COST BENEFIT ANALYSIS OF EXISTING BULK CARRIERS
A CASE STUDY ON APPLICATION OF FORMAL SAFETY ASSESSMENT TECHNIQUES

DET NORSKE VERITAS
Cost Benefit Analysis of Safety Measures for Existing Bulk Carriers

A case study applying FSA techniques

Formal Safety Assessment (FSA) is on the agenda both in the International Maritime Organisation (IMO) and in the International Association of Classification Societies (IACS). The objective is to develop a methodology which can be used in future rule-making processes, applying a risk based approach to identify means of controlling risks in a systematic and cost-effective way.

Following the high casualty rates of bulk carriers particularly in 1990 and 1991 IACS has carried out several studies with the aim to introduce measures that would enhance the safety also of existing bulk carriers. In the light of the casualty data base available DNV has performed a Cost Benefit Analysis (CBA) to see what improved insight such a methodology can provide in terms of assessing the overall safety and cost efficiency of a safety measure. In order to be able to rely on FSA and CBA it is of great importance to gain experience from real, practical analyses. This report describes the use of CBA for bulk carriers with emphasis on structural survivability.

The present study is based on the IACS December 1996 decision regarding retroactive requirements to existing bulk carriers as a condition of class, and should be seen as a supplement to the comprehensive studies carried out by IACS. It is believed that FSA will provide a better basis for decisions regarding safety issues.

Acknowledgements

The DNV study on bulk carriers has been carried out by the project team:

Monika Eknes (Senior Researcher), Ole Chr. Astrup (Principal Researcher), Knut Ronold (Principal Researcher) and Sverre Gran (Principal Researcher). In addition G. Holtsmark (Chief Engineer), G. Larsen (Chief Engineer), S. Valsgård (Head of Section), R. Skjong (Chief Scientist) and B. Hayman (Head of Section) have acted as a reference group for the project team.
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1. INTRODUCTION

1.1 Background

Marine transport, like any other means of transport and industrial activity, 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, crew and passengers, to port infrastructure or other vessels, to the marine and coastal environment, or to the business 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 costs, by adding further safety measures or achieving a higher standard of safety consciousness in operation. Nevertheless, it is impossible to eliminate them all together.

Decisions affecting safety are routinely made while managing ships, designing new ones, maintaining existing ships, establishing new classification rules, or in other ways regulating the shipping industry.

Such decisions might be:

- Whether a new type of safety equipment should be fitted on an existing ship.
- What type of safety features should be specified for a new ship.
- What level of safety should be achieved by new rules.
- Whether a type of ship which has suffered many accidents should be modified, and if so to what standard.

To answer questions such as these, the decision-maker must decide when the ship or the shipping operation should be considered safe enough, i.e. when risks are low and further safety measures should not be introduced. Risk acceptance criteria used in conjunction with Formal Safety Assessment are methods to address this issue systematically. In simple terms, risk acceptance criteria are yardsticks which help us answer the classical question “How safe is safe enough?”; a question comprising political and societal considerations.

Following the high casualty rates of bulk carriers in 1991 and 1992, IACS has carried out comprehensive studies aimed at defining measures that would enhance the safety of existing, as well as new, bulk carriers. In 1993 IMO and IACS introduced the Enhanced Survey Program (ESP) for bulk carriers in order to reduce the likelihood of water entering into a cargo hold (IMO Res. A744 with amendments). It is estimated that the complete bulk fleet will have passed an Enhanced Survey of all cargo holds by the end of 1997.

Other risk reducing measures discussed at IMO are:

1. Strengthening of bulkhead between cargo hold no. 1 and 2.
2. Strengthening of all bulkheads.
3. Not allow full loading in alternate condition.
4. Reduction (by 10 or 20%) of maximum cargo loading.
5. Additional protection of cargo holds against corrosion.

Measures 3 and 4 are considered either alone or in combination with measure no. 1 IACS has carried out ramification studies of these measures at the request of IMO.
In December 1996 IACS decided that the risk reducing measure no. 1 shall be implemented on ships classed by the member societies according to a phased program. IACS has later concluded that measure no. 1 is sufficient.

