Bulk Ship Losses: A Statistical Analysis

Neil Gentle
Research Leader
Bureau of Transport and
Communications Economics

Stephen Wheatstone
Principal Research Officer
Bureau of Transport and
Communications Economics

Abstract:

From July 1988 to the end of 1992 six large dry bulk carriers have sunk after sailing from Western Australian iron ore ports. Most of these have sunk sailing westward from Australia. Structural failure is suspected as the major causal factor in these casualties, but this raises the question of why do the majority of sinkings occur with ships sailing westward when the major focus of the iron ore trade is on North Asia. Are there any differences between ships carrying iron ore from Australia and those sailing from other major iron ore exporting countries?

The paper discusses the technical factors that influence structural failure. Statistical techniques are then used to address the above questions using Lloyd's voyage data for bulk ships departing from major bulk exporting countries.

Contact Author:

Neil Gentle
Bureau of Transport and Communications
Economics
GPO Box 501
CANBERRA ACT 2601

Telephone: (06) 274 6735
Fax: (06) 274 7170

1 Introduction

From July 1989 to the end of 1992 six bulk ships have sunk after departing from iron ore ports in Western Australia. Another ship required repairs in South Africa after sustaining severe structural damage.

Australia is not unique in the loss of bulk ships. In the three years ended July 1992 36 bulk ships have been lost through structural failure or suspected structural failure. Although Australia is not unique, there is still the issue of whether bulk ships leaving Australian ports fail at an excessive rate. This paper uses statistical techniques to examine the factors that may contribute to structural failure.

The major source of data is a set of voyage records purchased from Lloyd's Maritime Information Services Limited for bulk ships over 30 000 deadweight tonnes (dwt) departing from the major bulk exporting countries of Australia, Brazil, India, South Africa and the USA. These countries are major bulk exporters of coal, iron ore and grains. Ship casualty data were obtained from the Department of Transport and Communications, Lloyd's Register (1992a,b) and Nippon Kaiji Kyokai (NKK 1992).

2 The Data

Lloyd's voyage data provided information on ports of origin and destination, date of departure, date of arrival, ship name, Lloyd's register number, date of build, flag, classification society, dwt. Casualty reports contained the same information (apart from date of arrival), and for most, but not all casualties, the location of the ship when it failed[1]

The casualty data also indicated the cargo the ship was carrying at the time of failure. Unfortunately this information was not readily available from the voyage records for ships which successfully completed their voyages. However, for many of these voyages, the cargo carried could be inferred from the port of origin. In particular iron ore ports tended to be one commodity ports allowing the cargo to be identified unambiguously. Coal and grain are frequently loaded at the same port (eg Gladstone and Newcastle in Australia) and it was not always possible to classify ships sailing from these ports as carrying grain or coal. For this reason these commodities were combined in the analysis of the voyage data.

Fearnleys (1992) provided another source of data on commodities and voyages which allowed some additional analysis of the possible effect of commodities on the risk of structural failure.

---

[1] A ship which is unable to complete a voyage because of damage to its structure is defined as having failed structurally. Not all structural failures result in a ship sinking although most do. Casualties include structural failures, but also include groundings, collisions and other incidents that prevent ships from completing voyages.

3 Failure Modes

Several factors are usually operating at the time a ship fails structurally. The condition of the ship, weather conditions and crew performance were identified in the report by the House of Representatives Standing Committee on Transport, Communications and Infrastructure (HORSCTOCI 1992) as major categories of factors. Crew performance is not examined in this paper.

Cracking of main frames and their brackets is a common occurrence in bulk ships that have failed or have suffered significant damage (Lloyd's Register 1992a, NKK 1992, American Bureau of Shipping 1992). In some ships cracking has led to reduced support for the side plates or even complete loss of some plates.

Deterioration of the ship's structure, leading to cracking and eventually failure can be initiated through physical damage during loading or unloading operations and through corrosion and fatigue. Good maintenance can repair the initial damage and keep the structure in a sound condition. With poor maintenance the initial damage can spread until the structure is seriously weakened.

The data required to statistically examine the factors leading to structural failure are not always available. The following sections briefly discuss the major factors and what readily available data can act as proxies for the underlying factors.

