APPENDIX IV

SHIP OIL SPILL RISK MODELS

APPENDIX IV - SHIP OIL SPILL RISK MODELS

Contents

IV.1 INTRODUCTION

IV.1.1 Objective

This appendix describes the models of ship oil spill risks that will be used in the project. The models are based on an analysis of ship accident experience, and are compared with previous risk estimates. The models cover ship accidents in ports and at sea. They are applicable to spills from all types of ships, with particular focus on oil tankers.

IV.1.2 Data Sources

The main data sources are the Lloyd's Register Fairplay (LRF) Casualty and Fleet Databases, supplemented by DNV analyses of other public-domain information such as Lloyd's Casualty Reports (LCR).

The LRF database covers all ships over 100GT world-wide. DNV extracted data in February 2011, covering the period up to the end of December 2010.

IV.1.3 Accident Severity

The LRF database categorises accidents into 3 severities: total loss, serious casualty and non-serious incident.

Total loss is where the ship ceases to exist after a casualty, either due to it being irrecoverable (actual total loss) or due to it being subsequently broken up (constructive total loss). The latter occurs when the cost of repair would exceed the insured value of the ship.

Serious casualties are defined as those involving:

- Total loss (as above).
- Breakdown resulting in the ship being towed or requiring assistance from ashore.
- Flooding of any compartment.
- Structural damage rendering the ship unseaworthy.

The term "serious casualty" includes total loss, unless stated explicitly as "serious casualty excluding total loss".

Non-serious incidents are defined by LRF as minor very superficial damage without the need for major repairs, or no significant delay in the voyage schedule, e.g. being stranded on a sand bar and floating off after the next high tide, or a minor engine breakdown repaired by the seagoing staff without an interruption to the voyage.

IV.1.4 Accident Trends

Figure IV.1.1 shows the historical trend in the annual numbers of the accidents in the world-wide fleet. During this time, the size of the exposed fleet steadily increased from 76,000 to 106,000 ships. This results in a trend in the accident frequencies as shown in Figure IV.1.2, which uses a logarithmic scale to make the trend in total losses clearer.

Figure IV.1.1 Accident Trends, 1980-2010

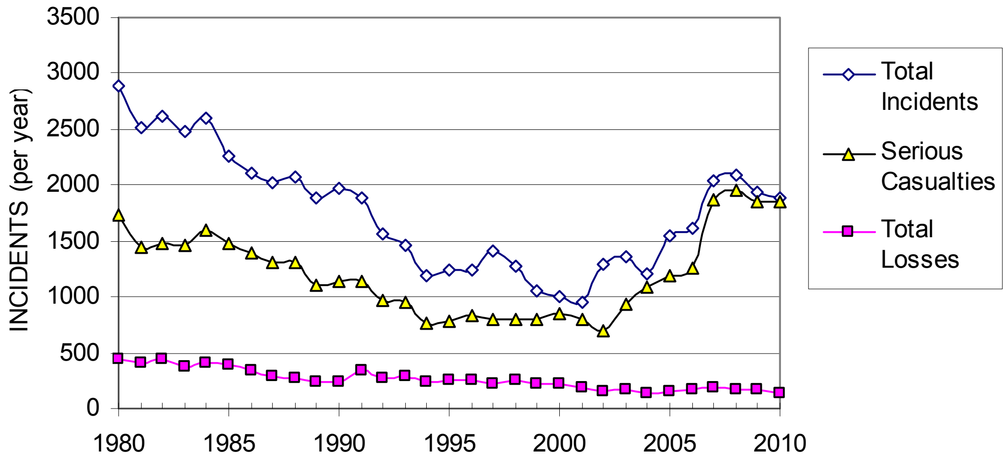
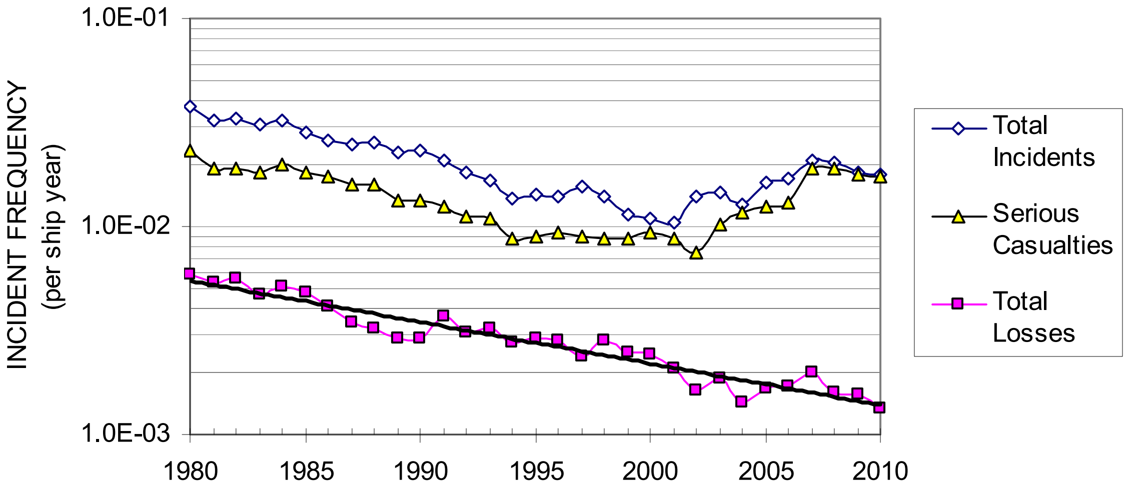


Figure IV.1.2 Accident Frequency Trends, 1980-2010



The plot shows that the frequency of total losses has declined at an average rate of approximately 5% per year, with some fluctuations that may be related to economic cycles Bijwaard & Knapp 2009). The frequencies of serious casualties (excluding total losses) followed a similar decline until 2002, but then increased significantly until 2007, since when it appears to have resumed its decline from a higher base. This pattern may result from a decline in safety standards in the world fleet during 2002-07, but is more likely to reflect a change in reporting and categorisation patterns in the LRF data. Unlike total loss, the definition of serious casualty is somewhat unclear, and may be affected by changes in interpretation.

In order to obtain average frequencies for the present study, it is necessary to average data over several years. The period 2008-10 may be most relevant but is too short to provide reliable results. Therefore the period 2000-10 is used, as this covers the period when serious casualties were increasing, without being excessively influenced by any one part of this period.

IV.1.5 Ship Types

In order to model the relative risks in different ports, with different mixes of ship types, several different ship types are distinguished. Their contributions to the world fleet and to Australian port calls are shown in Table IV.1.1. It is evident that the Australia has a different fleet mix to world average, which may be modelled using the frequencies for different ship types.

Table IV.1.1 Ship Type Breakdown

SHIP TYPE	WORLD FLEET (ship-years)	AUSTRALIAN DATA (port visits)
Oil tankers	7%	7%
Chemical tankers	3%	5%
Bulk carriers	7%	42%
General cargo ships	17%	9%
Container ships	4%	18%
Fishing vessels	25%	0%
Other ships	36%	19%
All ships	100%	100%

IV.1.6 Accident Categories

In order to model the relative risks in different locations, and the effects of oil spill prevention and mitigation measures the following accident categories are distinguished:

CN Collision - leak due to striking or being struck by another ship, whether under way, anchored or moored. Excludes striking underwater wrecks.

CT Contact - leak due to striking or being struck by an external object, but not another ship or the sea bottom. Includes striking offshore rigs/platforms, whether under tow or fixed.

FX Fire/explosion - leak due to fire and/or explosion where this is the first event reported. This includes fires due to engine damage, but not fires due to other categories, such as collision etc.

HD Hull damage - leak due to damage to hull, structural failure, loss of stability or flooding. It includes the LRF category “foundered”.

TS Transfer spill - leak due to failure or error during loading/unloading cargo or fuel oil. This includes loading in port and during ship-to-ship transfer. It excludes offshore loading (see Appendix V.5.2). Typical causes include overflow, hose failure, errors in setting valves etc.

UD Unauthorised discharge - pollution due to deliberate or accidental discharge of oil or oily water through hull valves, pipes or scuppers, except due to loading/unloading. Typical causes include, bilge pumping, hydraulic line failure, errors during internal fuel transfer, separator faults, oil in ballast water etc.

WS Wrecked/stranded - striking the sea bottom, shore or underwater wrecks. This is split into:

GD Drift grounding - leak due to grounding while not under control, typically due to loss of propulsion and/or anchors in adverse weather.

GP Powered grounding - leak due to grounding while under power, typically due to navigational error. This includes cases where power is lost close to the point of grounding, before the ship begins to drift.

The following category is neglected as not significant in Australia, compared to the other categories:

LT War loss/damage during hostilities - leak due to hostile acts.

IV.2 COLLISION

IV.2.1 Definition

In this analysis, collision is defined as an event where two vessels accidentally come into contact with each other while under way, anchored or moored. This may lead to sinking, grounding or to a fire on the vessel, but this study focuses on the potential for oil spills.

The analysis includes collisions involving vessels moored at a berth, jetty or quay. These were covered separately as "strikings" in the previous study (DNV 1999), but it in reality the traffic data in port areas is insufficiently detailed to model these accurately in a nationwide study.

In the LRF data, collisions are coded for each involved ship, and so the data below refers to collision involvements. The spill probabilities take account of the fact that usually only one of the two ships spills any oil.

IV.2.2 Collision Frequencies

Table IV.2.1 shows collision experience and the size of the world fleet during 2000-10 from LRF. Table IV.2.2 and Figure IV.2.1 show the collision frequencies calculated from this data.

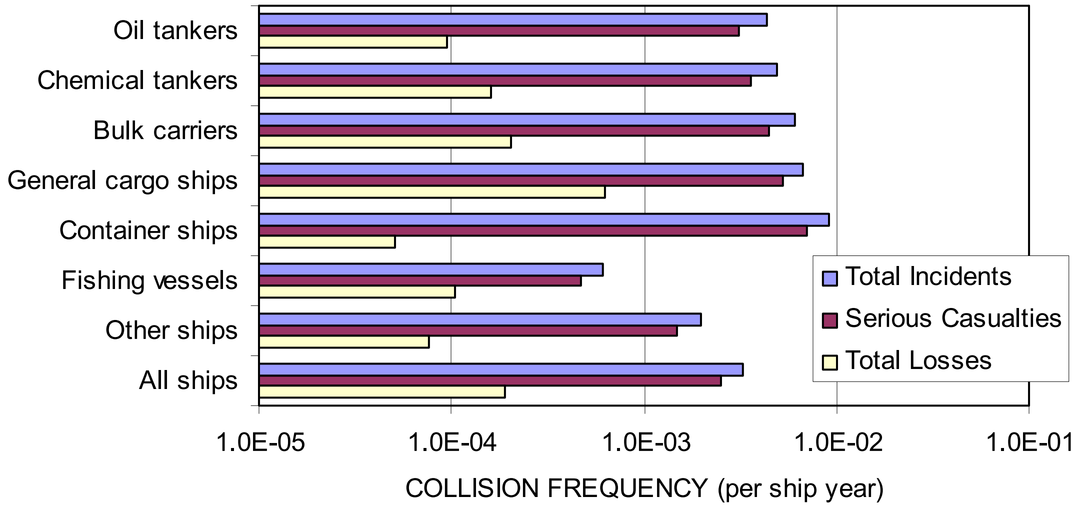
Table IV.2.1 Collision Experience, 2000-10

SHIP TYPE	EXPOSURE (ship years)	NON-SERIOUS INCIDENTS	SERIOUS CASUALTIES (exc total loss)	TOTAL LOSS
Oil tankers	74,471	96	224	7
Chemical tankers	37,292	51	128	6
Bulk carriers	78,265	126	336	16
General cargo ships	184,878	263	864	116
Container ships	39,527	84	279	2
Fishing vessels	268,966	38	100	28
Other ships	382,588	184	536	29
All ships	1,065,986	842	2,467	204

Table IV.2.2 Collision Frequencies (per ship year), 2000-10

SHIP TYPE	NON-SERIOUS INCIDENTS	SERIOUS CASUALTIES (exc total loss)	TOTAL LOSS
Oil tankers	1.3E-03	3.0E-03	9.4E-05
Chemical tankers	1.4E-03	3.4E-03	1.6E-04
Bulk carriers	1.6E-03	4.3E-03	2.0E-04
General cargo ships	1.4E-03	4.7E-03	6.3E-04
Container ships	2.1E-03	7.1E-03	5.1E-05
Fishing vessels	1.4E-04	3.7E-04	1.0E-04
Other ships	4.8E-04	1.4E-03	7.6E-05
All ships	7.9E-04	2.3E-03	1.9E-04

Figure IV.2.1 Collision Frequencies, 2000-10



Comparing the different ship types, it is possible that the variations in frequencies of incidents and serious casualties are affected by differences in reporting standards between the different ship types. The variation in frequency of total loss is more in line with subjective judgements about their relative risks.

Because oil spill data is most comprehensive for oil tankers, the frequencies for the other ship types are expressed as modification factors defined as:

$$MF_{type} = \frac{\text{Accident frequency for vessel type}}{\text{Accident frequency for oil tanker}}$$

These MFs are shown in Table IV.2.3.