In fact the IACS December 1996 decision consists of two essential risk reducing elements. The first is a further extension of the scope of the periodical surveys of the hull in the cargo hold area beyond that of the Enhanced Survey Program introduced in 1993. The second implies structural modifications or strengthening of a larger share of the world’s 4700 existing bulk carriers trading with heavy cargo. This second risk reducing measure has proved controversial, provoking widely different reactions ranging from enthusiastic support to full opposition. In fact the measure is supported by a good deal of statistical evidence from past experience. It may be argued that a more balanced discussion would have taken place if the matter of safety levels had been dealt with in a more quantitative way. This raises a series of questions:

- What level of safety are we aiming for?
- What are the acceptance criteria?
- What effect does different risk reduction measures mean in quantitative terms and at what cost.
- In short “How safe is safe enough?”.

FSA is a tool that helps address such issues in a systematic manner. In a recent DNV study, (Eknes et.al., 1997), FSA techniques were applied to the specific problem of existing bulk carriers, to see what improved insight such tools could provide.

1.2 The international scene

We live in a dynamic world where what is “safe enough today” most likely is not “safe enough tomorrow”. We need to define quantitative safety goals and apply methods to identify and control risks to achieve these goals. This argues for a choice of a risk based approach to safety; otherwise we will see a proliferation of regulations which do not necessarily lead to enhanced safety, but most certainly add costs. Fortunately, both in IMO (International Maritime Organisation) and in IACS (International Association of Classification Societies), the issue of risk based approach to regulatory work has come on the agenda under the name “Formal Safety Assessment”.

The shipping industry has started to use Formal Safety Assessment (FSA) techniques to help manage the safety of ships. Classification societies have, to a variable degree, developed rules based on the principles of risk analysis. Similar principles have been used in the probabilistic approach to stability in damaged condition, which was first adopted by IMCO (now IMO) in 1974, and have most recently been used by the NW European Project on Passenger/Ro-Ro Vessel Safety. In these approaches, the “required subdivision index” is a limited form of risk based acceptance criterion.

The International Code of Safety for High Speed Craft, adopted by IMO in June 1995, includes a numerical interpretation of qualitative acceptance criteria for failures. These are forms of risk criteria similar to the ones used in the aviation industry.

The IMO now has a working group discussing the application of FSA to the rule making process. However, we still have some way to go before formal safety assessment will be a commonly accepted way to communicate and discuss safety and environmental issues within shipping, as for instance in the case of bulk carriers.
2. THE BULK CARRIER LOSSES AND CASUALTIES

A series of bulk carrier losses, with a peak during 1991 and 1992, caught the attention of the marine industry and the public on the safety of this particular ship type. The observed rate of bulk carrier losses seen in the past fifteen years gives evidence of risks which were considered intolerable, in particular from a societal risk point of view. During the first three months of 1997 two bulk carriers with a total complement of 45 people have been lost.

2.1 Lessons learned

Investigations of reasons and causes to the many bulk carrier losses are hampered by the lack of material evidence. However, experience from serious casualties does provide some insight into what could have caused the losses.

In the worst bulk carrier tragedies, those where the vessel sank without trace, there is no material evidence and in many cases no reports on initial failures. Based on experiences from casualties with lesser consequences, assumptions that regard the sequence of events which lead to rapid loss of vessel may be made. Ingress of sea water to one hold, either through side shell damage or through hatch cover damage, is judged by experts to be the initiating event in most cases. The subsequent events may be as follows:

- Collapse of transverse watertight bulkheads adjacent to flooded hold and thus progressive flooding.
- Partial or total collapse of the hull girder due to extreme global loading conditions when one hold is flooded. This event is considered to have the highest probability in the case of vessels with alternate hold loading, in particular with flooding of hold no. 1.
- Shift of cargo due to liquefaction in flooded or partly flooded hold. Subsequent shift of cargo in other holds and capsizing.
- Buckling of deck in between hatches causes the hatch cover to come loose and water entering through the hatchway.

