Decisions based on risk analysis require some form of risk acceptance criteria. Presently the International Maritime Organisation (IMO)\(^1\) has initiated an activity on developing a risk-based approach to safety and environmental protection regulations. Explicit risk estimates are new to the IMO. At present, a number of FSA Trial Applications are presented, giving increased general knowledge of the risk level in the industry. The debate about risk acceptance has therefore just started.

The objective of this paper is to outline an approach by which societal risk acceptance criteria may be established. The idea is to make it possible to discriminate between ship types representing different risks and importance to society. The societal risk acceptance criteria are calibrated against occupational fatality rates, and transportation fatality rate for scheduled air traffic worldwide. Examples are given for some different ship types. It should be noted that many other criteria would be needed in the decision process, like e.g. individual risks, criteria based on cost effectiveness, and criteria for environmental consequences. Normally a decision would have to be based on acceptance by all these criteria. Only one specific method to arrive at societal risk criteria is dealt with herein.

1 INTRODUCTION

The IMO approach to risk based regulations is referred to as Formal Safety Assessment (FSA). The IMO Guidelines [1] describes FSA as a 5-step procedure. These steps are described in Table 1, and follows standards for quantitative risk assessment terminology closely. However, the analysis is not an analysis of a specific object in a specific environment (e.g. a ship in a specific trade), but a ‘generic ship’. In practice a ‘generic ship’ is one of those ship types or other concepts used to describe and limit the scope of a specific regulation. As seen below, this ‘generic ship’ concept is important for the risk acceptance debate, as it is less likely that a ‘generic’ or ‘representative’ ship represent intolerable risks, as only population averages are considered. This utilisation of risk assessment is not as unusual as it may seem, as ship specific risk assessment is required for the operational phase of each ship by the International Safety Management (ISM) Code, another mandatory IMO instrument.

In general, societal risk acceptance criteria, and the societies’ risk aversion against large or catastrophic accidents are lacking an explicit rationale. Some people would count the risk aversion against large accidents as one of the ‘risk conversion factors’ representing the bias ‘perceived risk’ as compared to ’actual risk’. For example Litai [2] is listing the following factors affecting this bias: Volition, Severity, Origin, Effect Manifestation, Exposure Pattern, Controllability, Familiarity, Benefit and Necessity. Although the rationality may be debated, criteria explicitly including severity are used by a large and increasing number of regulators. The problems of inconsistency are, however, quite frequently seen and debated. For example, a published FN diagram (Frequency of N or more fatalities, see figure 1) for Bulk Carriers [3,4] and an FN diagram for Passenger Ro/Ro ships [5] differ by one order of magnitude, the Bulk Carrier Criterion being the stricter for small N. This seems intuitively peculiar, since the

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\(^1\) IMO is the UN organisation for safety and environmental protection regulations
passenger Ro/Ro ships carry a large number of passengers. The approach suggested herein may explain such different criteria.

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This paper presents a method for establishing FN risk acceptance curves. The idea is that an FN acceptance criterion should reflect the importance of the shipping activity in question. The importance to society is measured by the economic activity represented by the different ship types. This may vary by orders of magnitude. The examples given for some ship types show that when the importance to the society is accounted for, the established FN acceptance curves vary within 1 to 2 orders of magnitude. The outlined method may be considered for any type of activity above a certain size. An obvious limitation for such the method is represented by activities of high economic value with low labour intensity in remote places, e.g. exploitation of offshore oil and gas resources.

2 METHODOLOGY

The objective of the outlined method is to establish transparent FN risk acceptance criteria with a rational foundation, which may be established from factual and available information. It is not suggested that this should be the only consideration in an actual decision on risk acceptance, as decisions on acceptance criteria or acceptance in a concrete decision on implementing a risk control option is a value judgement that should be made in the responsible organisation. In this respect the suggested method may be one of many input in the decision making process.

It is suggested to associate the acceptance criteria to the economic importance of the activity in question, and calibrating the criteria against the average fatality rate per unit economic production. The importance of an activity is measured most adequately in economic terms, assuming that what is paid in an open market represents the importance. Similarly, Gross National Product (GNP) is an aggregated indicator of the economic activity.

