.4.1 shows the trend during 2006-2012. The current value is uncertain because of the fluctuating number of fatalities, which was much lower in 2013 but much higher in 2014. Hence 2012 is considered a representative year.

Figure D.4.1 Airline Fatalities per $billion Revenue (based on IATA data)



Ticket revenue (i.e. excluding on-board sales) on RoPax ships is now estimated to be $0.05 million per passenger-year. This is based on annual reports from RoPax operators in the Baltic, North Sea, the English Channel and the Mediterranean. On a representative ship with 1000 passengers, it is $50m per ship year.

The constant k is now calculated for a representative ship with 1000 passengers. This results in k = 0.13. Although it might be more logical to calculate q from the total number of people on board, this would not significantly affect the result.

The benchmark intercept with the N=1 axis is therefore:

$$F_A = k\ q\ t\ N_p = 0.13 \times 0.73 \times 0.05/1000 \times 1000 = 4.7 \times 10^{-3} \text{ per ship year}$$

This is rounded to 5×10^{-3} per ship year. It is a factor of 2 lower than the previous value, but this is partly because it refers to a smaller passenger load. The stricter benchmark for fatality risk per unit revenue has been largely cancelled out by lower revenue per passenger.

D.4.2 Updated Criteria

The updated criteria for a representative ship with 1000 passengers are therefore:

- Upper criterion (intolerable risk) $F(N) > 5 \times 10^{-2} N^{-1}$
- Lower criterion (negligible risk) $F(N) < 5 \times 10^{-4} N^{-1}$

They are shown in Figure D.4.2.

Figure D.4.2 FN Criteria for 1000-Passenger Vessel (Updated Implementation)

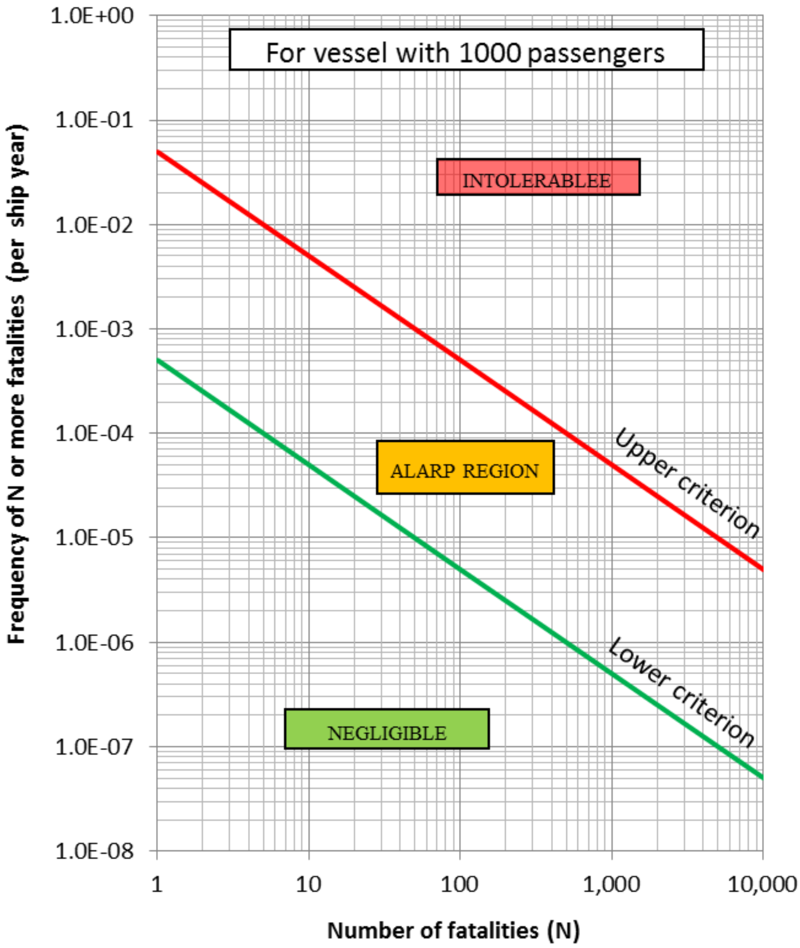


Table D.4.1 shows equivalents for other sizes of ship.