No single type of structural weakness can be pointed out as being the main contributory cause when bulk carrier losses have occurred. Leakage to or flooding of hold no. 1 is regarded as being the most likely and serious case. Available statistical data, (Eknes et.al., 1996), indicates that of all the reported water ingress incidents, more than 40% occurred in hold no. 1. A general observation seems to be the presence of serious corrosion in the cargo hold area in many cases of water ingress incidents.

2.2 Casualty statistics

A considerable share of the bulk carrier losses seen in the past can be attributed to structural failure leading to water ingress and subsequent loss of ship. In order to investigate this failure sequence in more detail, an extract of the bulk casualty data base was prepared by IACS based on data from Lloyds Marine Information Services (LMIS) Casualty Database (1996). This subset of the casualty data focuses on losses where structural failure may have been a cause, and excludes losses due to grounding, collision, explosion and fire etc. The data basis used in the analysis spans the time frame from 1980 to September 1996, and includes bulk carriers of standard configuration (single skin, double bottom, hopper and wing tanks) above 20,000dwt. 13 losses were added to the data prepared by LMIS. In total, the data used in the DNV analysis
consist of 95 casualties, of which 55 are total losses, see Figure 1. These losses cost the lives of 611 seamen.

![Distribution of Casualties by Year.](image)

**Figure 1:** Bulk carrier casualty distribution 1980 to September 1996.

Various hypotheses were tested on the statistical data, but few could be proved statistically from the available data. Age was the major parameter that came out of the study with a strong correlation to the loss rate. The estimated strong dependence of the mean loss rate on the age of the ships is in conformance with findings of a factorial analysis by Thyregod and Nielsen (1993) which concluded dependence on age to be most significant. Other parameters found to have an influence on the loss rate were heavy weather and heavy cargo. It was not possible to deduce an explicit relationship between these parameters and the loss rate.

Other important factors that influence on the loss rate are corrosion and maintenance, but these could not be investigated based on the LMIS data base. It is, however, reasonable to believe that the reason why ship age is found to be of importance is that the variability of ship standard increases with age due to wear and tear, poor maintenance, etc.
Figure 2: Frequency-Number of fatalities (F-N) curve due to vessel casualties: Bulk carrier and world fleet fatalities. All accident types, Eknes et.al. (1996)

Figure 2 shows the frequency of N or more fatalities for bulk carriers compared to that of the world fleet (passenger ships excluded) due to vessel casualties, e.g. structural failure, collision, grounding, fire, capsize etc. The accident history indicates a higher loss rate for bulk carriers than experienced for other ship types.

3. THE DNV BULK CARRIER STUDY

3.1 The steps of FSA

The typical steps in a FSA, Mathiesen and Skjong (1996), are shown in Table 1:

<table>
<thead>
<tr>
<th>Steps of FSA</th>
<th>In layman terminology</th>
<th>The professional language</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What might go wrong?</td>
<td>Hazard Identification</td>
</tr>
<tr>
<td>2a</td>
<td>How often or how likely?</td>
<td>Frequencies or Probabilities?</td>
</tr>
<tr>
<td>2b</td>
<td>How bad?</td>
<td>Consequence</td>
</tr>
<tr>
<td>2c</td>
<td></td>
<td>Risk = Probability x Consequence</td>
</tr>
<tr>
<td>3</td>
<td>Can matters be improved?</td>
<td>Identify risk management options</td>
</tr>
<tr>
<td>4</td>
<td>What would it cost and how much better would it be?</td>
<td>Cost Benefit Evaluation</td>
</tr>
<tr>
<td>5</td>
<td>What actions are worthwhile to take?</td>
<td>Recommendation</td>
</tr>
<tr>
<td>IMO</td>
<td>What actions to take?</td>
<td>Decision</td>
</tr>
</tbody>
</table>

Table 1: The steps of FSA, IMO (1996).
One difficulty in any FSA lies in establishing reasonable risk acceptance criteria. This was the case for bulk carriers, where no risk acceptance criteria have explicitly been stated.