Table IV.2.3 Collision Frequencies Relative to Oil Tankers, 2000-10

SHIP TYPE	NON-SERIOUS INCIDENTS	SERIOUS CASUALTIES (exc total loss)	TOTAL LOSS
Oil tankers	1.000	1.000	1.000
Chemical tankers	1.061	1.141	1.712
Bulk carriers	1.249	1.427	2.175
General cargo ships	1.104	1.554	6.675
Container ships	1.649	2.347	0.538
Fishing vessels	0.110	0.124	1.108
Other ships	0.373	0.466	0.806
All ships	0.613	0.769	2.036

IV.2.3 Oil Spill Probabilities

Table IV.2.4 shows oil spill experience due to collision for oil tankers during 2000-10 from LRF. These are based on oil spills with known quantities, and may be changed with further investigation of the LRF data where the oil spill quantities are unknown. They include ships that were loaded and in ballast, and hence in effect include a 50% probability of the ship being fully loaded, plus a 50% probability of it being in ballast with only bunker fuel on board.

Table IV.2.4 Oil Tanker Oil Spill Frequencies due to Collision, 2000-10

SEVERITY	OIL SPILLS	OIL SPILL PROBABILITY (per collision)	OIL SPILL FREQUENCY (per ship year)
Total losses	3	0.43	4.0×10^{-5}
Serious casualties (exc total losses)	33	0.15	4.4×10^{-4}
Non-serious incidents	3	0.03	4.0×10^{-5}
Total incidents	39	0.12	5.2×10^{-4}

The overall oil spill frequency of 5.2×10^{-4} is a factor of 2 lower than a previous study of tankers (DNV 2001), which estimated a value of 1.1×10^{-3} per ship year for 1992-97. This is consistent with the increasing use of double hulls since then. Since a total reduction by a factor of 4 was predicted for the adoption of double hulls (DNV 2001), the current oil spill probabilities are assumed to be a further factor of 2 lower than in the table above. This takes account of the absence of single hull tankers in Australian ports and waters.

Equivalent values are not available for other ship types, because they are much less closely monitored. On vessels other than oil tankers, oil spills would only involve bunker fuel. Therefore their spill probabilities can be estimated from spills of bunker fuel on tankers. Table IV.2.5 shows bunker spill experience due to collision for oil tankers during 1992-97, and compares it to the number of collisions to estimate the bunker spill probabilities. This data comes from a period when oil tankers were mainly single-hull, and so is valid for other types of ships.

Table IV.2.5 Oil Tanker Bunker Spill Probabilities due to Collision, 1992-97

SEVERITY	BUNKER SPILLS	COLLISIONS	BUNKER SPILL PROBABILITY (per collision)
Total losses	2	10	0.2
Serious casualties (exc TL)	4	53	0.08
Non-serious incidents	1	338	0.003
Total incidents	7	401	0.02

These probabilities are a factor of 2-10 less than for oil tankers. This is broadly consistent with the assumed factors of 3 to 10 that were used in the previous study (DNV 1999).

IV.2.4 Location Probabilities

Table IV.2.6 shows the breakdown of locations for oil spills from tankers due to collision, from which the location probabilities can be calculated as shown. Three location types are distinguished, as follows:

- Port – moored at a berth or jetty or inside a dock basin.
- Restricted water – in port approaches, rivers, enclosed bays or at an anchorage.
- Sea – in open water, including coastal channels and straits.

When applying to the present study, for consistency with AUSREP reporting, any point more than 2 hours from port is counted as being at sea. Hence the shipping routes in the Great Barrier Reef and Torres Strait (Figure I.3.2) are counted as locations at sea, and restricted water is only used for approach channels to individual ports.

Table IV.2.6 Locations of Oil Tanker Spills due to Collision, 2000-10

LOCATION	OIL SPILLS	LOCATION PROBABILITY (per spill)
Port	10	0.27
Restricted water	8	0.22
Sea	19	0.51
Total	37	1.00

IV.2.5 Oil Spill Frequencies

The oil spill frequencies are related to location-specific measures of exposure, as follows:

- In port - per port visit, assuming an average of 80 port visits per year.
- In restricted water - per km, assuming an average length of 30km in restricted water per port transit (approach or departure), i.e. 30x2x80 = 4800 km per year.
- At sea - per hour, assuming the ship is at sea for an average of 50% of the year, i.e. 365x24x0.5 = 4380 hours per year.

These exposures are based on estimates for oil tankers (DNV 2001), and are assumed valid for all ships types in the absence of better data.

Table IV.2.7 gives the overall oil spill frequencies due to collision for each ship type.

Table IV.2.7 Frequencies of Oil Spills due to Collision

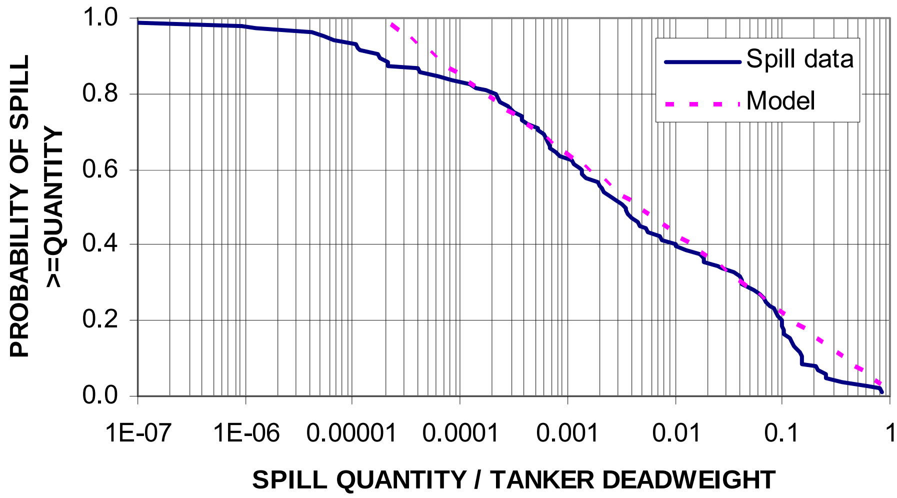
SHIP TYPE	IN PORT (per visit)	IN RESTRICTED WATER (per km)	AT SEA (per hour)	TOTAL (per year)
Oil tankers	8.8E-07	1.2E-08	3.1E-08	2.6E-04
Chemical tankers	1.0E-06	1.3E-08	3.5E-08	3.0E-04
Bulk carriers	1.2E-06	1.7E-08	4.3E-08	3.7E-04
General cargo ships	1.6E-06	2.2E-08	5.7E-08	4.8E-04
Container ships	1.9E-06	2.5E-08	6.4E-08	5.5E-04
Fishing vessels	1.7E-07	2.2E-09	5.8E-09	4.9E-05
Other ships	4.1E-07	5.5E-09	1.4E-08	1.2E-04

For oil tankers at sea (T1 tankers in 2% bad visibility), the previous study (DNV 1999) estimated a frequency of oil spills due to collision of 6.8×10^{-8} per ship hour. The current estimate of 3.1×10^{-8} per hour is a factor of 2 lower, reflecting the benefit of double hulls.

IV.2.6 Spill Size Distribution

Figure IV.2.2 shows the size distribution of spills due to collisions on oil tankers during 1992-2010. This includes data from 1992-99, in which the oil spill quantities have been investigated using sources other than LRF. These sources included Lloyd's Casualty Reports, the International Tanker Owners Pollution federation (ITOPF) and the International Oil Pollution Compensation (IOPC) fund. Where the spill quantity is not reported, estimates have been made based on the spill source or pollution extent, in order to reduce under-reporting. Although many of the spills were from single hull tankers, the size distribution (unlike the spill probability) is assumed applicable to double hull tankers too. In order to take account of the tanker size, the size distribution is expressed as a function of the spill size divided by the tanker deadweight.

Figure IV.2.2 Oil Tanker Oil Spill Size Distribution due to Collision, 1992-2010



A simple analytical model of spill quantity (Q) as a fraction of tanker deadweight (D) is fitted to the data as follows:

$P(Q/D) = 0.01 - 0.21 \log (Q/D)$ for Q and D in any consistent units, e.g. tonnes

The probability is by definition constrained to be within the range $0 \le P(Q/D) \le 1$.

The model diverges from the data in the region S/D<0.0001, but this may be interpreted as a correction for possible under-reporting of very small spills. It over-estimates the risk in the region 0.1 < S/D < 0.8 by up to a factor of 2, which is an inherent limitation of this simple model.

The mean spill quantity, given an oil spill due to collision, from oil tankers in the dataset was 6% of deadweight. The mean spill quantity from the model is 9% of deadweight. The difference results from the over-estimation described above.

Despite its limitations, this model is advantageous for the present study because it can be used to estimate the size distribution of bunker oil spills from other ship types. To do this, the deadweight is replaced by the bunker oil capacity. As with cargo spills, this takes account of the likelihood that the bunker tanks are only part full.

IV.2.7 Effect of Traffic Density

The traffic density in each sea area is available from AUSREP data. The collision frequencies at sea above are assumed to refer to a world average traffic density. The area of the world's oceans is approximately 360 million km^2. During 2000-10, there were on average 97,000 ships in the LRF database. If they spent an average of 50% of their time at sea (as above), this would be an average of 48,500 at sea. This implies a world average ship density of 48500/360 = 135 ships per million km^2. In fact, most ships cluster together in relatively few parts of the ocean, so a density of twice this is used, i.e. 270 ships per million km^2.

The collision frequency per ship hour or year at sea is assumed to be proportional to the traffic density in the area. This has been a common assumption since the first encounter-based collision models (Lewison 1980). In reality navigators may take more care in crowded waters. It implies a modification factor for the collision frequency as follows:

Collision frequency per hour = Average collision frequency per hour x MF_{traf}

MF_{traf} = Traffic density (per million km^2)/270

The traffic level in each port is available from BITRE data. In 2008-09 the average traffic was 26709/62 = 430 visits per port year. The collision frequencies in port and restricted waters above are assumed to refer to this average traffic level. The modification factor for ports and restricted waters are therefore:

MF_{traf} = Port visits (per year)/430

IV.2.8 Effect of Approach Type

The approach types for each port can be characterised by average approach channel length and width. In practice, approach length is taken into account explicitly by using the frequencies per km in restricted water, together with the length of restricted water from the port to the open sea. This has been estimated from the satellite photographs in Google Maps. Because AUSREP reporting begins within 2 hours of port departure, the approach length is limited to 2 hours x 8 knots x 1.85 km/nm = 30 km, in order to avoid double-counting of time in restricted water and at sea.

The modification factors for approach channel width (based on DNV 1999 and normalised to the wide river type) are:

Narrow rivers (under 0.5 km mean width)	MF_{width} = 4.2
Wide rivers (0.5 to 2.5 km mean width)	MF_{width} = 1.0
Wide estuaries (over 2.5 km mean width)	MF_{width} = 0.3
Open sea ports (lock/breakwater approach)	MF_{width} = 4.2

These factors are very old and improved data would be desirable. For each port, the mean channel width has been estimated from the satellite photographs in Google Maps, and used to categories each port into one of the 4 types above. The open sea category is taken to include ports with no river or estuary, but harbours protected by breakwaters or jetties extending into deep water with no protection from waves.

IV.2.9 Effect of Visibility

Visibility data has been obtained for each calculation sub-region, giving the proportion of time the visibility is "bad", defined as less than 1000m. The effect of visibility was modelled previously (DNV 1999) as:

Collision frequency in bad visibility = 6.9 x Collision frequency in good visibility

If on average bad visibility applies for 2% of the time, this implies a modification factor for the collision frequency as follows:

Collision frequency per hour = Average collision frequency per hour x MF_{vis}

MF_{vis} = 5.3 x Probability of bad visibility + 0.9

IV.2.10 Effect of Risk Reduction Measures

The effects of risk reduction measures are based on the previous study (DNV 1999):

- Vessel traffic services $MF_{VTS} = 0.16$
- Traffic separation scheme $MF_{STS} = 0.40$
- Compulsory pilotage $MF_{pilot} = 0.51$

These were based on a generic case where VTS, TSS and compulsory pilotage were unusual. This is still the case at sea, but most ports now have compulsory pilotage for most trading ships. Therefore in the case of ports, the modification is required in the few cases where there is not compulsory pilotage:

- Non-compulsory pilotage $MF_{pilot} = 2.0$

IV.2.11 Effect of Double Hull

Prior to 2010, many older oil tankers were of single hull design, in which the oil cargo is protected by just the side or bottom shell plating. Most non-tanker vessels are still of the same design, with single hull protection on their bunker oil tanks.

The International Convention for the Prevention of Pollution from Ships (MARPOL) required tankers over 20,000dwt to have segregated ballast tanks protectively located (SBT/PL), so as to provide some protection against impact damage, but this did not amount to a complete double hull. However, chemical tankers were required to have double hulls, with a narrow ballast space between the cargo tanks and the shell plate.