Loading and Unloading

Loading of ships can induce high stresses in the ship's structure. High density commodities are commonly loaded at rates of 6000 tonnes per hour with some ports having the ability to load at rates in excess of 10 000 tonnes per hour. The capacity of ballast pumps to counter stresses during loading of the ore can often be exceeded.

The unloading of bulk ships normally requires the use of large grabs. Lloyd's (1992a, 4) report that grabs with an empty weight of 35 tonnes are common. Despite the care of equipment operators the ship will be frequently subjected to repeated high stresses during the unloading process.

Bulldozers and pneumatic equipment are also used to remove adhering and inaccessible cargo. This form of equipment can very easily damage important structural members at the bottom of the hold.

An insufficient number of passes during the loading or unloading operation can lead to high localised stress. These high stresses can exceed the design limits resulting in plastic deformation, local cracking or even failure of structural components.

Unless the ship operator is careful about maintenance the damage sustained during these operations will accumulate leading to loss of structural integrity.

Fatigue and Corrosion

Mild steel will suffer fatigue failure if it experiences cyclic stresses over what is referred to as the endurance limit. The endurance limit is the magnitude of cyclic stresses above which the material will fail after one to ten million cycles of the stress. Structural designs usually take fatigue effects into account.

The loss of steel through corrosion accelerates the effect of fatigue. The reduced thickness of the steel increases the stresses which may then exceed the endurance limit and result in fatigue cracking and possible detachment of the side shell from the frame. Once a crack has been initiated through corrosion it can propagate quickly and can also be a source of further corrosion (American Bureau of Shipping 1992)

Plastic deformation of structural components, such as webs and frames, can also lead to an increase in stresses. The deformation can lead to increased stresses in both the deformed component and in adjoining members which are forced to take an increasing share of the load.

The type of cargo can influence the development of corrosion. Coal, especially when it contains a high proportion of sulphur, is an important bulk commodity that induces corrosion. The temperature of the coal can be as high as 38 degrees Centigrade. These high temperatures combined with the colder sea water outside the hull, can cause significant condensation on the inner side of the side shells. The condensation tends to collect at the lower parts of the hold where sulphuric acid results in the localised corrosion that is frequently found on the webs adjacent to the side plates (Lloyd's Register 1992a, 12).

Corrosion and fatigue are cumulative effects. This suggests that age of the ship may be a good indicator of the possible existence of these problems. Age is readily obtainable from the voyage data and is one of the main variables used in the analysis.

Owner

Maintenance can affect the degree of structural deterioration. Protective systems are usually installed in new ships to prevent corrosion. Poor maintenance of these systems can contribute to accelerated structural deterioration. The owner's approach towards the repair of these systems and damaged and corroded structural components can have a marked influence on the condition of a ship.

The foregoing suggests that maintenance quality can have a marked influence on ship safety. Because of this, ideally the analysis would include an examination of the relationship between owners and risk of ship failure. However, there were 762 different owners in the voyage data base making a useful analysis virtually impossible. Furthermore it is not always possible to accurately identify the beneficial owner of a ship. No owner could be identified for 25 ships in the voyage database. It is of interest that 14 of these ships were casualties and of these 12 suffered structural failure

Flag State and Classification Society

The flag state under which the ship is registered and the classification societycertifying the compliance of the vessel with recognised safety standards may bear some relationship to the standard of maintenance of the ship. Although the owner of the ship is directly responsible for its maintenance, owners may select flag states and classifications societies that are compatible with their approach to ship maintenance. CRA (1992) in its submission to the House of Representatives Standing Committee on Transport, Communications and Infrastructure (HORSCOTCI) inquiry into ship safety commented that "(c)lassification societies and some of the lesser Flag states are clearly wanting in their enforcement of regulations and obligations". Similarly the National Bulk Commodities Group (1992, 4) noted that there is "an unwillingness or inability of certain Flag States to ensure adherence to international standards by vessels under their flag". HORSCOTCI in its report was critical of some classification societies (HORSCOTCI 1992, 53). The Committee said "Put bluntly, ample evidence was put to the Committee that the quality of [classification society] inspections has gone down as the intensity of competition for clients has gone up" (HORSCOTCI 1992, 53). These views suggest that the possible relationship between bulk ship failures and flag and classification societies should be tested.