For occupational accidents the aggregated indicator, \( q \), is defined as the average fatality rate per GNP. For transport related accidents a similar aggregated indicator \( r \) is defined.

\[
q = \frac{\text{Number of occupational fatalities}}{\text{GNP}} \quad \text{to establish risk acceptance criteria for crew}
\]

\[
r = \frac{\text{Number of fatalities due to transportation}}{\text{Contribution to GNP from transportation}} \quad \text{to establish risk acceptance criteria for passengers}
\]

For a specific activity (e.g. a ship operation), an average acceptable Potential Loss of Life (\( PLL_a \)) may be based on the economic value (\( EV \)) of the activity.
\[ PLL_A = q \cdot EV \] for crew/workers or \[ PLL_A = r \cdot EV \] for passengers. (1)

This states that largely the distribution of the total occupational risk should be distributed between the different activities accounting for their contribution to GNP, and that large deviations from this should be judged an indication of good reasons for concern. A similar criterion should be established for a transport activity. For activities and trades, which are of less importance for the society, the society may not accept a high accidental fatality risk. For activities and trades of minor significance, and with minor contribution to the service production, only minor risks should be accepted. As the ultimate solution the fatality risk may be eliminated, by eliminating the activity itself. This way a safety budget would be established. E.g. a low economic importance corresponds to a low \( PLL_A \).

For societal risk it is accepted that FN curves are a useful tool, and their basis is not discussed further in this paper. Therefore an FN curve with inclination \( b \) is fitted to the resulting \( PLL_A \) by:

\[ PLL_A = \sum_{N=1}^{N_u} N f_N = F_1 \left( \frac{1}{N_u^{b-1}} + \sum_{N=1}^{N_u} \frac{N^{-1}(N+1)^b}{N^{b-1}(N+1)^b} \right) \] (2)

Here \( N_u \) is the upper limit of the number of fatalities that may occur in one accident. For a ship this is well defined as the maximum number of crew + passengers.

\( f_N \) is the frequency of occurrence of an accident involving \( N \) fatalities, and

\( F_1 \) is the frequency of accidents involving one or more fatalities.

Following the recommendation by most regulators, see [6-9], \( b = 1 \) is chosen, and the above simplifies to:

\[ PLL_A = F_1 \left( \frac{1}{N_u^{b-1}} + \sum_{N=1}^{N_u} N^{-1}(N+1)^b \right) = F_1 \sum_{N=1}^{N_u} \frac{1}{N} \] (4)

Some practitioners are of the opinion that \( b = 1 \) is not risk averse. This is wrong, as explained in details in a HSE document [10]. This may easily be realised by observing that small contributions to PLL comes from large \( N \). Since this small contributions are as ‘intolerable’ as the comparable large contributions from small \( N \), the \( b = 1 \) is risk averse.

If solved with respect to \( F_1 \), Equation (4) gives

\[ F_1 = \frac{PLL_A}{\sum_{N=1}^{N_u} \frac{1}{N}} \] (5)

The ALARP region is introduced by assuming that the risk is intolerable if more than one order of magnitude above the average acceptable and negligible if more than one order of magnitude below the average acceptable, in agreement with many regulations, e.g. [7,9,11]. This implies that the region where risks should be reduced to As Low As Reasonably Practicable (ALARP) ranges over two orders of magnitude, in agreement with most published FN acceptance criteria. In the ALARP area, cost-effectiveness considerations would be applied. Figure 1 therefore illustrates the general format of societal risk acceptance criterion employed in this paper.
3 STATISTICS FOR OCCUPATIONAL AND TRANSPORT ACCIDENTS

3.1 Number of Occupational Fatalities per unit Gross National Product

To develop FN criteria for crew in accordance with the method, the total operating revenue of the shipping activity in question needs to be related to a target average occupational fatality rate per GNP, \( q \). It would be desirable to include many OECD nations in the statistics. However, variability within OECD is generally not very large. The GNPs of the different OECD countries may be found at the OECD web site [12]. Data on occupational fatalities is not so easily accessible and only data from United States and Norway has been employed herein.

![Figure 1: General format of societal risk acceptance criterion.](image)

In the period from 1992 to 1995, the number of occupational fatalities in Norway was 299, varying between 57 and 90 per year [13]. Statistics of Norway also reports the GNP at current prices in Norwegian Kroner (NOK). By assuming an annual inflation rate in the period of 2%, and an average exchange rate between NOK and £ of £ 1 = NOK 12, the accumulated GNP in the same period is £ 264,443 million (the same conversion factors are used throughout the paper, and all numbers are in 1990 units). Per year the GNP in Norway varied between £ 62,871 and 70,099 million. The ratio between occupational fatalities and GNP, \( q \) may then be estimated according to Equation (1) to be 1.1 fatalities per £ billion GNP in Norway for the period from 1992 to 1995, varying between 1.3 and 0.85 in the time period.