In general, no decision should be based on a single risk acceptance criterion. But a range of criteria should be used. Of relevance here, are criteria on

- individual risk,
- societal risk and
- a cost-benefit acceptance criterion to decide when risks are As Low As Reasonably Practical.

These criteria are all discussed in the draft FSA guidelines, IMO (1996).

Individual risk acceptance criteria should be used to limit risks to individual workers and members of the public. Societal risk acceptance criteria should be used to limit risks to the affected population as a whole. By expressing societal risk criteria on a F-N curve, they can also address the catastrophic risks.

### 3.2 Individual risks

Individual risks at work are commonly expressed as a fatal accident rate (FAR), which is the number of fatalities per $10^8$ exposed hours. The number $10^8$ exposed working hours is roughly the number of hours at work in 1000 working lifetimes. For a ship, the number of hours exposed is the number of hours at sea multiplied with the number of people aboard.

Eknes et.al. (1996) has calculated typical FAR values for bulk carriers taken from historical data. Table 2 compares this FAR value for bulk carriers with fatal accident rates from other typical industries, Spouge (1997). The FAR value for bulk carriers includes all accident types, not only structural failure, in order to compare with other industries.

Most industries use $10^{-3}$ as a maximum acceptable risk for workers, Spouge (1997). Hence, from Table 2 it is seen that the individual risk for seamen on bulk carriers is not unacceptable.

### 3.3 Societal risks

Societal risk criteria are used to limit the risks to crew, local communities, or to society as a whole from the hazardous activity. In particular, they are used to limit the risks of catastrophes affecting many people at once. Societal risks include the risks to every exposed person, even if they are only exposed on one brief occasion.

Societal risk criteria can be expressed as F-N curves. The use of F-N curves requires the definition of a slope as well as an overall level, Spouge (1997). F-N curves derived from historical accidents in hazardous industry activities tend to show slopes of about -1 in a log-log plot. This observation and other reasoning, Spouge (1997), have led to common industry practice of adopting this slope in the risk acceptance criteria. In addition, the intolerable and negligible risk levels have to be defined. Altogether, this defines three regions in the F-N diagram: the negligible region, the ALARP (As Low As Reasonably Practical) region and the intolerable region. Eknes et.al (1997) established the F-N curve for the different risk control options for 15 years and older bulk carriers, see Figure 2. The results were compared to historical casualty data (before ESP) demonstrating the risk reduction for the different control options.
<table>
<thead>
<tr>
<th>Industry</th>
<th>FAR (number of fatalities per 10^8 hours)</th>
<th>Individual risk ^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and gas production ^1</td>
<td>30.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Agriculture ^1</td>
<td>4.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Forestry ^1</td>
<td>7.6</td>
<td>15.0</td>
</tr>
<tr>
<td>Deep sea fishing ^2</td>
<td>42.0</td>
<td>84.0</td>
</tr>
<tr>
<td>Energy production</td>
<td>1.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Metal manufacturing</td>
<td>2.9</td>
<td>5.5</td>
</tr>
<tr>
<td>Chemical industry ^1</td>
<td>1.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Mechanical engineering ^1</td>
<td>1.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Electrical engineering ^1</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Construction ^2</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Railways ^2</td>
<td>4.8</td>
<td>9.6</td>
</tr>
<tr>
<td>All manufacturing ^1</td>
<td>1.0</td>
<td>1.9</td>
</tr>
<tr>
<td>All services ^1</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>All industries ^2</td>
<td>0.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Bulk carriers ^1</td>
<td>6.6</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Table 2: Individual risk and Fatal Accident Rate for different industries and jobs in UK compared with that of bulk carriers.