The US Oil Pollution Act in 1990 (OPA 90) imposed double hull requirements on new and existing oil tankers, according to vessel age limits (between 23 and 30 years, as from 2005) and set deadlines (2010 and 2015) for the phasing out of single-hull oil tankers in the USA.

The International Maritime Organisation (IMO) established double hull standards in 1992 which required all oil tankers over 600 dwt delivered from July 1996 to have a double hull or equivalent. Tankers over 20,000 dwt and delivered before July 1996 had to comply with the double-hull standards by the time they were 25 years old, or 30 years with SBT/PL. These age limits are close to the end of the commercial life for most tankers.

Accelerated phase-out requirements were adopted by IMO in 2005, which required Category 1 tankers (i.e. pre-MARPOL tankers over 20,000 dwt with no SBT/PL) to be phased out by 2005. Category 2 tankers (i.e. MARPOL tankers over 20,000 dwt with SBT/PL) were to be phased out by 2010, as were smaller Category 3 tankers (over 5000dwt).

Virtually all oil tankers are now of double-hull design. Most single-hull oil tankers were phased out of operation by the end of 2010. A very small proportion are permitted to remain in operation if they are less than 25 years old, pass condition assessments and are approved by the national administration. None of these now visit Australia.

A total reduction in oil spill probability by a factor of 4 was predicted for the adoption of double hulls (DNV 2001). This is consistent with the recent data on oil spill probabilities, and has been used in the probabilities selected in Section IV.2.3.

IV.2.12 Effect of Ship Size

There is a trend towards increasing ship size. Larger ships are more difficult to manoeuvre in ports of a given size. On the other hand, this difficulty is quite evident, and so tends to be compensated by improved manoeuvring devices, pilotage requirements and tug assistance. Available data (DNV 2001) suggests that there is no significant effect of ship size on accident frequencies, and that apparently lower frequencies on small ships may be due to under-reporting. Therefore the accident frequencies are here assumed independent of ship size.

Larger ships tend to have larger cargoes and larger bunker capacities, and therefore tend to spill larger quantities in an accident. This is accounted for by expressing the spill quantity as a fraction of the deadweight or bunker capacity (Section IV.2.6). In fact, this may over-estimate the effect of ship size, but at present no better model is available that is simple enough for the present study.

Larger ships tend to have slightly smaller bunker capacities, as a fraction of deadweight. This is accounted for by using different fractions for the three ship size categories (Appendix I.2.4).

Overall, this produces oil spill risks that increase with ship size, when measured in tonnes per ship year, but remain largely unaffected by ship size when measured in tonnes spilled per tonne of cargo shipped.

IV.2.13 Validation

The generic oil spill frequencies above have been combined with the exposure of trading ships in Australia (Appendix I) to estimate the rate of oil spills due to collisions in Australian ports and waters. This gives an expected rate of 0.13 oil spills per year due to collision, of which only 7% were due to oil tankers. When small commercial vessels (SCVs) are included, the total rises to 1.4 per year.

This does not take account of traffic density or other specific features of Australian ports and waters. It also does not take account of the fact that spills from trading ships and SCVs would be of very different sizes. The oil spill risk model, which does represent these, gives a rate of spills over 1 tonne due to collision of 0.12 per year for trading ships, which rises to 0.22 per year when SCVs are included.

AMSA spill data (Appendix III) shows a total of 6 oil spills over 1 tonne due to collision during 1982-2010, which is an average of 0.21 per year. Of this, 50% was due to oil tankers and two of the events were oil tankers holed by tugs. This data also includes 2 spills, one from a fishing vessel and one from a dredger, which are included in the small commercial vessel category.

Table IV.2.8 Frequencies of Oil Spills Over 1 Tonne due to Collision

SHIP TYPE	PREDICTED FREQUENCIES (per year)	HISTORICAL SPILLS 1982-2010	HISTORICAL FREQUENCIES (per year)
Oil tankers	0.01	3	0.10
Chemical tankers	0.00	0	0.00
Bulk carriers	0.06	1	0.03
General cargo ships	0.01	0	0.00
Container ships	0.03	0	0.00
Other ships (inc SCVs)	0.11	2	0.07
All ships	0.22	6	0.21

The comparison in Table IV.2.8 shows that the model predicts spill frequencies that are close to historical average. The low predicted frequency of spills from oil tankers compared to the historical data results from the increasing adoption of double hulls. Other differences may result from the small number of historical events or under-reporting in the data. It is concluded that the current model is sufficiently accurate and does not require adjustment.

IV.3 CONTACT

IV.3.1 Definition

In this analysis, contact is defined as an event where a ship strikes or is struck by an external object, but not another ship or the sea bottom. These events were known as "impacts" in the previous study (DNV 1999), but the standard LRF term is now used here. It also includes collisions with offshore rigs/platforms, whether under tow or fixed. It includes collisions with ice where these damage the ship. The consequences can include sinking, grounding or fire on the vessel, but this study focuses on the potential for oil spills.

IV.3.2 Contact Frequencies

Table IV.3.1 shows impact frequencies on oil tankers during 2000-10 from LRF. There are too few events to give reliable figures for other ship types, so the modification factors from collisions (Table IV.2.3) are used to estimate them.

Table IV.3.1 Contact Frequencies on Oil Tankers, 2000-10

SEVERITY	CONTACTS	CONTACT FREQUENCY (per ship year)
Total losses	3	4.0×10^{-5}
Serious casualties (exc total losses)	45	6.0×10^{-4}
Non-serious incidents	26	3.5×10^{-4}
Total incidents	74	9.9×10^{-4}

IV.3.3 Oil Spill Probabilities

There were 11 cases of oil spills from oil tankers due to contact during 2000-10 according to LRF. These are preliminary figures and may be changed with further validation of the LRF data. All were serious casualties. This gives an average oil spill probability of 11/74 = 0.15 given a contact, and an oil spill frequency of $0.15 \times 9.9 \times 10^{-4} = 1.5 \times 10^{-4}$ per ship year.

This is a factor of 4 lower than a previous study of tankers (DNV 2001), which estimated a value of 5.7×10^{-4} per ship year for 1992-97. This is consistent with the increasing use of double hulls since then, and the relatively high benefit of double hulls for contacts, which are mainly low-energy impacts.

In order to distribute the oil spill probability by event severity, the values from collision are increased by a factor of 0.15/0.12 = 1.25. This also takes account of the additional benefit of double hulls adopted since the above data was collected.

Equivalent values are not available for other ship types, because they are much less closely monitored. Therefore their spill probabilities are also assumed to be 1.25x those for collisions.

IV.3.4 Location Probabilities

Table IV.3.2 shows the breakdown of locations for oil spills from tankers due to contact, from which the location probabilities can be calculated as shown. The tanker oil spill data records no contacts at sea. The frequency of this event is estimated from the frequency of collisions with offshore platforms below.

Table IV.3.2 Locations of Oil Tanker Spills due to Contact, 2000-10

LOCATION	OIL SPILLS	OIL SPILL FREQUENCY (per ship year)	LOCATION PROBABILITY (per spill)
Port	7	9.2×10^{-5}	0.63
Restricted water	4	5.3×10^{-5}	0.36
Sea	0	1.4×10^{-6}	0.01
Total	11	1.5×10^{-4}	

IV.3.5 Collisions with Offshore Platforms

The world average frequency of collisions with offshore platforms is estimated as follows. There were 24 recorded passing vessel collisions with offshore installations world-wide during 1990-2002 (OGP 2010). This source also indicates that 46% of passing vessel collisions involved fishing vessels, 23% involved offshore vessels associated with other installations and hence 31% involved other merchant ships. The world-wide vessel exposure during this period is obtained from LRF, and the average collision frequencies are obtained as shown in Table IV.3.3. The average oil spill probability is taken as 0.15 from above. This gives the average oil spill frequencies shown in the table.

Table IV.3.3 Estimate of Ship-Platform Collision Frequencies, 1990-2002

SHIP TYPE	% OF SHIP-PLATFORM COLLISIONS	SHIP-PLATFORM COLLISIONS	EXPOSURE (ship years)	COLLISION FREQUENCY (per ship year)	OIL SPILL FREQUENCY (per ship year)
Fishing vessels	46%	11	329,940	3.3×10^{-5}	5.0×10^{-6}
Offshore vessels	23%	5.5	49,923	1.1×10^{-4}	1.6×10^{-5}
Other merchant ships	31%	7.4	782,396	9.5×10^{-6}	1.4×10^{-6}
Total	100%	24	1,162,259	2.1×10^{-5}	3.1×10^{-6}

IV.3.6 Oil Spill Frequencies

The oil spill frequencies are related to location-specific measures of exposure, as above. Table IV.3.3 gives the overall oil spill frequencies due to contact for each ship type.

Table IV.3.3 Frequencies of Oil Spills due to Contact

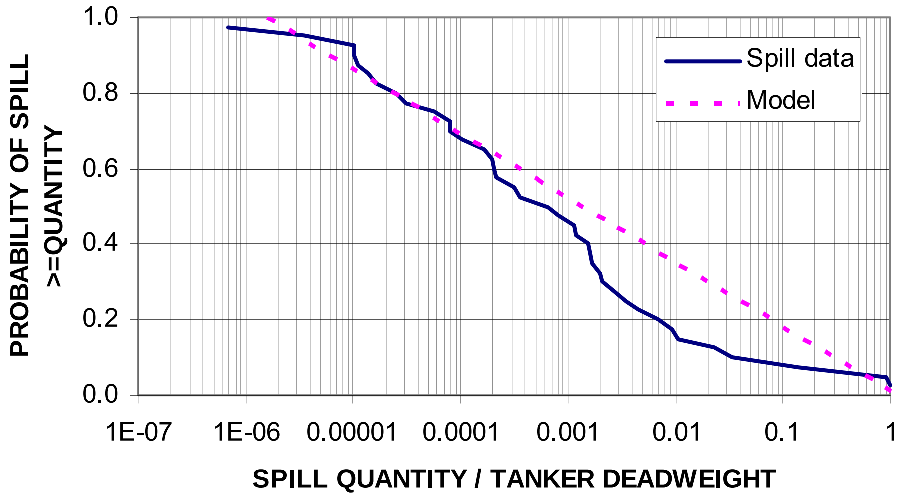
SHIP TYPE	IN PORT (per visit)	IN RESTRICTED WATER (per km)	AT SEA (per hour)	TOTAL (per year)
Oil tankers	1.1E-06	1.1E-08	3.2E-10	1.5E-04
Chemical tankers	5.1E-07	5.1E-09	3.2E-10	6.7E-05
Bulk carriers	6.5E-07	6.4E-09	3.2E-10	8.4E-05
General cargo ships	9.8E-07	9.5E-09	3.2E-10	1.3E-04
Container ships	8.8E-07	8.6E-09	3.2E-10	1.1E-04
Fishing vessels	5.4E-08	1.1E-09	1.1E-09	1.5E-05
Other ships	2.1E-07	2.1E-09	3.2E-10	2.8E-05

For oil tankers, the oil spill frequency of 1.1×10^{-6} per port visit is a factor of 11 lower than the previous study (DNV 1999), which estimated a value of 1.3×10^{-5} per visit for impacts in wide river ports. This may be due to more recent data, including the effects of double hulls.

IV.3.7 Spill Size Distribution

Figure IV.3.1 shows the size distribution of spills due to contacts on oil tankers during 1992-2010 from LRF and other sources. In order to take account of the tanker size and bunker capacity on other ships, the size distribution is expressed as a function of the spill size divided by the tanker deadweight.

Figure IV.3.1 Oil Tanker Oil Spill Size Distribution due to Contact, 1992-2010



A simple analytical model of spill quantity (Q) as a fraction of tanker deadweight or bunker capacity (D) is fitted to the data as follows:

$$P(Q/D) = 0.01 - 0.17 \log (Q/D)$$ for Q and D in any consistent units, e.g. tonnes

The probability is by definition constrained to be within the range $0 \le P(Q/D) \le 1$.

The model over-estimates the risk in the region $0.0002 < S/D < 0.6$ by up to a factor of 2, which is an inherent limitation of this simple model.

The mean spill quantity, given an oil spill due to contact, from oil tankers in the dataset was 5.6% of deadweight. The mean spill quantity from the model is 7.5% of deadweight. The difference results from the over-estimation described above.

IV.3.8 Effect of Offshore Platform Density

The frequency of collisions with offshore platforms reflects the average density of offshore platforms. The world-wide exposure of offshore platforms during 1990-2002 was 97,627 (OGP 2010), which is an average of 7500 platforms. Compared to the area of world oceans, this is an average density of 7500/360 million = 21 platforms per million km^2.

The collision frequency per ship hour or year at sea is assumed to be proportional to the platform density in the area. This implies a modification factor for the collision frequency as follows:

Collision frequency per hour = Average collision frequency per hour x MF_{plat}

MF_{plat} = Platform density (per million km^2)/21

IV.3.9 Effect of Ice

The presence of ice and icebergs off the Australian Antarctic Territory is expected to increase the probability of contacts resulting in oil spills. On the other hand, any such increase will be mitigated by the very evident nature of the hazard, the existence of protection measures in design and precautions in operating procedures, the wish to avoid accidents in remote areas where assistance will be difficult, and the concern to protect the Antarctic environment. Furthermore, the relative absence of other obstacles such as offshore installations, floating debris, anchors etc in Antarctic waters may result in the overall frequency of spills due to contacts being similar to average in other operating areas. No data is known that compares the frequencies of such events in the Antarctic with other sea areas. Therefore at present no adjustment is made to the spill frequency.