Cargo Type

During the three year period from July 1989 to June 1992 36 bulk ships were reported as casualties with structural failure being the main cause or suspected as being the main cause of the loss. Of these 36 ships 24 were carrying iron ore at the time of failure. Therefore there is a reasonable presumption that the characteristics of the cargo are an important factor in the failure of the ship.

Iron ore is a particularly dense cargo. It has a density of 0.4 m^3/tonne compared with 1.23 to 1.29 m^3/tonne for coal and wheat (Strang 1971).

As a consequence of this high density bulk carriers can not be loaded to their volume capacity when carrying iron ore. There are two basic methods of partially filling the holds. The first is to partially fill each hold (homogeneous loading). The second way is to load only the alternate holds, usually only the odd numbered holds. Even with alternate hold loading the cargo often does not occupy a large proportion of the space in loaded holds.

The purpose of alternate hold loading is to raise the ship's centre of gravity in order to moderate roll motions of the ship. This reduces some localised stresses on the ship, provides a more comfortable ride for the crew and allows faster loading of the ship. However, alternate hold loading induces high shear stresses, particularly at hold boundaries (American Bureau of Shipping 1992).

The higher stresses induced by alternate hold loading can increase the risk of structural failure. Although ships that adopt alternate hold loading are strengthened to allow this practice, if the ship has previously suffered corrosion, the the structure may not be able to be safely accommodated increased stresses.

Weather

The main effect of bad weather is to increase the forces acting on the structure of the ship. Nearly all of the bulk ships that have failed experienced bad weather at the time of failure. For example modelling undertaken on behalf of the Department of Transport and Communications shows that waves in excess of 16 metres may be experienced by ships in the South Indian Ocean, the location of five of the casualties of ships departing from Australia (DTC 1992).

Combination of Factors

The discussion so far suggests that it is unlikely that failure of a ship can be attributed to a single cause. A possible sceriario is that a ship, which has been poorly maintained so that its structural integrity is compromised through corrosion and fatigue cracking, is loaded with iron ore. It then encounters heavy seas, but does not slow down because of time pressures to deliver its cargo on time. The heavy seas prove too much for the already weakened structure, subjected to high stresses from its cargo of iron ore. The inadequately trained crew fail to recognise that there is a problem until the failure has progressed to the point of total failure

The foregoing also suggests that age is likely to be a good proxy for the deterioration of the ship's condition through corrosion and physical damage caused by loading and unloading practices. Flag state and classification society may be reasonable proxies for the owner's approach to maintenance. Although the HORSCOTCI (1992) report indicated that crew performance is a factor in ship failure, the data do not permit crew ability to be examined directly. However, crew nationality and flag state are often correlated so that flag state may also be an indirect measure of crew ability.

Data on weather conditions encounbtered during successful voyages are not reasily available. However, the possibility of bad weather can be associated with particular areas of the oceans or routes and these may be useful proxies for weather conditions.

Commodity can be analysed directly. The stresses imposed on a ship's structure by a cargo can be influenced by the size of the ship and the characteristics of the waves through which the ship is passing. Size is easily analysed. Wave data are available and are examined later in the paper, However, wave characteristics are related to the route the ship traverses therefore route may also be a useful proxy for wave characteristics.

4 Exploratory Statistical Analysis

An initial statistical analysis was undertaken to develop some understanding of the importance of the factors discussed in the previous section. Each factor was assumed to have no influence on risk of failure. This null hypothesis was then tested using a chi-square test. A contingency table to test the contribution of a particular factor to failure risk requires estimation of the expected number of successful voyages as well

Table 1 **Analysis of Failures by Commodity**

Year	*Iron Ore*	*Coal*	*Grain*	*Bauxite & Alumina*	*Phosphate*	*Other*	*Total*
Number of voyages							
	3373	5010	4322	1193	974	1039	15911
Number of failures							
Expected	6.8	10.1	8.7	2.4	2.0	2.1	32
Actual	24	1	0	2	3	2	32
χ^2	43.7	8.2	8.7	0.1	0.6	0.0	61.3[a]

a Includes the contribution of successful voyages.
Note: The critical 0.05 value of χ^2 for 5 degrees of freedom is 11.07
Source: Fearnleys (1992), Lloyd's Register (1992b)

as failed ones. Although successful voyages were included in the analysis, they made minimal contributions to the chi-square score. For this reason the contingency tables in the paper do not reproduce this part of the analysis.