^1 Spouge (1997). Fatalities are for the period Apr 87-Mar 91.
^2 Lees (1996): Fatalities are for the period 1987 to 1990.
^3 Eknes et.al. (1996): Fatalities are for the period 1980 to 1996.
^a Individual risk is given as a probability of death in 10^5 years.
b Includes 167 fatalities on Piper Alpha.

Figure 3: F-N curve expressing the effect of different risk control options as applied to bulk carriers 15 years and older.
The ALARP region was chosen according to Eknes and Skjong (1997), and is largely based on comparison with risk acceptance criteria used in other industries. The assumptions regarding the risk reduction due to the Enhanced Survey Program are discussed in Section 0.

### 3.4 Risk reduction due to the Enhanced Survey Program

The basic rule requirements for Close-up Examination of oil tankers and bulk carriers are extensive. Close-up inspections imply that the details of the structural components are within the close visual inspection range by the surveyor, i.e. normally within reach of hand. The ESP will result in more extensive annual, intermediate and renewal surveys.

In general it is difficult to estimate the effect of ESP from data, due to the low number of ship-years since ESP was implemented. Ships that have passed an ESP only accounts for 2 800 ship-years of a total of 60 000 ship-years present in the current data basis. This means that ESP has a negligible influence on the current data basis. In order to obtain the likely range for the risk reducing effect of ESP, the average loss rate is estimated based on different scenarios:

1. The observed average loss rate of 7 to 9 year old ships due to water ingress is $0.55 \cdot 10^{-3}$ per ship year, while the average for ships older than 10 years is $1.5 \cdot 10^{-3}$ per ship year. The scope of the ESP is considerably increased for ships 10 years of age and older, as compared with the previous scope of surveys. The average loss rate of 7 to 9 year old ships may therefore be used as a lower limit for the loss rate that can be expected for older ships after they become subjected to ESP. If it is somewhat optimistically assumed that the older ships maintained by ESP have the same standard as the 7 to 9 year old ships, this gives a reduction of 63% of the average loss rate for ships older than 10 years.

2. If on the other hand it is assumed that ESP ensures that the older ships have the same standard as the 15-year old ships, then the average loss rate for ships older than 10 years will be $7.9 \cdot 10^{-4}$ per ship year. The reduction in the average loss rate for ships older than 10 years will then be 47%.

3. During February 1997, the first two bulk carriers subject to ESP were lost. The total number of ships with ESP ships since 1993 is assumed to represent 2800 ship years. The aposteriori loss rate is determined using Bayes Theorem and updating the prior distribution with the two observed bulk carrier losses, Eknes et al. (1996). The loss rate for 10 year and older ships is then estimated to $8.7 \cdot 10^{-4}$ per ship year. The observed reduction, given these two observations, is 42%.

Based on the above loss rate calculations, 40% was used as a conservative estimate of the risk reducing effect of the Enhanced Survey Program.

### 3.5 Cost Benefit Analysis

Cost Benefit Analysis (CBA) is in risk assessment usually used to assess the marginal return of additional safety measures comparing:

- The cost of implementing the measure.
- The benefit of the measure, in terms of the risk that would be averted.

The purpose of CBA is to show whether the benefits of a measure outweigh its costs, and thus indicate whether it is appropriate to implement the measure. CBA cannot provide a definitive decision, because factors others than risks and costs may be relevant, but it provides an important
guide. In order to compare different risk control options the risks and costs are expressed as a ratio, known as the Implied Cost of Averting a Fatality (ICAF).

The definition is

\[ ICAF = \frac{\text{Net annual cost of measure}}{\text{Reduction in annual fatality rate}} \]

A supplementary measure for reducing the risk associated with bulk carriers decided by IACS is to strengthen the bulkhead between cargo hold no. 1 and 2. The implied cost of this risk reducing measure is a one-time cost. It is assumed that ESP is in force when the bulkhead is strengthened. As risk reduction, strengthening of a bulkhead has the purpose of avoiding, or at least, delaying the sinking of a ship once water ingress has started and a loss is in progress, thereby to gain time and allow for evacuation of the crew. Such strengthening of bulkheads will thus be of significance with respect to those ship losses where the ships have sunk fast with little or no chance for the crew to evacuate, while it will not be of significance for those ship losses where the crew has had time to evacuate.