IV.3.10 Effect of Approach Type

The approach types for each port can be characterised by average approach channel length and width. The modification factor for approach channel length is implicit in the formulation of frequency per km of approach. The modification factors for approach channel width (based on DNV 1999 and normalised to the wide river type) are:

Narrow rivers (under 0.5 km mean width)	MF_{width} = 3.1
Wide rivers (0.5 to 2.5 km mean width)	MF_{width} = 1.0
Wide estuaries (over 2.5 km mean width)	MF_{width} = 1.05
Open sea ports (lock/breakwater approach)	MF_{width} = 1.05

These factors are very old and are considered to be very uncertain.

IV.3.11 Other Effects

Other possible effects on the contact frequency are:

- Visibility - assumed to be the same as for collisions.
- Risk reduction measures (VTS, TSS and pilotage) - assumed to be the same as for collisions.
- Traffic density - no effect.
- Ship size - no significant effect.
- Sea state - no significant effect.

IV.3.12 Validation

The generic oil spill frequencies above have been combined with the exposure of trading ships in Australia (Appendix I) to estimate the rate of oil spills due to contacts in Australian ports and waters. This gives an expected rate of 0.023 oil spills per year due to contact, of which only 7% is due to oil tankers. When small commercial vessels (SCVs) are included, the total rises to 0.43 per year.

This does not take account of pilotage or other specific features of Australian ports and waters. It also does not take account of the fact that spills from trading ships and SCVs would be of very different sizes. The oil spill risk model, which does represent these, gives a rate of oil spills over 1 tonne due to contact of 0.016 per year for trading ships, which rises to 0.054 when SCVs are included

AMSA spill data (Appendix III) shows a total of 2 oil spills over 1 tonne due to contacts during 1982-2010, which is an average of 0.069 per year. One of these was on a trading ship.

Table IV.3.4 Frequencies of Oil Spills Over 1 Tonne due to Contact

SHIP TYPE	PREDICTED FREQUENCIES (per year)	HISTORICAL SPILLS 1982-2010	HISTORICAL FREQUENCIES (per year)
Oil tankers	0.001	0	0.00
Chemical tankers	0.001	0	0.00
Bulk carriers	0.006	0	0.00
General cargo ships	0.002	1	0.03
Container ships	0.004	0	0.00
Other ships (inc SCVs)	0.040	1	0.03
All ships	0.054	2	0.07

The comparison in Table IV.3.4 shows that the model predicts spill frequencies that are reasonably close to historical average. The differences may result from the small number of historical events. It is concluded that the current model is sufficiently accurate and does not require adjustment.

IV.4 FIRE/EXPLOSION

IV.4.1 Definition

In this analysis, fire/explosion includes any fire and/or explosion that does not result from another event category. For example, it includes fires due to engine damage, but not fires due to collision or transfer spill.

IV.4.2 Fire/Explosion Frequencies

Table IV.4.1 shows fire/explosion experience and the size of the world fleet during 2000-10 from LRF. Table IV.4.2 and Figure IV.4.1 show the fire/explosion frequencies calculated from this data.

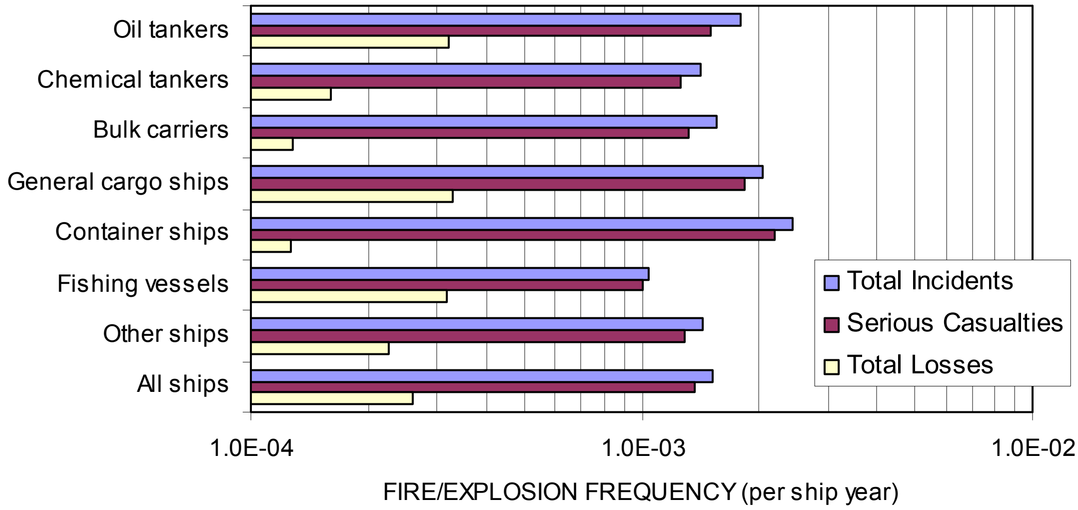
Table IV.4.1 Fire/Explosion Experience, 2000-10

SHIP TYPE	EXPOSURE (ship years)	NON-SERIOUS INCIDENTS	SERIOUS CASUALTIES (exc total loss)	TOTAL LOSS
Oil tankers	74,471	21	88	24
Chemical tankers	37,292	6	41	6
Bulk carriers	78,265	19	93	10
General cargo ships	184,878	35	280	61
Container ships	39,527	10	81	5
Fishing vessels	268,966	11	185	85
Other ships	382,588	59	404	86
All ships	1,065,986	161	1,172	277

Table IV.4.2 Fire/Explosion Frequencies, 2000-10

SHIP TYPE	NON-SERIOUS INCIDENTS	SERIOUS CASUALTIES (exc total loss)	TOTAL LOSS
Oil tankers	2.8E-04	1.2E-03	3.2E-04
Chemical tankers	1.6E-04	1.1E-03	1.6E-04
Bulk carriers	2.4E-04	1.2E-03	1.3E-04
General cargo ships	1.9E-04	1.5E-03	3.3E-04
Container ships	2.5E-04	2.0E-03	1.3E-04
Fishing vessels	4.1E-05	6.9E-04	3.2E-04
Other ships	1.5E-04	1.1E-03	2.2E-04
All ships	1.5E-04	1.1E-03	2.6E-04

Figure IV.4.1 Fire/Explosion Frequencies, 2000-10



IV.4.3 Oil Spill Probabilities

There were 6 cases of oil spills from oil tankers due to fire/explosion during 2000-10 according to LRF. These are preliminary figures and may be changed with further validation of the LRF data. Of these, 5 were serious casualties and 1 was a total loss. This gives an average oil spill probability of 6/133 = 0.045 given a fire/explosion, and an oil spill frequency of $0.045 \times 1.8 \times 10^{-3} = 8.1 \times 10^{-5}$ per ship year.

This is a factor of 5 lower than a previous study of tankers (DNV 2001), which estimated a value of 4.2×10^{-4} per ship year for 1992-97. This may be due to improved fire fighting performance since then, but it could also indicate large uncertainties in the spill probability estimates.

Equivalent values are not available for other ship types, because they are much less closely monitored. Therefore their spill probabilities are estimated from spills of bunker fuel on tankers. Table IV.4.3 shows bunker spill experience due to fire/explosion for oil tankers during 1992-97, and compares it to the total number of fires/explosions to estimate the bunker spill probabilities. The validity of this data for other ships is questionable, and data direct from non-tankers would be preferable.

Table IV.4.3 Oil Tanker Bunker Spill Probabilities due to Fire/Explosion, 1992-99

SEVERITY	BUNKER SPILLS	CONTACTS	BUNKER SPILL PROBABILITY (per collision)
Total losses	7	29	0.24
Serious casualties (exc TL)	1	74	0.014
Non-serious incidents	0	65	0
Total incidents	8	168	0.048

IV.4.4 Location Probabilities

Table IV.4.4 shows the breakdown of locations for oil spills from tankers due to fire/explosion. There were no spills in port, so a probability of "0.7" is assumed.

Table IV.4.4 Locations of Oil Tanker Spills due to Fire/Explosion, 2000-10

LOCATION	OIL SPILLS	LOCATION PROBABILITY (per spill)
Port	0.7	0.10
Restricted water	1	0.15
Sea	5	0.75
Total	6.7	1.00

IV.4.5 Oil Spill Frequencies

The oil spill frequencies are related to location-specific measures of exposure, as above. Table IV.4.5 gives the overall oil spill frequencies due to fire/explosion for each ship type.

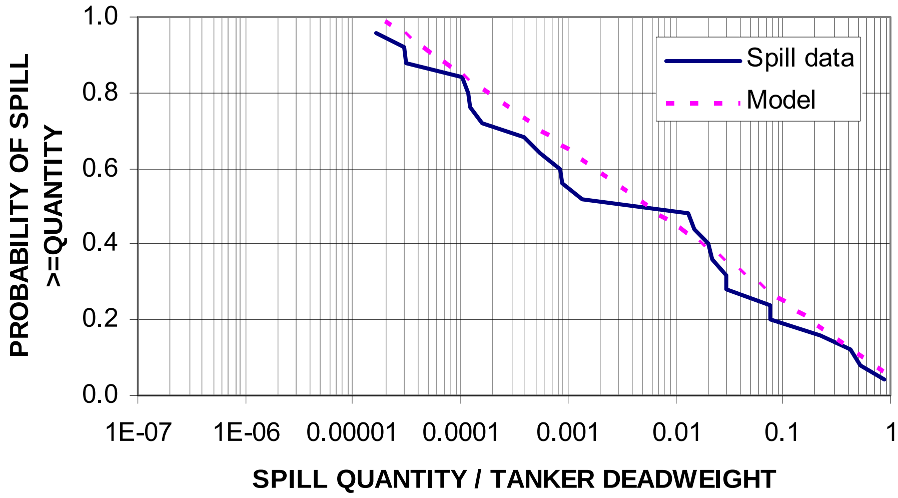
Table IV.4.5 Frequencies of Oil Spills due to Fire/Explosion

SHIP TYPE	IN PORT (per visit)	IN RESTRICTED WATER (per km)	AT SEA (per hour)	TOTAL (per year)
Oil tankers	1.1E-07	2.5E-09	1.4E-08	8.1E-05
Chemical tankers	7.0E-08	1.7E-09	9.1E-09	5.4E-05
Bulk carriers	6.1E-08	1.5E-09	8.0E-09	4.7E-05
General cargo ships	1.3E-07	3.1E-09	1.7E-08	1.0E-04
Container ships	7.6E-08	1.8E-09	9.9E-09	5.8E-05
Fishing vessels	1.1E-07	2.7E-09	1.5E-08	8.6E-05
Other ships	8.9E-08	2.1E-09	1.2E-08	6.9E-05

IV.4.6 Spill Size Distribution

Figure IV.4.2 shows the size distribution of spills due to fire/explosion on oil tankers during 1992-2010 from LRF and other sources. In order to take account of the tanker size and bunker capacity on other ships, the size distribution is expressed as a function of the spill size divided by the tanker deadweight.

Figure IV.4.2 Oil Tanker Oil Spill Size Distribution due to Fire/Explosion, 1992-2010



A simple analytical model of spill quantity (Q) as a fraction of tanker deadweight or bunker capacity (D) is fitted to the data as follows:

$$P(Q/D) = 0.05 - 0.2 \log (Q/D)$$ for Q and D in any consistent units, e.g. tonnes

The probability is by definition constrained to be within the range $0 \leq P(Q/D) \leq 1$.

The mean spill quantity, given an oil spill due to fire/explosion, from oil tankers in the dataset was 10% of deadweight. The mean spill quantity from the model is 13% of deadweight. The difference results from a slight over-estimation throughout the range.

IV.4.7 Comparison with Previous Study

For oil tankers at sea, the previous study estimated a frequency of oil spills due to fire/explosion of 4.1×10^{-8} per ship hour. The current estimate is a factor of 3 lower, and is explained by the use of more recent data.

For bulk carriers at sea, the previous study estimated a frequency of oil spills due to fire/explosion of 6.8×10^{-9} per ship hour. The current estimate is slightly higher, but this is within the uncertainties on the estimate.

For oil tankers in restricted water, the previous study estimated a frequency of oil spills due to fire/explosion of 2.9×10^{-7} per km. The current estimate is a factor of 100 lower, and is explained by the use of more recent data.

For oil tankers in port, the previous study estimated a frequency of oil spills due to fire/explosion of 1.1×10^{-5} per visit. The current estimate is a factor of 100 lower, and is explained by the use of more recent data.

IV.4.8 Validation

The generic oil spill frequencies above have been combined with the exposure of trading ships in Australia (Appendix I) to estimate the rate of oil spills due to fire/explosion in

Australian ports and waters. This gives an expected rate of 0.027 oil spills per year due to fire/explosion, of which 12% is due to oil tankers. When small commercial vessels (SCVs) are included, the total rises to 0.81 per year.