These statistical tests give an indication of which factors might be important, but do not provide a measure of the relative strength of each factor. The small number of failed voyages limits the ability of the chi-square analysis to examine interactions between the factors. This issue is taken up below through the use of logit analysis.

Commodity

The discussion on modes of failure suggested that the carriage of iron ore may have an important influence on failure risk. Table 1 summarises an analysis of ship failures and the commodities carried at the time of failure. This analysis is based on world-wide data which allows a better disaggregation of the commodity data than the voyage data. The Fearnley's data allows an estimate to be made of the number of voyages employed in carrying each commodity and these estimates were used to estimate the number of failures that could be expected under the null hypothesis.

The results show that ships carrying iron ore had far more failures than would be expected if commodity had no effect on failure risk. Coal and grain had far fewer casualties and the remaining commodities had failures in line with what could be expected if commodity had no influence on failure risk. The analysis supports the view that the carriage of iron ore significantly increases the risk of failure compared with the carriage of other commodities.

Commodity and Age

Table 2 shows the age distribution of voyages in the Lloyd's voyage data. Iron ore tends to be carried in older ships than other commodities. The median age of iron ore ships was around 12 years compared with 9 years for all bulk ship voyages in the data base.

Table 2 **Age Distribution of Voyages by Commodity**

	Age group (years)						
	0-4	*5-9*	*10-14*	*15-19*	*20-24*	*>24*	*Total*
Coal and Grain	2554 (14.6)	6551 (37.5)	3491 (20.0)	3527 (20.2)	1200 (6.9)	143 (0.8)	17466 (100.0)
Iron Ore	857 (16.0)	1428 (26.6)	817 (15.2)	1325 (24.7)	649 (12.1)	285 (5.3)	5361 (100.0)
Other	865 (14.1)	2555 (41.6)	1314 (21.4)	1109 (18.0)	285 (4.6)	17 (0.3)	6145 (100.0)

Note: Row percentages in brackets
Source: Lloyd's Voyage data

Table 3 **Analysis of Age by Commodity Group**

	Age (years)						
Commodity	*0-4*	*5-9*	*10-14*	*15-19*	*20-24*	*>24*	*Total*
Expected failures							
Iron ore	2.4	3.7	2.2	3.4	1.7	0.7	14
Coal, grain and other	0.8	1.7	1.0	1.0	0.3	0.0	5
All voyages	3.0	6.9	3.6	3.9	1.4	0.3	19.0
Actual failures							
Iron ore	0	2	1	6	5	0	14
Coal, grain and other	0	0	0	2	3	0	5
All voyages	0	2	1	8	8	0	19
Chi-square							
Iron ore	2.4	0.8	0.6	2.0	6.6	0.7	13.1[a]
Other	0.6	1.7	0.8	0.1	44.3	0.0	47.5[a]
All voyages	3.0	3.4	1.9	4.4	31.9	0.3	44.9[a]

a Total chi-square scores include contribution from successful voyages. Critical χ^2 for 0.05 level of significance and 5 degrees of freedom is 11.07
Note: Figures may not add to totals due to rounding.
Source: BTCE estimates based on Lloyd's voyage data.

More significantly, iron ore is more likely to be carried in old ships than are other commodities. Ships 15 years and older were used for 42 per cent of iron ore voyages compared with 28 per cent for coal and grain and 22 per cent for other commodities. Of the 36 ships that failed structurally world-wide during the analysis period, 31 were in this age group.

The use of old ships for iron ore may be related to its low value. For iron ore, transport costs can be a substantial part of its *cif* [2] price. Charterers would therefore have an incentive to seek out low freight rate vessels and these would most likely be older ships.