A fraction of all bulk carrier losses are severe in the sense that the entire crew or most of the crew is lost. This fraction refers to the situation before strengthening of the bulkhead is taken into consideration. Figure 3 is telling that the main focus should be to reduce these severe losses. Based on the observed bulk carrier losses in the reference period 1980-96, 21 of the total of 55 losses were severe according to the definition (more than half of the crew was lost). This gives an estimated fraction with mean 0.382 and a standard error of 0.066. It is assumed that for this fraction of the bulk carrier fleet, the strengthening of the bulkhead between cargo holds no. 1 and 2 will lead to a 50% reduction in the expected number of fatalities per loss, whereas for the remaining fraction of the fleet, no reduction in the expected number of fatalities per loss is foreseen. Based on the 21 observed severe bulk carrier losses in the past, the expected number of fatalities in a severe loss is estimated to have a mean value of 27.71, and the standard error of the estimate is 1.77.

The necessary steel reinforcement will vary with the ship size. The values used in the present analysis are given in Table 3, IACS (1996). The cost of the steel renewal is assumed to vary between USD 4000 and 8000 per tonne, with USD 6000 per tonne used in the analysis. It is assumed that the upgrading work will be carried out during special survey, implying little or no off-hire costs, IACS (1996).

<table>
<thead>
<tr>
<th>Size</th>
<th>Mean Weight Estimate of Steel Reinforcement</th>
<th>Fraction to be upgraded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handysize</td>
<td>10 tonnes</td>
<td>70%</td>
</tr>
<tr>
<td>Panamax</td>
<td>12.5 tonnes</td>
<td>70%</td>
</tr>
<tr>
<td>Capesize</td>
<td>25 tonnes</td>
<td>70%</td>
</tr>
</tbody>
</table>

Table 3: Necessary steel reinforcement of bulkhead no.1 for different ship sizes and fraction of fleet to be upgraded.

The ICAFs for upgrading the transverse bulkhead between cargo hold no. 1 and 2 are calculated for 10, 15 and 20 year old Capesize, Panamax and Handysize bulk carriers, see Figure 4.
The oil industry operating in the North Sea use acceptance criteria for ICAFS of 3 Million USD and higher. On the other hand, the criterion used for improving safety standards in Norwegian road transportation is less than 0.5 Million USD. The IACS December 1996 decision to implement retroactive requirements to existing bulk carriers, thus places the decision by IACS in between North Sea operators and Norwegian road transportation.

4. CONCLUSIONS

The time invested in this study has contributed to a better understanding of the high rate of loss seen in the bulk carrier fleet. Loss data and fleet data which for a great part are not easily available have been compiled and analysed, and loss rates have been estimated. This has provided a basis for analysing the risks of bulk carrier losses within the framework of conventional F-N curves. This has further allowed a comparison with other risks as well as with typical societal risk acceptance criteria. It has been demonstrated how a systematic FSA approach can be applied to analyse data and produce a rational basis for making decisions regarding safety of bulk carriers. The method is of course applicable to other types of ships, as well as other types of industrial hazards.

- A major finding of this study is that societal risk is the dimensioning acceptance criterion, not individual risk.
- It will be cost effective from a societal point of view to strengthen the bulkhead between no. 1 and 2 cargo holds for the majority of the bulk carriers in the fleet. This supports the decision already made by IACS in December 1996 in this respect.
• The experience to date with the Enhanced Survey Programme indicates that the risk reduction of this safety measure is about 40%. This assessment includes the two recent losses of bulk carriers that had passed an Enhanced Survey.

• It is felt that the study has contributed to a better understanding of how to assess safety philosophy in general and bulk carrier safety in particular. The applicability of the current analysis procedures has been demonstrated by a case study involving structural failure of bulk carriers.

5. REFERENCES