This does not take account of the fact that spills from trading ships and SCVs would be of very different sizes. The oil spill risk model, which does represent these, gives a rate of oil spills over 1 tonne due to fire/explosion of 0.019 per year for trading ships, which rises to 0.14 when SCVs are included

AMSA spill data (Appendix III) shows a total of 2 oil spills over 1 tonne due to fire/explosion during 1982-2010, which is an average of 0.069 per year. Both were on fishing vessels.

Table IV.4.6 Frequencies of Oil Spills Over 1 Tonne due to Fire/Explosion

SHIP TYPE	PREDICTED FREQUENCIES (per year)	HISTORICAL SPILLS 1982-2010	HISTORICAL FREQUENCIES (per year)
Oil tankers	0.00	0	0.00
Chemical tankers	0.00	0	0.00
Bulk carriers	0.01	0	0.00
General cargo ships	0.00	0	0.00
Container ships	0.00	0	0.00
Other ships (inc SCVs)	0.12	2	0.07
All ships	0.14	2	0.07

The comparison in Table IV.4.6 shows that the model predicts spill frequencies that are higher than the historical average. This could result from under-reporting in the AMSA data, or an over-estimate in the model, but could also result from the small number of historical events. It is not considered appropriate to adjust the frequencies at present.

IV.5 HULL DAMAGE

IV.5.1 Definition

In this analysis, hull damage is defined as an event where a ship suffers damage to the hull structure that does not result from another event category. For example, it includes damage due to corrosion or structural overload, but not damage due to collision or explosion. It includes the LRF category "foundered" and the events known as "structural failure/foundering" in the previous study (DNV 1999). It also includes many events included by LRF under the category "hull/machinery damage". In addition, it includes oil spills related to loss of stability, heeling or flooding.

IV.5.2 Hull Damage Frequencies

Table IV.5.1 shows the frequencies of hull/machinery damage and foundering on oil tankers during 2000-10 from LRF. This includes many cases of machinery failure, and so may over-estimate the true frequency of hull damage. Incident reporting is less complete on other ship types, so the modification factors from collisions (Table IV.2.3) are used to estimate the frequencies.

Table IV.5.1 Hull Damage Frequencies on Oil Tankers, 2000-10

SEVERITY	HULL/MACHINERY DAMAGE	FOUNDERIN G	FREQUENCY (per ship year)
Total losses	7	22	3.9×10^{-4}
Serious casualties (exc total losses)	257	6	3.5×10^{-3}
Non-serious incidents	76	0	1.0×10^{-3}
Total incidents	340	28	4.9×10^{-3}

IV.5.3 Oil Spill Frequencies

Table IV.5.2 shows oil spill experience due to hull damage for oil tankers during 2000-10 from LRF. These are based on oil spills with known quantities, and may be changed with further investigation of the LRF data where the oil spill quantities are unknown. They are considered to be reasonable estimates of the frequencies of spills of 1 tonne or more.

Table IV.5.2 Oil Tanker Oil Spill Frequencies due to Hull Damage, 2000-10

SEVERITY	OIL SPILLS	OIL SPILL PROBABILITY (per hull damage event)	OIL SPILL FREQUENCY (per ship year)
Total losses	2	0.069	2.7×10^{-5}
Serious casualties (exc total losses)	25	0.095	3.4×10^{-4}
Non-serious incidents	6	0.079	8.1×10^{-5}
Total incidents	33	0.090	4.4×10^{-4}

The oil spill probabilities do not show the expected variation with event severity. This may be because of the effect of machinery damage and double hulls, or the apparent change in categorisation of serious casualties (Section IV.1.4).

Equivalent values are not available for other ship types, because they are much less closely monitored. Therefore their spill probabilities are estimated from spills of bunker fuel on tankers. Table IV.5.3 shows bunker spill experience due to hull damage for oil tankers during 1992-97, and compares it to the total number of hull damage events to estimate the bunker spill probabilities. The validity of this data for other ships is questionable, and data direct from non-tankers would be preferable.

Table IV.5.3 Oil Tanker Bunker Spill Probabilities due to Hull Damage, 1992-99

SEVERITY	BUNKER SPILLS	HULL/MACHINERY DAMAGE + FOUNDERING	BUNKER SPILL PROBABILITY (per hull damage event)
Total losses	6	23	0.26
Serious casualties (exc TL)	3	148	0.020
Non-serious incidents	1	493	0.002
Total incidents	10	663	0.015

In this case, the oil spill probabilities do show the expected variation with event severity. This may be because the data refers mainly to single hulls and had a different interpretation of serious casualties.

IV.5.4 Location Probabilities

Table IV.5.4 shows the breakdown of locations for oil spills from tankers due to hull damage.

Table IV.5.4 Locations of Oil Tanker Spills due to Hull Damage, 2000-10

LOCATION	OIL SPILLS	LOCATION PROBABILITY (per spill)
Port	13	0.39
Restricted water	5	0.15
Sea	15	0.45
Total	33	1.00

IV.5.5 Oil Spill Frequencies

The oil spill frequencies are related to location-specific measures of exposure, as above. Table IV.5.5 gives the overall oil spill frequencies due to hull damage for each ship type.

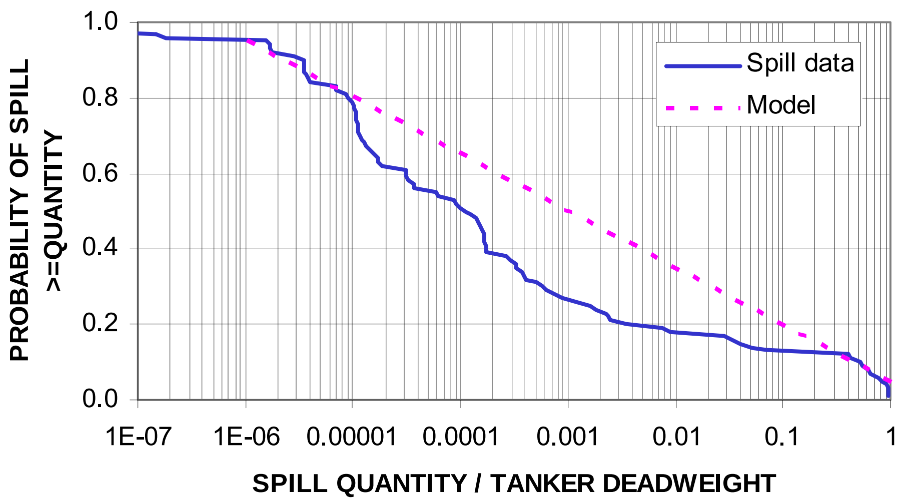
Table IV.5.5 Frequencies of Oil Spills due to Hull Damage

SHIP TYPE	IN PORT (per visit)	IN RESTRICTED WATER (per km)	AT SEA (per hour)	TOTAL (per year)
Oil tankers	2.2E-06	1.4E-08	4.6E-08	4.4E-04
Chemical tankers	1.3E-06	8.1E-09	2.7E-08	2.6E-04
Bulk carriers	1.6E-06	1.0E-08	3.4E-08	3.3E-04
General cargo ships	3.9E-06	2.5E-08	8.2E-08	7.9E-04
Container ships	1.1E-06	7.1E-09	2.3E-08	2.3E-04
Fishing vessels	6.0E-07	3.8E-09	1.3E-08	1.2E-04
Other ships	5.7E-07	3.7E-09	1.2E-08	1.2E-04

IV.5.6 Spill Size Distribution

Figure IV.5.1 shows the size distribution of spills due to hull damage on oil tankers during 1992-2010 from LRF and other sources. In order to take account of the tanker size and bunker capacity on other ships, the size distribution is expressed as a function of the spill size divided by the tanker deadweight.

Figure IV.5.1 Oil Tanker Oil Spill Size Distribution due to Hull Damage, 1992-2010



A simple analytical model of spill quantity (Q) as a fraction of tanker deadweight or bunker capacity (D) is fitted to the data as follows:

$$P(Q/D) = 0.05 - 0.15 \log (Q/D)$$ for Q and D in any consistent units, e.g. tonnes

The probability is by definition constrained to be within the range $0 \leq P(Q/D) \leq 1$.

The model over-estimates the risk in the region $0.00001 < S/D < 0.3$ by up to a factor of 2, which is an inherent limitation of this simple model.

The mean spill quantity, given an oil spill due to hull damage, from oil tankers in the dataset was 9% of deadweight. The mean spill quantity from the model is 11% of deadweight. The difference results from the over-estimation described above.

IV.5.7 Effect of Weather

The frequencies of hull damage reflect world average weather conditions. Weather conditions have been categorised as defined in Appendix VI.4.4. As in the previous study, the following modifiers are used for the different weather conditions:

Calm	$MF_{weather} = 1$
Fresh	$MF_{weather} = 1$
Gale	$MF_{weather} = 7.2$
Storm	$MF_{weather} = 13.4$

The overall modifier for any calculation region depends on the probabilities of the different weather conditions as follows:

$$MF_{weather} = P_{calm} + P_{fresh} + 7.2\ P_{gale} + 13.4\ P_{storm}$$

This is only applied for ships at sea, because hull damage in port is more commonly due to corrosion than weather impacts.

IV.5.8 Validation

The generic oil spill frequencies above have been combined with the exposure of trading ships in Australia (Appendix I) to estimate the rate of oil spills due to hull damage in Australian ports and waters. This gives an expected rate of 0.12 oil spills per year due to hull damage, of which 13% is due to oil tankers. When small commercial vessels (SCVs) are included, the total rises to 1.4 per year.

This does not take account of the fact that spills from trading ships and SCVs would be of very different sizes. The oil spill risk model, which does represent these, gives a rate of oil spills over 1 tonne due to hull damage of 0.07 per year for trading ships, which rises to 0.24 when SCVs are included.

AMSA spill data (Appendix III) shows a total of 19 oil spills over 1 tonne due to hull damage during 1982-2010, which is an average of 066 per year. Of these, only 5 are known to be from trading vessels, i.e. 0.17 per year.

Table IV.5.6 Frequencies of Oil Spills Over 1 Tonne due to Hull Damage

SHIP TYPE	PREDICTED FREQUENCIES (per year)	HISTORICAL SPILLS 1982-2010	HISTORICAL FREQUENCIES (per year)
Oil tankers	0.01	3	0.10
Chemical tankers	0.00	0	0.00
Bulk carriers	0.03	0	0.00
General cargo ships	0.01	2	0.07
Container ships	0.01	0	0.00
Other ships (inc SCVs)	0.18	14	0.48
All ships	0.24	19	0.66

The comparison in Table IV.5.6 shows that the model predicts spill frequencies that are lower than the historical average. The reasons for this are difficult to determine, because of a lack of reliable information on this type of event. It cannot be due to under-reporting in the

AMSA data, or the limited number of historical events, but might be due to the lack of information about the underlying cause of the hull damage. Therefore it is not considered appropriate to adjust the frequencies at present.

IV.6 TRANSFER SPILL

IV.6.1 Definition

In this analysis, transfer spill is defined as an event where a ship releases oil to the sea due to failure or error during loading/unloading cargo or fuel oil. This includes loading in port and during ship-to-ship transfer. It excludes offshore loading, which is covered in Appendix V.5.2. Typical causes include overflow, hose failure, errors in setting valves etc.

IV.6.2 Spill Frequencies for Cargo Transfers in Port

During 2000-10, LRF identifies 10 transfer spills on oil tankers with known quantities released. The oil tanker exposure during this period was 74,471 ship years. Based on an average of 80 port visits per ship year, each normally involving a cargo transfer (either loading or discharging) this is 5.6 million cargoes transferred. This gives a transfer spill frequency of 1.7 x 10^{-6} per cargo transferred. However, this data includes many events of unknown quantity, and so may be an under-estimate.

Data for 1992-97 was previously reviewed more comprehensively, and included 72 transfer spills during an exposure of 40,103 ship years. Based on 80 port visits per ship year, this gives a transfer spill frequency of 2.2 x 10^{-5} per cargo transferred. This is a comprehensive survey of public-domain information, but does not include many spills in countries that do not openly report spills.

The best-reported statistics for leaks during transfers of bulk dangerous goods between ship and shore are for Great Britain during a 5.25 year period over 1981-85, derived from the HSE's NADOR database. The reporting requirements only refer to leaks of over 1 tonne of flammable gas or highly flammable (i.e. low-flash) liquids. These were combined with estimates of cargoes transferred to give the leak frequencies in Table IV.6.1 (Technica 1990).

Table IV.6.1 Cargo Transfer Spill Frequencies in Ports in Great Britain

CARGO TYPE	NUMBER OF SPILLS 1981-85	MEAN SPILL (tonnes)	SPILL FREQUENCY (per cargo transferred)
Crude oil	2	20	1.9 x 10^{-4}
Petroleum products (low-flash only)	5	11	1.8 x 10^{-4}
Chemicals (low-flash only)	1	16	1.5 x 10^{-4}
Liquefied gas	1	?	7.6 x 10^{-5}

The spill frequency of 1.8 x 10^{-4} was used in the previous study (DNV 1999) for all oil products. Although this experience is old, and the spill frequencies may have reduced since then, it remains the best available estimate.