Table 3 provides a statistical analysis of age by commodity group. All voyages are analysed irrespective of commodity and, as well, iron ore and the remaining commodities are analysed independently. The analysis suggests that age plays an important part in structural failure irrespective of commodity carried. Ships in the 15 to 24 years group appear to be especially at risk of failure.

An interesting feature is that ships over 24 years experienced no failures. This could be related to size since very old ships tend to be small ships or because there are few voyages by ships in this age group. Table 2 shows that 5.3 per cent of voyages of ships carrying iron ore were by ships in the over 24 age group. The expected number of failures in this group using the average failure rate for all iron ore voyages is less than one. This suggest that the absence of failures in the over age group is not inconsistent with age being an important factor in failure risk.

It may also be a result of a difference in the structures of these very old ships compared with newer ships. In the early 1970s design of ship structures changed to a more analytical technique that allowed designers to produce more economical designs using reduced metal thicknesses. These designs often have reduced safety factors to allow for the improved design methods and as a result may be more likely to lose structural integrity through corrosion at an earlier age.

Size

Earlier it was suggested that size and sea conditions may interact to impose high stresses in bulk ships. Size is analysed in table 4. The analysis suggests that ships in the range 80 000 to 100 000 deadweight tonnes could face higher than expected risks of failure.

This raises the question of how size might be related to risk of failure. One possible explanation is that there could be some relationship between ship size and the characteristics of the seas through which the ship sails. For example, interaction between the length of the ship and wave height and period could result in higher stresses than a ship of different length might encounter. If this hypothesis is correct than there could be some relationship between route and ship failure. The different failure rates depending on exporting region suggests this might be so.

---

[2] Cost, insurance and freight. The *cif* price is essentially the landed price of the good.

Table 4 Failures of Iron Ore Ships by Size

	Size ('000 dwt)					
Route	*30-50*	*50-80*	*80-100*	*100-150*	*>150*	*Total*
Number of voyages	1400	1065	117	1312	1469	5363
Number of failures	0 (3.7)	5 (2.8)	3 (0.3)	5 (3.4)	1 (3.8)	14
Chi square	3.7	1.8	23.8	0.7	2.1	32.1

Note Expected number of failures in brackets. Critical χ^2 for 0.05 level of significance and 4 degrees of freedom is 9.49.

Source: BTCE estimates based on Lloyd's voyage data

Table 5 Failure Analysis of Iron Ore Voyages by Route

Route	*Voyages*	*Actual failures*[a]	*Expected failures*	*Chi-squared*
Brazil-Asia	475	2	1.2	0.5
Sth Africa-Asia	102	2	0.3	11.3
W Aust-Nth Europe	290	6	0.8	36.3
W Aust-Nth Asia	820	1	2.1	0.6
Other routes	3676	3	9.6	4.5
Total	5363	14	14.00	53.3[a]

a Chi-square total includes contribution from successful voyages.

Note Critical χ^2 for 0.05 level of significance and 4 degrees of freedom is 9.49

Source: BTCE estimates based on Lloyd's voyage data

Route Analysis

Iron ore routes from Australia and other major iron routes terminating in Asia are analysed in table 5. The analysis shows that two of these routes appear to have especially high failure risk. These routes are; Western Australia to Northern Europe, and South Africa to Asia. Both the Western Australia to Northern Europe and South Africa to Asia routes pass through the Southern Indian Ocean. This is an area that can produce severe weather conditions, suggesting that route might be a proxy for bad weather.

A further possibility is that ships departing from Western Australia may be older or of a different size from the ships which trade on other routes. The distribution of the size of ships on the routes from Western Australia to Japan and from Western Australia to Northern Europe were compared with other ships carrying iron ore. This comparison is shown in table 6. which shows that there is a significant difference between the size distribution between ships departing from Western Australia and other iron ore routes. The ships departing from Western Australia tended to be larger than other ships carrying iron ore.