Table D.4.1 FN Criteria for Various Ships

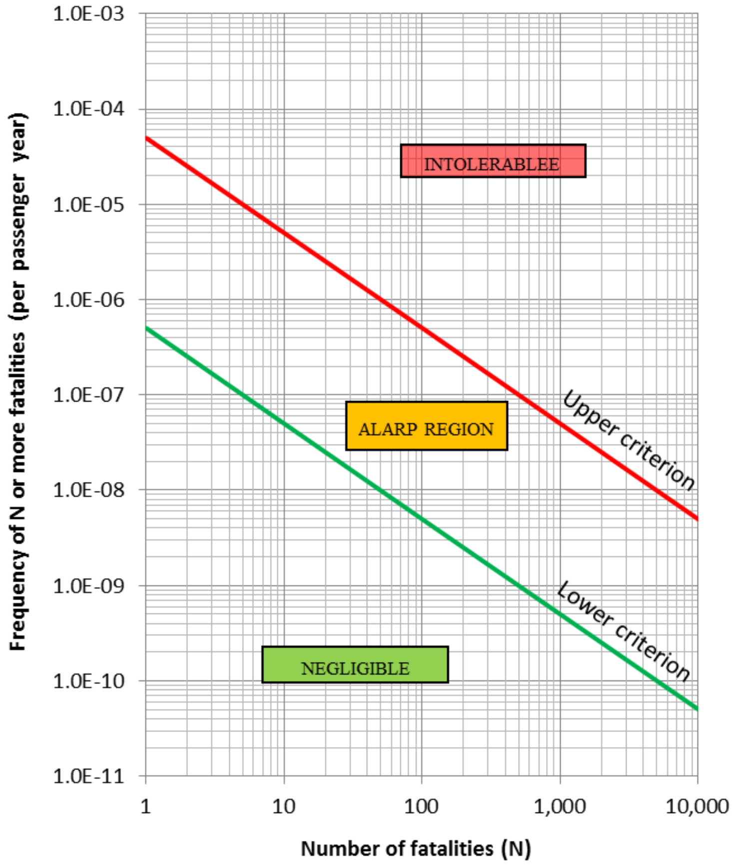
SHIP TYPE	PASSENGERS	k	INTOLERABLE CRITERION	NEGLIGIBLE CRITERION
Small cruise	270	0.16	$1.6 \times 10^{-2} N^{-1}$	$1.6 \times 10^{-4} N^{-1}$
Medium cruise	2700	0.12	$1.2 \times 10^{-1} N^{-1}$	$1.2 \times 10^{-3} N^{-1}$
Large cruise	4622	0.11	$1.8 \times 10^{-1} N^{-1}$	$1.8 \times 10^{-3} N^{-1}$
Small RoPax	282	0.16	$1.6 \times 10^{-2} N^{-1}$	$1.6 \times 10^{-4} N^{-1}$
Medium RoPax	1318	0.13	$6.3 \times 10^{-2} N^{-1}$	$6.3 \times 10^{-4} N^{-1}$
Large RoPax	1875	0.12	$8.2 \times 10^{-2} N^{-1}$	$8.2 \times 10^{-4} N^{-1}$

The variation of k is relatively small, but the variation in the criteria is significant, which may result in misleading results if the criteria are applied to vessels much smaller or larger than the representative vessel. Therefore, it may be preferable to express the criteria as a function of the number of passengers, as follows:

- Upper criterion (intolerable risk) $F(N) > 5 \times 10^{-5} N_P N^{-1}$
- Lower criterion (negligible risk) $F(N) < 5 \times 10^{-7} N_P N^{-1}$

They are shown in Figure D.4.3. The frequency is normalised by the number of passengers because this is the most convenient indicator of the economic value of a passenger vessel. In general, the full passenger capacity should be used for this, and assumed to be on-board all year. Nevertheless, in calculating the FN curve, all passenger and crew fatalities should be included.

Figure D.4.3 Generic FN Criteria (Updated Implementation)



D.4.3 Application

These criteria are intended to be used as guidelines, not as rigid decision-making tools. The decision whether risk control options are necessary to make the risk acceptable should also be influenced by the criterion for value of preventing fatalities (VPF). However, if the FN curve for an individual ship is in the intolerable region, this suggests that cost-effective risk control options may exist, and highlights the fatality range (and associated accident scenarios) on which risk reduction should be focussed.

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