IV.6.3 Spill Frequencies for Bunkering in Port

The frequency of ship bunkering is assumed to be once every 3 weeks while trading. Assuming an average of 50% of the time is spent at sea, this would be approximately 10 times per year.

The frequency of oil spills while bunkering is assumed to be as for cargo transfer.

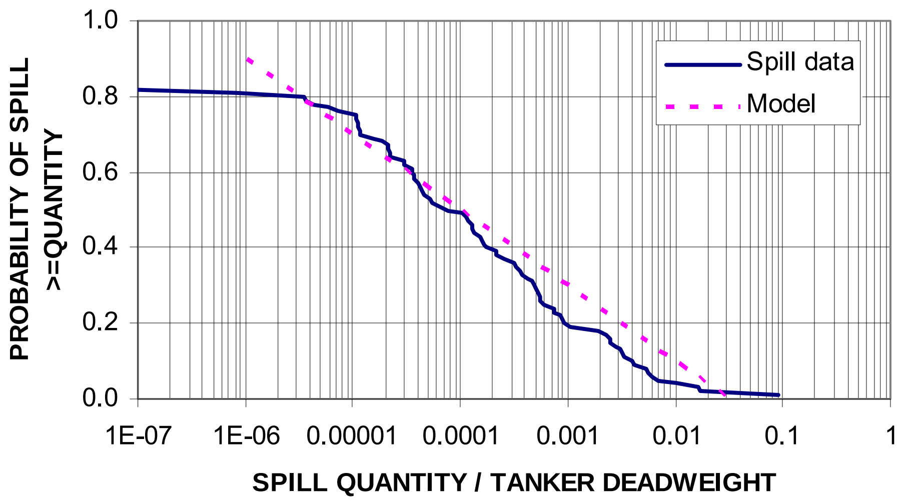
IV.6.4 Spill Frequencies for Ship-to-Ship Transfers

UK experience of ship-to-ship transfer was estimated to be 1 spill over 1 tonne in 2000 tanker lightering operations, giving a spill frequency of 5 x 10^{-4} per transfer operation (DNV 1997). Although this was only once incident, and was not based on systematic data collection, the result was consistent with US data, and therefore is adopted for the present study.

IV.6.5 Spill Size Distribution

Figure IV.6.1 shows the size distribution of spills due to transfer on oil tankers during 1992-2010 from LRF and other sources. In order to take account of the tanker size and bunker capacity on other ships, the size distribution is expressed as a function of the spill size divided by the tanker deadweight.

Figure IV.6.1 Oil Tanker Oil Spill Size Distribution due to Transfer, 1992-2010



A simple analytical model of spill quantity (Q) as a fraction of tanker deadweight or bunker capacity (D) is fitted to the data as follows:

P(Q/D) = -0.3 - 0.2 log (Q/D) for Q and D in any consistent units, e.g. tonnes

The probability is by definition constrained to be within the range 0 ≤ P(Q/D) ≤ 1.

The model over-estimates the risk for very small Q/D, which may be seen as a correction for under-reporting. It over-estimates in the region 0.0001 < S/D < 0.2, and under-estimates in the region 0.3 < S/D < 1, and it is the latter that dominates the spill quantity.

The mean spill quantity, given an oil spill due to transfer, from oil tankers in the dataset was 0.25% of deadweight. The mean spill quantity from the model is 0.22% of deadweight. The difference results from the under-estimation described above.

IV.6.6 Validation

The generic oil spill frequencies above have been combined with the exposure of trading ships in Australia (Appendix I) to estimate the rate of oil spills due to transfer in Australian ports and waters. This gives an expected rate of 0.86 oil spills per year due to transfer, of which 45% is due to oil tankers. When small commercial vessels (SCVs) are included, the total rises to 21 per year.

This does not take account of the fact that spills from trading ships and SCVs would be of very different sizes. The oil spill risk model, which does represent these, gives a rate of oil spills over 1 tonne due to transfer of 0.38 per year for trading ships. The size distribution in Section IV.6.5, combined with the typical fuel capacity on SCVs (Appendix I.4.2) results in no predicted transfer spills exceeding 1 tonne on SCVs.

AMSA spill data (Appendix III) shows a total of 27 oil spills over 1 tonne due to transfer during 1982-2010, which is an average of 0.93 per year. Of these, 13 (48%) were due to oil tankers.

Table IV.6.2 Frequencies of Oil Spills Over 1 Tonne due to Transfer

SHIP TYPE	PREDICTED FREQUENCIES (per year)	HISTORICAL SPILLS 1982-2010	HISTORICAL FREQUENCIES (per year)
Oil tankers	0.18	13	0.45
Chemical tankers	0.01	1	0.03
Bulk carriers	0.09	1	0.03
General cargo ships	0.02	3	0.10
Container ships	0.04	0	0.00
Other ships (inc SCVs)	0.05	9	0.31
All ships	0.38	27	0.93

The comparison in Table IV.6.2 shows that the model predicts spill frequencies that are lower than the historical average. This may be due to improvements in pollution prevention over this period over this period, or because the spill size distribution for tankers is not applicable to SCVs. It cannot be due to under-reporting in the AMSA data, or the limited number of historical events. However, it is not considered appropriate to adjust the frequencies at present.

IV.7 UNAUTHORISED DISCHARGE

IV.7.1 Definition

In this analysis, unauthorised discharge is defined as deliberate or accidental discharge of oil or oily water through hull valves, pipes or scuppers, except due to loading/unloading. Typical causes include, bilge pumping, hydraulic line failure, errors during internal fuel transfer, separator faults, oil in ballast water etc.

The scope of the study excludes deliberate illegal discharges, but in the data it is impractical to distinguish these from accidental discharges. Given that both are likely to be under-reported, the frequencies from the data are here used to represent accidental discharges.

IV.7.2 Oil Spill Frequencies

During 2000-10, LRF identifies only 1 unauthorised discharge on oil tankers with a known quantity released. The oil tanker exposure during this period was 74,471 ship years. This gives a spill frequency of 1.3×10^{-5} per ship year. However, this data includes many events of unknown quantity, and so may be an under-estimate.

Data for 1992-97 was previously reviewed more comprehensively, and included 14 spills during an exposure of 40,103 ship years. This gives a spill frequency of 3.5×10^{-4} per ship year. This is a comprehensive survey of public-domain information, but does not include many spills in countries that do not openly report spills or trace the source of discharges. In the absence of any better data, these frequencies are increased by a factor of 2 to compensate for under-reporting. This gives a spill frequency of 7.0×10^{-4} per ship year.

Oil spills from other ship types are reported less comprehensively, so the modification factors from collisions (Table IV.2.3) are used to estimate them.

IV.7.3 Location Probabilities

Table IV.7.1 shows the breakdown of locations for oil spills from tankers due to unauthorised discharge.

Table IV.7.1 Locations of Oil Tanker Spills due to Unauthorised Discharge, 1992-97

LOCATION	OIL SPILLS	LOCATION PROBABILITY (per spill)
Port	5	0.36
Restricted water	2	0.14
Sea	7	0.50
Total	14	1.00

IV.7.4 Oil Spill Frequencies

The oil spill frequencies are related to location-specific measures of exposure, as above. Table IV.7.2 gives the overall oil spill frequencies due to unauthorised discharge for each ship type.

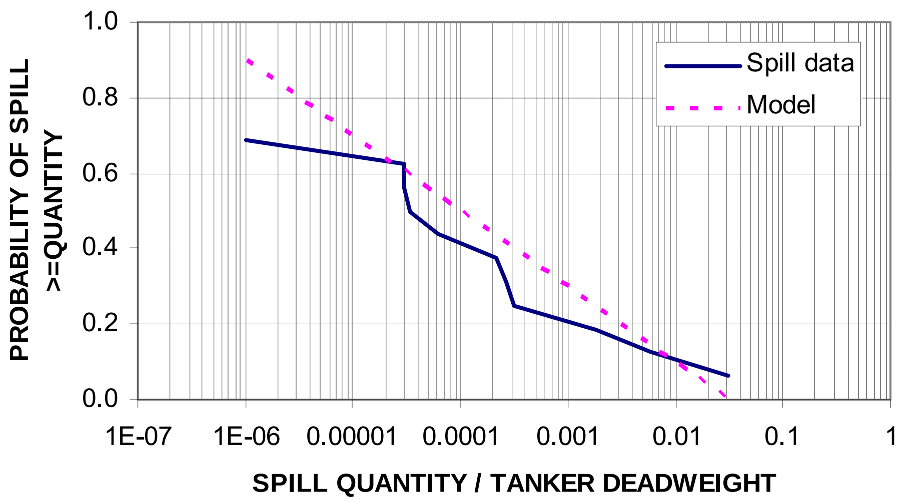
Table IV.7.2 Frequencies of Oil Spills due to Unauthorised Discharge

SHIP TYPE	IN PORT (per visit)	IN RESTRICTED WATER (per km)	AT SEA (per hour)	TOTAL (per year)
Oil tankers	3.1E-06	2.1E-08	8.0E-08	7.0E-04
Chemical tankers	3.3E-06	2.2E-08	8.5E-08	7.4E-04
Bulk carriers	3.9E-06	2.6E-08	1.0E-07	8.7E-04
General cargo ships	3.4E-06	2.3E-08	8.8E-08	7.7E-04
Container ships	5.1E-06	3.4E-08	1.3E-07	1.2E-03
Fishing vessels	3.4E-07	2.3E-09	8.7E-09	7.7E-05
Other ships	1.2E-06	7.8E-09	3.0E-08	2.6E-04

IV.7.5 Spill Size Distribution

Figure IV.7.1 shows the size distribution of spills due to unauthorised discharge on oil tankers during 1992-2010 from LRF and other sources. In order to take account of the tanker size and bunker capacity on other ships, the size distribution is expressed as a function of the spill size divided by the tanker deadweight.

Figure IV.7.1 Oil Tanker Oil Spill Size Distribution due to Unauthorised Discharge, 1992-2010



A simple analytical model of spill quantity (Q) as a fraction of tanker deadweight or bunker capacity (D) is fitted to the data as follows:

$$P(Q/D) = -0.3 - 0.2 \log (Q/D)$$ for Q and D in any consistent units, e.g. tonnes

The probability is by definition constrained to be within the range $0 \leq P(Q/D) \leq 1$.

The model over-estimates the risk for very small Q/D, which may be seen as a correction for under-reporting. It over-estimates in the region 0.00003 < S/D < 0.005, and under-estimates in the region 0.01 < S/D < 1, and it is the latter that dominates the spill quantity.

The mean spill quantity, given an oil spill due to unauthorised discharge, from oil tankers in the dataset was 0.36% of deadweight. The mean spill quantity from the model is 0.22% of deadweight. The difference results from the under-estimation described above.

IV.7.6 Validation

The generic oil spill frequencies above have been combined with the exposure of trading ships in Australia (Appendix I) to estimate the rate of oil spills due to unauthorised discharge in Australian ports and waters. This gives an expected rate of 0.29 oil spills per year due to unauthorised discharge, of which 9% is due to oil tankers. When small commercial vessels (SCVs) are included, the total rises to 3.0 per year.

This does not take account of the fact that spills from trading ships and SCVs would be of very different sizes. The oil spill risk model, which does represent these, gives a rate of oil spills over 1 tonne due to unauthorised discharge of 0.11 per year for trading ships. The size distribution in Section IV.7.5, combined with the typical fuel capacity on SCVs (Appendix I.4.2) results in no unauthorised discharges predicted to exceed 1 tonne on SCVs.

AMSA spill data (Appendix III) shows a total of 14 oil spills over 1 tonne due to unauthorised discharge during 1982-2010, which is an average of 0.48 per year. Of these, 6 (43%) were due to oil tankers.

Table IV.7.3 Frequencies of Oil Spills Over 1 Tonne due to Unauthorised Discharge

SHIP TYPE	PREDICTED FREQUENCIES (per year)	HISTORICAL SPILLS 1982-2010	HISTORICAL FREQUENCIES (per year)
Oil tankers	0.01	6	0.21
Chemical tankers	0.00	0	0.00
Bulk carriers	0.05	0	0.00
General cargo ships	0.01	1	0.03
Container ships	0.02	1	0.03
Other ships (inc SCVs)	0.01	6	0.21
All ships	0.11	14	0.48

The comparison in Table IV.7.3 shows that the model predicts spill frequencies that are lower than the historical average. This may be due to improvements in pollution prevention over this period, or because LRF data for oil tankers is more under-reported than assumed, and also because the spill size distribution for tankers is not applicable to SCVs. It cannot be due to under-reporting in the AMSA data, or the limited number of historical events, but might be due to the lack of information about the underlying cause of the hull damage. Therefore, it is not considered appropriate to adjust the frequencies at present.

IV.8 GROUNDING

IV.8.1 Definition

In this analysis, grounding (known by LMIS as "wrecked/stranded") is defined as striking the sea bottom, shore or underwater wrecks. This is split into:

- Drift grounding - grounding while not under control, typically due to loss of propulsion and/or anchors in adverse weather.
- Powered grounding - grounding while under power, typically due to navigational error. This includes cases where power is lost close to the point of grounding, before the ship begins to drift.