The analysis was extended to compare the size distributions for the same routes but only for ships 15 years and older. This allowed comparison of voyages for ships which

Table 6 Route Analysis of Iron Ore Voyages

(voyages)

Route	*Size ('000 dwt)* 30-50	50-80	80-100	100-150	>150	*Total*
All voyages						
WA Nth Asia[a]	72 (213)	58 (163)	7 (17.6)	247 (201)	436 (225)	820
WA Nth Europe[b]	1 (75.4)	33 (57.7)	6 (6.2)	110 (71.2)	140 (79.5)	290
Other iron ore	1322	976	102	959	894	4253
Voyages in ships 15 years and older						
WA Nth Asia[c]	5 (43.7)	4 (33.4)	6 (3.6)	67 (41.2)	86 (46.0)	168
WA N Europe[d]	0 (27.1)	9 (20.7)	6 (2.2)	49 (25.5)	40 (28.5)	104
Other iron ore	533	444	81	537	351	1946

a $\chi^2 = 376.7$ b $\chi^2 = 151.3$ c $\chi^2 = 112.5$ d $\chi^2 = 66.3$

Notes Expected voyages in brackets

Critical χ^2 for 0.05 level of significance and 4 degrees of freedom is 9.49

Source: BTCE estimates based on Lloyd's voyage data.

appear to be the most at risk. The results of this analysis are also shown in table 6. Again there is a significant difference between the distributions of the Western Australian departures compared with other iron ore voyages. A comparison between the two Western Australian routes shows that the distributions are significantly different with the major difference being that the route to North Asia has a much higher proportion of ships in the 30 000 to 80 000 dwt range. The difference was less for older ships.

The proportion of older ships varies markedly between the three routes. The proportion of old ships (15 years and older) is 20.5 per cent on the Western Australia to North Asia route, 35.9 per cent on the Western Australia to North Europe route and 45.7 per cent on the other iron ore routes. The higher proportion of old ships on the Western Australia to North Europe route compared with the Western Australia to North Asia route suggests that the high failure rate on the North Europe route is related to the age of the vessels employed on that route. However the higher proportion of older ships on the other iron ore routes also suggests that the route may also be very important.

Bad Weather

Although the route appears to be implicated, this may be related to the expectation of bad weather on each route. The effect of bad weather was tested by first classifying voyages into those that were likely to experience bad weather and those that were not. Those voyages that passed through regions with maximum expected wave heights over 14 metres during the season of the voyage were classified as potentially bad weather voyages. The expected wave heights were obtained from British Maritime Technology (1986).

Table 7 Analysis of Bad Weather Areas for Iron Ore Voyages

Exporting region	*Failures* *Actual*	*Expected*	*Chi-squared*
Bad weather			
Brazil	3	1.85	0.72
South Africa	2	0.20	15.88
India	0	0.07	0.07
Western Australia	7	1.41	22.24
Eastern Australia	0	0.16	0.16
Non bad weather			
Brazil	0	2.88	2.88
South Africa	0	0.43	0.43
India	2	2.96	0.31
Western Australia	0	3.93	3.93
Eastern Australia	0	0.10	0.10
Total	14	14.00	46.74[a]

a Critical χ^2 for 0.05 level of significance and 9 degrees of freedom is 16.92.

Source: BTCE estimates based on British Maritime Technology (1986) and Lloyd's voyage data

Table 8 Analysis of Flag

Flag category	*Actual*	*Expected*
Bad	11	5.6
Poor	4	5.2
Fair	2	4.0
Good	2	4.2
Total	19	19

Note: $\chi^2 = 7.62$. Critical value for 0.05 level of significance and 3 degrees of freedom is 7.81

Table 7 shows that bad weather is possibly at factor in bulk ship losses for voyages departing from South Africa and Western Australia.

Flag and Classification Society

Much of the debate about bulk ship losses suggests that ships of particular flag states and using particular classification societies are more likely to be poorly maintained than ships in other registries and classification societies. To test the hypothesis that flag of registry was an indicator of high we failure risk first classified both flags and classification societies according to their casualty performance. Each category contained about 25 per cent of the fleet.