The work related fatality statistics in the US is available from the Bureau of Labour Statistics [14]. In the period from 1992 to 1997, the accumulated number of occupational fatalities was 31,905, varying between 6,632 and 6,202 fatalities per year. The GNP may be found [12]. An average exchange rate between USD and GBP of £2 = $3 has been used throughout. The accumulated GNP in the same time period was £ 22,169,700 million, varying between £ 3,407,372 and 4,060,180 million per year. The average ratio between occupational fatalities and GNP is 1.7 fatalities per £ billion GNP, varying between 1.8 and 1.5 in the period.
The ratio of occupational fatalities per GNP has been declining over the six-year period in the US, and there also appears to be a declining trend in Norway. It would be preferable that an average ratio of occupational accidents per GNP for all OECD countries was used when establishing the societal risk acceptance curve by the suggested approach. Attempts have been made to look up similar data on occupational fatalities for other OECD countries as well. Based on the rather limited samples, a work related fatality rate per £ billion of 1.5 is used in the examples below, \( q = 1.5 \) fatalities/£ billion. Better statistics is likely to change this number. However, aggregated indicators like this do not usually vary much within OECD member countries. The reason for using OECD statistics is that some 95% of the global GNP are represented by OECD member countries, and therefore presumably a similar high percentage of the marine transport.

### 3.2 Transport Related Accidents

To develop societal risk acceptance criteria for passengers it is suggested to use the relation between the total number of transport related fatalities and the associated operating revenue from transport services as the starting point. However, these data have only proven easily accessible for air traffic.

From 1990 to 1994, the total number of fatalities for schedules airlines worldwide was 4122, varying between 495 and 1,097 per year [15]. In the same period, the corresponding operating revenues generated by passengers were £ 475,800 million, varying between £ 91,800 and 100,300 million. The average ratio, \( r \), is then estimated to \( r = 8.6 \) fatalities/£ billion operating revenue from passengers, varying between 5.4 and 11.5 in the period.

This ratio is used to calibrate societal risk acceptance criteria for passengers on different ship types. It would be interesting to make comparison with other means of transport, e.g. railway, public buses, and cars. However, air traffic is selected here because of its known high safety standards and good statistics.

### 4 SOCIETAL RISK ACCEPTANCE AS FN CURVES

The suggested procedure is tested on some of the common ship types that are used to define the scope of the regulations (referred to as ‘generic ship’ in [1]): oil tankers, chemical tankers, gas tankers, bulk carriers, container vessels, Ro/Ro passenger vessels, and high speed crafts (HSCs).

The economic data has been found by using Clarkson Research Studies [16], and available annual reports from some ship owners that put this on the web, e.g. [17,18]. The figures also contain historic risk data. These are extracted from [19], representing the period 1988-1998. Further details may be found in [20]. The results are given in Figures 2 –4.
Figure 2: FN acceptance criterion and historic risk (crew).

Figure 3: FN acceptance criterion and historic risk figures for crew for Bulk Carriers and Container Ships.
5 CONCLUSION

The proposed method for establishing Risk Acceptance Criteria as FN diagrams gives Target Annual Fatal Accident Rates, $F_1$, varying from $10^{-3}$ (for Bulk Carriers and Container Vessels) to $10^{-2}$ (for the Ro/Ro Passenger Vessels), which is within an order of magnitude for the ship types investigated. Both for the Bulk Carrier and the Passenger Ro/Ro vessels, where acceptance criteria have been presented previously, the suggested method produce results in agreement with those published acceptance criteria [3-5]. The method therefore could be a basis for defining acceptance criteria for other ship types in a consistent framework. For the High Speed Crafts, two different size categories were studied, and the variation in the estimated $F_1$ ranges over 1.5 orders of magnitude. This indicates that where the variation in the number of crew or passengers is large, separate acceptance criteria should be established for different size categories of the ships. This would be consistent with normal procedures for risk based rules: if the variation is too large due to variability in design solutions, size etc., separate categories should be defined in the regulations.

The proposed method seems adequate to remove some of the inconsistencies of the FN curves, particularly related to different size ships. Using the method to establish FN risk acceptance curves could facilitate transparency of the risk acceptance criteria. When the method is used, the resulting curves may be verified independently and improved, as more data becomes available.

The method seems promising. Currently, the data on which results are based is for some ship types limited, and caution should therefore be shown.
The resulting curves also suggest that all ship types (generic ships) be within the ALARP area. This is also in agreement with what should normally be expected, as it should be expected that intolerable risks were removed by the existing regulations. It is also clear that risks were higher in the near past, and that some ship types would represent intolerable risks. An example is bulk carriers that would be judged intolerable prior to the new International Association of Classification Societies (IACS) requirements was introduced in 1997.

It should be noted that many other criteria would be needed in the decision process, like e.g. individual risks, criteria based on cost effectiveness [21], and criteria for environmental and economic consequences. Normally a decision would have to be based on acceptance by all these criteria. Only one specific method to arrive at societal risk criteria is dealt with herein.

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