These are treated together at first and split at a later stage.

IV.8.2 Grounding Frequencies

Table IV.8.1 shows grounding experience and the size of the world fleet during 2000-10 from LRF. Table IV.8.2 and Figure IV.8.1 show the grounding frequencies calculated from this data.

Table IV.8.1 Grounding Experience, 2000-10

SHIP TYPE	EXPOSURE (ship years)	NON-SERIOUS INCIDENTS	SERIOUS CASUALTIES (exc total loss)	TOTAL LOSS
Oil tankers	74,471	61	195	27
Chemical tankers	37,292	38	108	3
Bulk carriers	78,265	82	420	33
General cargo ships	184,878	139	1,047	166
Container ships	39,527	19	178	8
Fishing vessels	268,966	17	186	56
Other ships	382,588	90	558	67
All ships	1,065,986	446	2,692	360

Table IV.8.2 Grounding Frequencies, 2000-10

SHIP TYPE	NON-SERIOUS INCIDENTS	SERIOUS CASUALTIES (exc total loss)	TOTAL LOSS
Oil tankers	8.2E-04	2.6E-03	3.6E-04
Chemical tankers	1.0E-03	2.9E-03	8.0E-05
Bulk carriers	1.0E-03	5.4E-03	4.2E-04
General cargo ships	7.5E-04	5.7E-03	9.0E-04
Container ships	4.8E-04	4.5E-03	2.0E-04
Fishing vessels	6.3E-05	6.9E-04	2.1E-04
Other ships	2.4E-04	1.5E-03	1.8E-04
All ships	4.2E-04	2.5E-03	3.4E-04

Figure IV.8.1 Grounding Frequencies, 2000-10

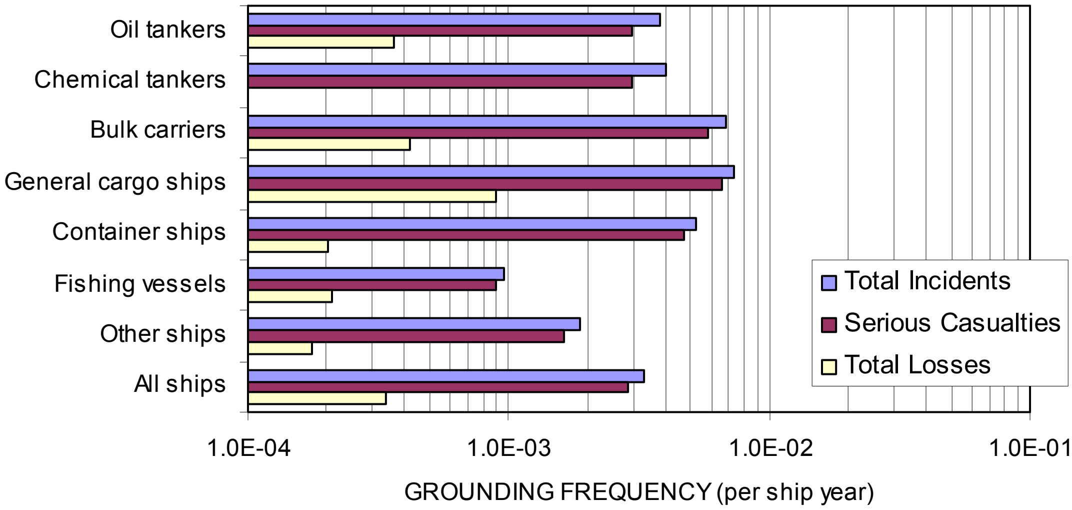


Table IV.8.3 shows the breakdown of tanker groundings by cause, based on an earlier dataset that was analysed in more detail (DNV 2001). The distribution of causes is unlikely to have changed significantly since then. It shows that drift groundings comprise 7% of non-serious incidents, 21% of serious casualties (excluding total losses) and 31% of total losses.

Table IV.8.3 Causes of Oil Tanker Groundings, 1992-97

CAUSE	NON-SERIOUS INCIDENTS	%	SERIOUS CASUALTIES (exc TL)	%	TOTAL LOSSES	%
Human error	143	93%	61	79%	9	69%
Fog	0	0%	0	0%	0	0%
Submerged object/wreck	0	0%	0	0%	0	0%
Total powered groundings	143	93%	61	79%	9	69%
Engine failure	2	1%	7	9%	1	8%
Steering failure	2	1%	5	6%	0	0%
Broke moorings	3	2%	1	1%	2	15%
Broke tow	0	0%	1	1%	0	0%
Dragged anchor	4	3%	2	3%	1	8%
Total drift groundings	11	7%	16	21%	4	31%
Total groundings	154	100%	77	100%	13	100%

IV.8.3 Oil Spill Probabilities

Table IV.8.4 shows oil spill experience due to grounding for oil tankers during 2000-10 from LRF. These are based on oil spills with known quantities, and may be changed with further investigation of the LRF data where the oil spill quantities are unknown. They are considered to be reasonable estimates of the frequencies of spills of 1 tonne or more.

Table IV.8.4 Oil Tanker Oil Spill Frequencies due to Grounding, 2000-10

SEVERITY	OIL SPILLS	OIL SPILL PROBABILITY (per grounding)	OIL SPILL FREQUENCY (per ship year)
Total losses	3	0.011	4.0×10^{-5}
Serious casualties (exc total losses)	21	0.011	2.8×10^{-4}
Non-serious incidents	7	0.011	9.4×10^{-5}
Total incidents	31	0.011	4.2×10^{-4}

The oil spill probabilities do not show the expected variation with event severity. This may be because of the effect of double hulls, or the apparent change in categorisation of serious casualties (Section IV.1.4). The low number of total loss events makes this probability uncertain.

Equivalent values are not available for other ship types, because they are much less closely monitored. Therefore their spill probabilities are estimated from spills of bunker fuel on tankers. Table IV.8.5 shows bunker spill experience due to grounding for oil tankers during 1992-97, and compares it to the total number of groundings to estimate the bunker spill probabilities. The validity of this data for other ships is questionable, and data direct from non-tankers would be preferable.

Table IV.8.5 Oil Tanker Bunker Spill Probabilities due to Grounding, 1992-99

SEVERITY	BUNKER SPILLS	GROUNDING	BUNKER SPILL PROBABILITY (per grounding)
Total losses	4	13	0.31
Serious casualties (exc TL)	3	77	0.039
Non-serious incidents	0	154	0
Total incidents	7	244	0.029

In this case, the oil spill probabilities do show the expected variation with event severity. This may be because the data refers mainly to single hulls and had a different interpretation of serious casualties.

IV.8.4 Location Probabilities

Table IV.8.6 shows the breakdown of locations for oil spills from tankers due to grounding. There were no spills in port, so a probability of “0.7” is assumed.

Table IV.8.6 Locations of Oil Tanker Spills due to Grounding, 2000-10

LOCATION	OIL SPILLS	LOCATION PROBABILITY (per spill)
Port	0.7	0.03
Restricted water	10	0.40
Sea	14	0.57
Total	24.7	1.00

IV.8.5 Oil Spill Frequencies

The oil spill frequencies are related to location-specific measures of exposure, as above. Tables IV.8.7 and IV.8.8 give the overall oil spill frequencies due to powered and drift grounding for each ship type.

Table IV.8.7 Frequencies of Oil Spills due to Powered Grounding

SHIP TYPE	IN PORT (per visit)	IN RESTRICTED WATER (per km)	AT SEA (per hour)	TOTAL (per year)
Oil tankers	1.2E-07	2.9E-08	4.4E-08	3.4E-04
Chemical tankers	3.8E-08	9.0E-09	1.4E-08	1.1E-04
Bulk carriers	9.0E-08	2.1E-08	3.3E-08	2.5E-04
General cargo ships	1.3E-07	3.1E-08	4.7E-08	3.6E-04
Container ships	6.4E-08	1.5E-08	2.3E-08	1.8E-04
Fishing vessels	2.3E-08	5.5E-09	8.5E-09	6.5E-05
Other ships	2.9E-08	6.9E-09	1.1E-08	8.2E-05

Table IV.8.8 Frequencies of Oil Spills due to Drift Grounding

SHIP TYPE	IN PORT (per visit)	IN RESTRICTED WATER (per km)	AT SEA (per hour)	TOTAL (per year)
Oil tankers	2.8E-08	6.6E-09	1.0E-08	7.9E-05
Chemical tankers	1.1E-08	2.6E-09	4.1E-09	3.1E-05
Bulk carriers	3.0E-08	7.1E-09	1.1E-08	8.4E-05
General cargo ships	4.7E-08	1.1E-08	1.7E-08	1.3E-04
Container ships	2.0E-08	4.7E-09	7.3E-09	5.6E-05
Fishing vessels	9.0E-09	2.2E-09	3.3E-09	2.6E-05
Other ships	1.0E-08	2.4E-09	3.7E-09	2.9E-05

IV.8.6 Drift Grounding Model

In order to take account of emergency towing capabilities, the frequency of drift grounding at sea is calculated for individual sub-regions using the following model.

Drift grounding may result from engine or steering failure, and may be prevented by repair of the failure, by the use of the ship's anchor, or by emergency towing vessels. The drift grounding frequency is therefore the product of the following:

- Frequency of engine/steering breakdown at sea.
- Probability of drift direction towards the shore.
- Probability of failure to self-repair in time taken to drift onto shore.
- Probability of failure to halt drifting using anchors.
- Probability of failure of emergency towing in time taken to drift onto shore.

The frequency of drift grounding (F_{ground}) is expressed as:

$$F_{ground} = F_{breakdown} P_{onshore} (1 - PS_{repair}) \cdot (1 - PS_{anchor}) \cdot (1 - PS_{tow})$$

The components are considered in turn below.

The breakdown frequency ($F_{breakdown}$) is taken as 2 x 10^{-4} per ship hour based on company-reported propulsion and steering failures on oil tankers (DNV 1996).

The probability of drifting towards the shore ($P_{onshore}$) is based on the wind data for the sub-region, as in the previous study (DNV 1999).

The available time to stop the drift before grounding (T_{ground}) depends on the distance offshore (D_{zone}), the component of wind velocity in the direction of the shore (V_{wind}) if positive, and the ship's drift velocity as a fraction of the wind velocity (RV_{drift}):

$$T_{ground} = \frac{D_{zone}}{V_{wind} RV_{drift}}$$

The average distances to shore for each zone are taken as:

Near-shore (up to 12 nm offshore)	D_{zone} = 6 nm
Intermediate waters (12-50 nm offshore)	D_{zone} = 30 nm
Deep sea (50-200nm offshore)	D_{zone} = 120 nm

Four weather categories are considered, with the representative wind speeds shown in Table IV.8.9.

Table IV.8.9 Weather Categories

WEATHER	BEAUFORT NUMBERS	WIND SPEED RANGE (knots)	REPRESENTATIVE WIND SPEED (knots)
Calm	0-4	0-15	5
Fresh	5-6	16-26	20
Gale	7-9	27-47	40
Storm	10-12	≥48	60

Vessel drift speeds depend on their size and shape, and on whether they begin to "sail", i.e. drift in a forward direction. Table IV.8.10 shows drift speeds for large ships (over 40,000dwt) (Technica 1987), and these are used as representative values here. They are higher than the drift speed of 3% of wind speed used in the previous study (DNV 1999).

Table IV.8.10 Representative Vessel Drift Speeds

WEATHER	WIND SPEED (knots)	VESSEL DRIFT SPEED (knots)	DRIFT SPEED / WIND SPEED (%)
Calm	5	0.8	16%
Fresh	20	1.5	7.5%
Gale	40	2.1	5.3%
Storm	60	2.3	3.8%

The times to ground are then as shown in Table IV.8.11.