This method of categorising ships introduces some circularity into the testing procedure so that it would be expected that the number of failures would decrease from the worst

Table 9 Results of Logit Analysis

Variable	*Parameter Estimate*	*Standard Error*
Intercept	-14.33	1.48
Iron ore	2.94	1.09
Other commodities[a]	2.85	1.13
Age	0.22	0.05
South Africa - Asia	2.77	0.81
WA - Nth Europe	3.76	0.64
Brazil - Asia	1.63	0.83
Flag	1.41	0.49

Notes: Log likelihood ratio for intercept and covariates = 222.05, Chi square for covariates = 94.43.

a Commodities other than iron ore, coal or grain. Coal and grain voyage failure probabilities are estimated by setting the iron ore and other commodites variables to zero.

Source: BTCE estimates based on Lloyd's voyage data.

category to the best. The results for the flag analysis in table 8 show that this was in fact found, but the results were not significant. The number of categories was reduced to two by combining the poor, fair and good categories. This gave a significant, but not strongly significant, result at the 5 per cent level of significance.

The analysis of classification societies does not allow rejection of the null hypothesis that structural failures occurred randomly among classification societies.

5 Logit Analysis

The chi-square analysis gives useful insights into the factors that might contribute to ship failure. However, chi-square analysis does not allow estimation of the relative strengths of individual factors. Logit analysis allows strengths of the variables to be explored. It is well suited to binary dependent variables such as in this application.If failures are coded as 1 and succesful voyages as 0, then the model represents the probability fo a ship failing. The relatively small number of ship failures (19 in the data base) compared with the large number of successful voyages (almost 29 000) means that there are limitations on how much additional insight that can be obtained.

The logistic curve used in this analysis was the standard form:

$$\Pr(\text{Ship fails}) = e^{\beta' \mathbf{x}}/(1 + e^{\beta' \mathbf{x}}) \qquad (1)$$

where β is a vector of coefficients to be estimated and $\mathbf{x}$ is a vector of explanatory variables.

The vector β is estimated by maximum likelihood techniques. The theory of logit analysis is described in several books such as Cox (1970).

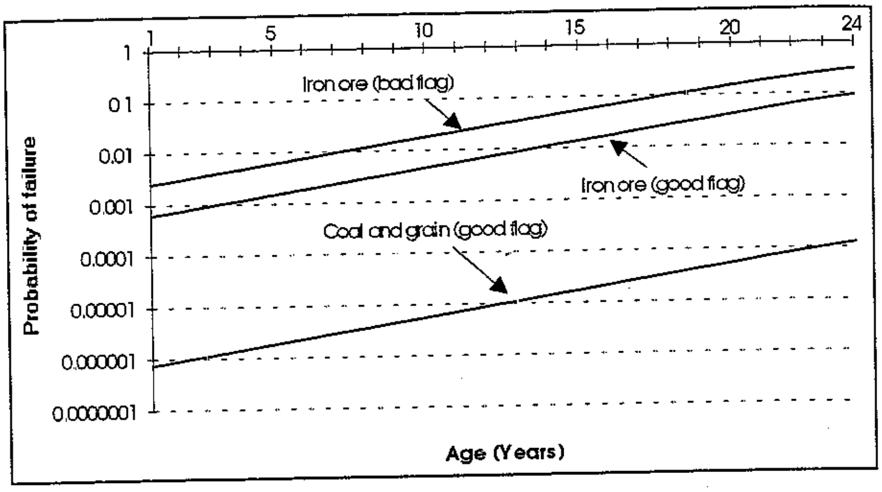

Figure 1 **Results of Logit Analysis for Ships Carrying Iron Ore from Western Australia to Europe Compared with Coal and Grain Voyages.**

The most useful of the logit analyses are those that allow testing of the combined effect of the explanatory variables. Table 9 shows the result of one such analysis combining route, age, flag and commodity. Size was not included because it was not significant when tested on its own or with other explanatory variables. Dummy variables were used for commodity, routes and flag. Age was included as a continuous variable

Although table 1 implies that iron ore is more significant than other commodities as an indicator of failure probability, the results in table 9 imply that iron ore and other commodities have similar effects on failure risk. The three routes included in the analysis are predominantly iron ore routes. Thsi suggests that much of the effect of iron ore on failure probability is included in the route parameters. Because of the small number of failures it was not possible to fully separate the effects of route and commodity

The results suggest that the major factors contributing to structural failure are route, commodity and age of the ship. Although flag is significant, it has a lesser contribution to failure risk than route or commodity.

The results of the analysis are illustrated in figure 1. Three cases are shown. Two are for ships carrying iron ore from Western Australia to North Europe, one for ships sailing under a 'good' flag and the other for ships sailing under a 'bad' flag. The third case is for ships carrying coal or grain on other routes and sailing under a 'good' flag. The carriage of iron ore on the Western Australia to North Europe route increases the risk to significant levels or above that facing a ship of 24 years carrying coal or grain. If the ship also flies a flag of one of the registries allocated to the bad category, the risk is increased further. The coal and grain and the iron ore with the bad flag curves in figure 1 represent the extreme cases estimated by the model.

In figure 1, ships sailing under 'bad' flags have a risk of failure equal to that of a ship six years older sailing under a 'good' flag. Alternatively, on average ships sailing under 'bad' flags tend to have an effective age six years older than a ship sailing under a 'good' flag. The ratio of the change in probability from the coal and grain case to the Australia to Northern Europe route is much larger than the ratio between bad and good flags suggesting that choice of route has a much greater impact on failure risk than the flag of the ship.

The probability of failure predicted by the analysis should not be considered reliable. The confidence limits of the predictions are likely to be rather wide. In addition, the analysis is based on a small number of failures. A small change in the number of failures could change the probabilities markedly. The value of the model is in illustrating the relative strengths of the variables. For example figure 1 illustrates the major effect that choice of route has on failure probability.

6 Conclusion

The results of the statistical analysis confirm what has been suspected for several years:age and commodity play an important role in the structural failure of bulk ships. Route also plays an important role. It has not been possible to separate the effects of commodity and route High risk of failure is probably a combination of the two. The high stresses imposed by carrying high density commodities such as iron ore are compounded by the additional stresses imposed by extreme weather conditions frequently encountered on some routes. This is an area where further research into likely weather conditions and the loads old ships can safely carry in those conditions could make a useful contribution to bulk ship safety.

Although the flag a ship sails under can be an indication of ship condition it is by no means as strong an indication as is often suggested. Identity of owner is likely to be a better indication, but the information available did not allow such an analysis to be made in this study.

7 References

American Bureau of Shipping 1992 *Submission No 39*, House of Representatives Standing Committee on Transport, Communications and Infrastructure Inquiry into Ship Safety.

Australian Coal Association 1992 *Submission No 27*, House of Representatives Standing Committee on Transport, Communications and Infrastructure Inquiry into Ship Safety.

British Maritime Technology 1986 *Global Wave Statistics*, Unwin, Old Woking, England.

Cox D. R. 1970 *The Analysis of Binary Data*, Methuen, London.

CRA 1992 *Submission No 30*, House of Representatives Standing Committee on Transport, Communications and Infrastructure Inquiry into Ship Safety.

DTC 1992 *Submission No 34*, House of Representatives Standing Committee on Transport, Communications and Infrastructure Inquiry into Ship Safety

Fearnleys 1992 *World Bulk Trades 1991*, Fearnresearch, Oslo, Norway and earlier issues.

HORSCOTCI 1992 *Inquiry into Ship Safety, Report from the House of Representatives Standing Committee on Transport Communications and Infrastructure*, AGPS Canberra.

Lloyd's Register 1992a *Bulk Carriers - The Safety Issues*, Ship Division, London

--- 1992b *Casualty Return 1991*, London and earlier issues.

National Bulk Commodities Group 1992 *Submission No 31*, House of Representatives Standing Committee on Transport, Communications and Infrastructure Inquiry into Ship Safety.

NKK 1992 *Study Report on Bulk Carriers Loss*, Japan.

Strang F.G. 1971 *Handbook* F.G. Strang Pty Ltd, Melbourne.

Acknowledgments

The assistance and comments of Dr Leo Dobes and other colleagues at the Bureau of Transport and Communications Economics and by Dr Trevor Breusch of the Australian National University during the research undertaken for this paper are gratefully acknowledged. Nevertheless the views expressed in the paper are those of the authors and are not necessarily shared by the Bureau of Transport and Communications Economics or the Department of Transport and Communications.