Table IV.8.11 Time to Drift Grounding (hours) for Onshore Winds

WEATHER	NEAR-SHORE ZONE	INTERMEDIATE ZONE	DEEP SEA ZONE
Calm	8	38	150
Fresh	4	20	80
Gale	3	14	57
Storm	3	13	53

The probability of drift grounding given a breakdown (P_{ground}) then depends on the probability of onshore wind conditions ($P_{onshore}$) and the probabilities of saving by self-repair, anchoring or towing in the available time:

$$P_{ground} = P_{onshore}\left(1 - PS_{repair}\right)\cdot\left(1 - PS_{anchor}\right)\cdot\left(1 - PS_{tow}\right)$$

The self-repair probability is estimated from company-reported failure durations on oil tankers (DNV 1996):

$$PS_{repair} = 1 - 10^{-0.1 T_{ground}} \qquad \text{for } T_{ground} \text{ in hours}$$

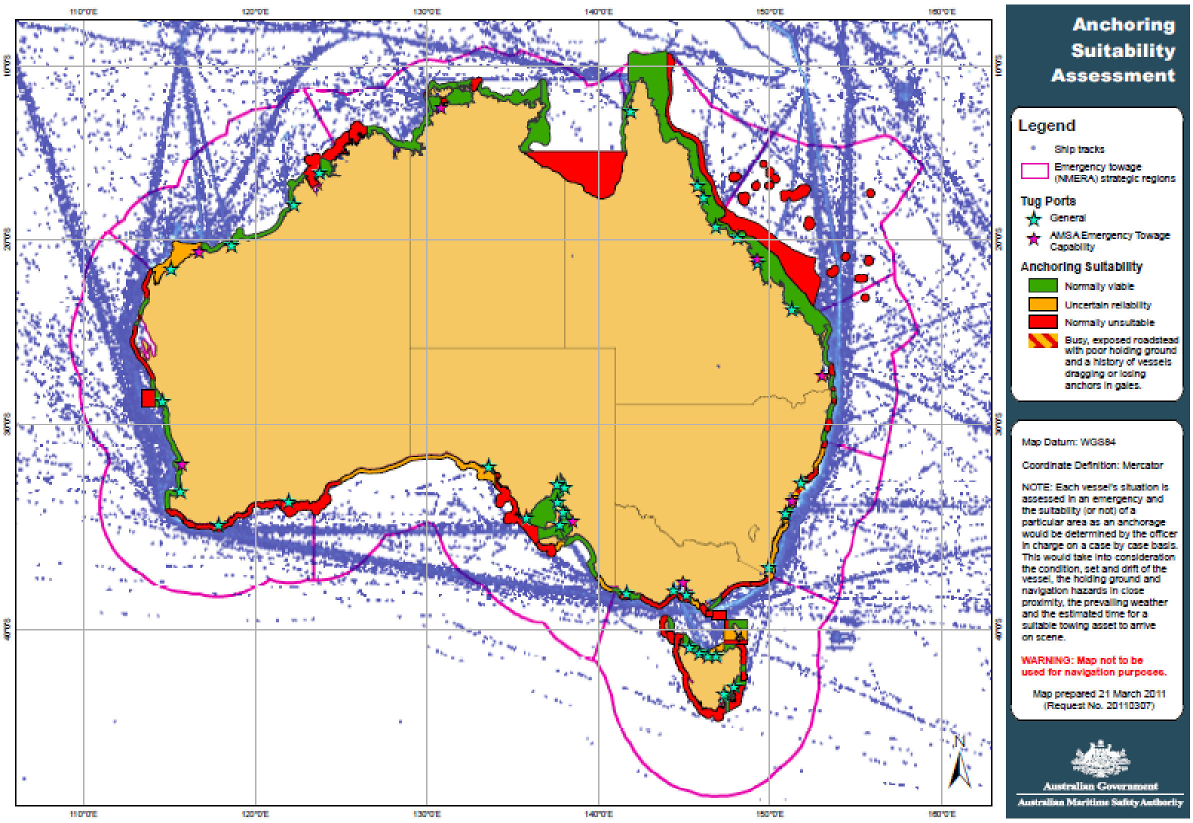
The anchor save probability depends on the weather and the nature of the sea bed. To be effective anchoring requires a long shallow shoreline with mud or sandy bottom. Anchoring is impractical on shorelines that are very steep or rocky, or in severe weather. Therefore the anchor save probability is approximated as a function of the probability that the shore is suitable ($P_{suitable}$) and that the wind is at least gale force:

$$PS_{anchor} = P_{suitable}\cdot\left(1 - (P_{gale} + P_{storm})\right)$$

Suitability of the shore for anchoring is evaluated from information provided by AMSA (Figure IV.8.2). The probability ($P_{suitable}$) for each sub-region is the fraction of the coast in the closest near-shore region that is suitable. The categories on the map are interpreted as follows:

Normally viable $P_{suitable} = 1.0$
Uncertain reliability $P_{suitable} = 0.5$
Normally unsuitable $P_{suitable} = 0.0$

Figure IV.8.2 Anchoring Suitability



The tug save probability depends on the weather and the time required for the tug to arrive and connect the tow. It is taken as:

$$PS_{tug} = (1 - P_{storm}) \quad \text{if } T_{tow} < T_{ground}; \qquad 0 \text{ otherwise}$$

The necessary time for a tug to arrive (T_{tow}) depends on the distance from the tug base to the drifting ship (D_{tug}), the maximum tug speed (V_{tug}), and the time taken to mobilise the tug and connect the tow (T_{tug}):

$$T_{tow} = \frac{D_{tug}}{V_{tug}} + T_{tug}$$

Table IV.8.12 shows the assumed mobilisation times, transit speeds and tow connection times for the main tug types (Appendix I.6.5).

Table IV.8.12 Tug Response Times

TUG TYPE	MOBILISATION TIME (hours)	TRANSIT SPEED (knots)	CONNECTION TIME (hours)
Level 1 (Cairns)	0	12	1
Level 2	4	8	1
Level 3 (Gladstone)	4	8	1

The drift grounding frequency per hour in any zone is then the sum of the contributions from the 4 weather conditions:

$$F_{ground} = F_{breakdown} \sum_{weather} P_{weather} P_{ground}$$

The national average drift grounding frequency ($F_{average}$) is found as the weighted sum of the grounding frequencies in each zone, taking account of the ship hours (H) in each zone:

$$F_{average} = \frac{\sum_{zone} F_{ground} H_{zone}}{\sum_{zone} H_{zone}}$$

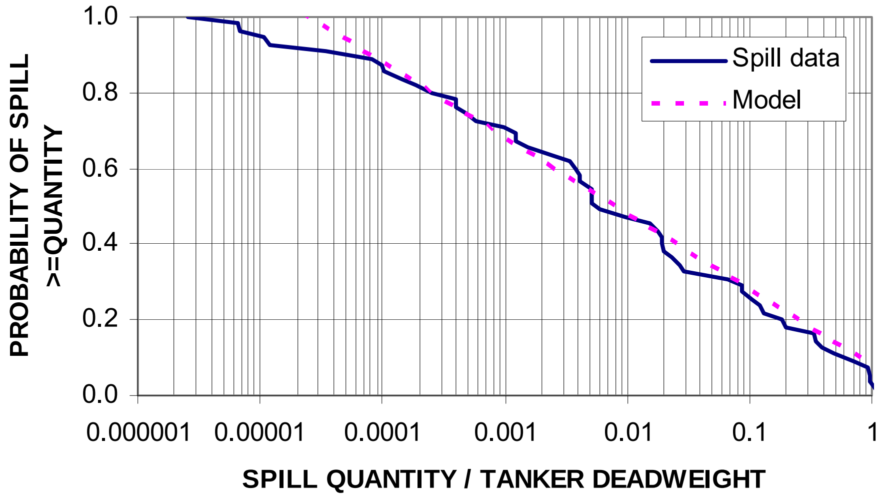
The result is 2.5 x 10^{-6} per ship hour at sea. This is high compared to the data in Section IV.8.2, and suggests pessimism in the model above, or perhaps greater navigational difficulty in Australia than world average. However, this is cancelled out by expressing the results as a frequency modifier, as follows:

$$MF_{drift} = \frac{F_{ground}}{F_{average}}$$

IV.8.7 Spill Size Distribution

Figure IV.8.3 shows the size distribution of spills due to grounding on oil tankers during 1992-2010 from LRF and other sources. In order to take account of the tanker size and bunker capacity on other ships, the size distribution is expressed as a function of the spill size divided by the tanker deadweight.

Figure IV.8.3 Oil Tanker Oil Spill Size Distribution due to Grounding, 1992-2010



A simple analytical model of spill quantity (Q) as a fraction of tanker deadweight or bunker capacity (D) is fitted to the data as follows:

$$P(Q/D) = 0.08 - 0.2 \log (Q/D)$$ for Q and D in any consistent units, e.g. tonnes

The probability is by definition constrained to be within the range $0 \le P(Q/D) \le 1$.

The mean spill quantity, given an oil spill due to grounding, from oil tankers in the dataset was 13% of deadweight. The mean spill quantity from the model is 16% of deadweight.

IV.8.8 Effect of Risk Reduction Measures

The effects of risk reduction measures on powered grounding are based on the previous study (DNV 1999):

- Vessel traffic services $MF_{VTS} = 0.80$
- Traffic separation scheme $MF_{STS} = 1.00$ (i.e. no effect)
- Compulsory pilotage $MF_{pilot} = 0.51$

IV.8.9 Effect of Coast Type

The effects of the coast type on the spill probabilities due to grounding are assumed to be:

Rocky coast	$MF_{coast} = 3$
Reef	$MF_{coast} = 1.0$
Sand/mud coast	$MF_{coast} = 0.67$

IV.8.10 Effect of Distance Offshore

Grounding can only occur on the coastline or on offshore reefs. Therefore the grounding frequency at sea must reflect the distance between the ship's route and the nearest potential grounding points.

The frequency of powered grounding may be related to the number of critical course changes that are necessary to avoid grounding, and which by definition create a grounding opportunity if they are not executed as planned. This can be calculated for a specific ship's route and coastline, but a simpler method is needed for the present study. Ships are unlikely to continue for more than 20 minutes beyond a planned course change, and so the probability of a powered grounding from a location more than 4 nm from the nearest coast or reef is negligible. The present study uses a near-shore zone (up to 12 nm offshore). AUSREP data (Appendix I.3) shows trading ships spend an average of 31% of their time in this zone, so the average grounding frequency must be 3x higher there than average. Data on small commercial vessels (Table I.4.5) shows they spend an average of 92% of their time in this zone, so for them the grounding frequency there is only 1.1x higher than average. The modification factors are summarised as:

Near-shore (up to 12 nm offshore)	MF_{zone} = 3 for trading ships
	MF_{zone} = 1.1 for SCVs
Intermediate waters (12-50 nm offshore)	MF_{zone} = 0
Deep sea (50-200nm offshore)	MF_{zone} = 0

In cases where there are reefs in the intermediate zone, an MF_{zone} of 1 is used.

For drift grounding, the effect of distance offshore is represented explicitly in the model above.

IV.8.11 Effect of Approach Type

The approach types for each port can be characterised by average approach channel length and width. The modification factor for approach channel length is implicit in the formulation of frequency per km of approach. The modification factors for approach channel width (based on DNV 1999 and normalised to the wide river type) are:

Narrow rivers (under 0.5 km mean width)	MF_{width} = 6.3
Wide rivers (0.5 to 2.5 km mean width)	MF_{width} = 1.0
Wide estuaries (over 2.5 km mean width)	MF_{width} = 0.5
Open sea ports (lock/breakwater approach)	MF_{width} = 4.1

These factors are very old and are considered to be very uncertain. They are assumed to apply to both powered and drift grounding in restricted water.

IV.8.12 Effect of Navigation Difficulty

The existence of navigational hazards, such as reefs, shallow water, strong tides or lack of navigational aids may be expected to increase the frequency of powered grounding. However, in general, ships compensate for navigational difficulties by taking extra care in navigation and watchkeeping, and so it is not necessarily the case that more hazardous regions result in higher accident frequencies. In the previous study (DNV 1999) the relative level of navigation risks was evaluated qualitatively for each region. However no method was developed to adjust the accident frequencies, as further work was considered necessary before this could be done. It is difficult to distinguish between the identified hazards and the factors that have been modelled above. Therefore these factors are omitted from the present study too.

IV.8.13 Other Effects

Other possible effects on the powered grounding frequency are:

- Visibility - assumed to be the same as for collisions.
- Approach length - assumed to be the same as for collisions.
- Traffic density - no effect.
- Ship size - no significant effect.
- Sea state - no significant effect (for powered groundings).

IV.8.14 Validation

The generic oil spill frequencies above have been combined with the exposure of trading ships in Australia (Appendix I) to estimate the rate of oil spills due to grounding in Australian ports and waters. This gives an expected rate of 0.10 oil spills per year due to grounding, of which 13% is due to oil tankers. When small commercial vessels (SCVs) are included, the total rises to 1.3 per year.

This does not take account of traffic patterns or other specific features of Australian ports and waters. It also does not take account of the fact that spills from trading ships and SCVs would be of very different sizes. The oil spill risk model, which does represent these, gives a rate of oil spills over 1 tonne due to grounding of 0.11 per year for trading ships, which rises to 0.78 when SCVs are included..

AMSA spill data (Appendix III) shows a total of 15 oil spills over 1 tonne due to grounding during 1982-2010, which is an average of 0.52 per year. Of these, 5 were due to trading ships, i.e. 0.17 per year.

Table IV.8.13 Frequencies of Oil Spills Over 1 Tonne due to Grounding

SHIP TYPE	PREDICTED FREQUENCIES (per year)	HISTORICAL SPILLS 1982-2010	HISTORICAL FREQUENCIES (per year)
Oil tankers	0.01	0	0.00
Chemical tankers	0.00	0	0.00
Bulk carriers	0.05	3	0.10
General cargo ships	0.02	2	0.07
Container ships	0.01	0	0.03
Other ships (inc SCVs)	0.69	10	0.34
All ships	0.78	15	0.52

The comparison in Table IV.8.13 shows that the model predicts spill frequencies that are reasonably close to historical average. The differences may result from the small number of historical events. It is concluded that the current model is sufficiently accurate and does not require adjustment.

IV.9 REFERENCES

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