LLOYD'S

Emerging Risk Report 2018

Society & Security

Steering the course

A different approach to modelling marine risk

Centre for
Risk Studies

UNIVERSITY OF CAMBRIDGE
Judge Business School

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About Lloyd’s

Lloyd's is the world's specialist insurance and reinsurance market. Under our globally trusted name, we act as the market's custodian. Backed by diverse global capital and excellent financial ratings, Lloyd's works with a global network to grow the insured world – building the resilience of local communities and strengthening global economic growth.

With expertise earned over centuries, Lloyd's is the foundation of the insurance industry and the future of it. Led by expert underwriters and brokers who cover more than 200 territories, the Lloyd’s market develops the essential, complex and critical insurance needed to underwrite human progress.

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The Centre for Risk Studies is a multidisciplinary centre of excellence for the study of the management of economic and societal risks. The Centre's focus is in the analysis, assessment, and mitigation of global vulnerabilities for the advancement of political, business and individual decision makers.

The Centre provides frameworks for recognising, assessing and managing the impacts of systemic threats. The research programme is concerned with catastrophes and how their impacts ripple across an increasingly connected world with consequent effects on the international economy, financial markets, firms in the financial sectors and global corporations. To test research outputs and guide new research agendas, the Centre engages with the business community, government policy makers, regulators and industry bodies.

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Contents

Executive summary

Marine risks are changing. Although insurers can draw on several centuries of marine loss data, it is not as useful for assessing the probability of a severe marine loss because today's safety standards, trends and shipping patterns are very different.

Lloyd's and the Cambridge Centre for Risk Studies worked with marine experts, underwriters, actuaries, exposure managers to overcome this challenge. This report presents the Lloyd's-Cambridge Marine Risk Model to help insurers understand the 'tail risk' of potential losses they might experience in their marine portfolio. This analysis helps marine underwriters improve their estimation of the capital they need to support this important line of insurance business.

This model is an important evolution of the methodology of managing the insurance losses arising from severe marine events, and is a useful starting point from which to develop further models with marine insurance experts.

We believe, this is the first time a fully probabilistic severe loss model has been applied in this way to marine insurance.

A changing risk landscape

Since 1995 the Lloyd's market has managed its collective exposure to extreme marine losses by monitoring the losses that the Lloyd's Market could suffer in a hypothetical shipping catastrophe through the Lloyd's realistic disaster scenarios (RDS).

Since these scenarios were originally developed, the marine risk landscape has changed, and there are now a number of trends that will influence the likelihood and severity of marine events in the coming years. Vessels are getting bigger and being used more intensively. The average age of the global fleet is increasing as the lifetime of various vessels is extended.

New routes have opened (for example in the polar regions) and the large majority of shipping relies on a few strategic routes.

Changes in the regulatory and litigation landscapes have contributed to increasing compensation payouts, practices in dealing with salvage, spills, and wreck removal, all of which have implications for estimating the cost of future marine catastrophes. Consolidation of the shipping industry and the uncertainty around future economics of shipping are all adding to a changing pattern of risk.

Recognising these changing circumstances, Lloyd's strengthened its marine RDS in 2016.

The new scenarios quantify the total losses from a tanker (greater than 50,000 Deadweight tonnage) colliding with a cruise ship (2,000 passengers, 800 staff and crew) in US waters, and, separately, the sinking of a US-owned cruise ship (4,000 passengers, 1,500 staff and crew).

Following its RDSs review Lloyd's worked with Cambridge on a model that provides an alternative way of quantifying the risk of marine catastrophes to assess the likelihood and costs of extreme marine events. This project concluded that the current marine scenarios in Lloyd's RDS are extreme, but plausible and they remain appropriate for Lloyd's oversight.

Methodology

From the review of historical case studies, and with the help of specialists in marine risks and the experience of marine insurance underwriters, Cambridge developed a list of the types of scenarios that could cause severe losses to marine insurers in the future.

This involved a process of constructing hypothetical scenarios, and exploring the situations and variables that could make losses unexpectedly severe. This process made use of an advisory panel of marine risks specialist advisors and marine insurance market specialists, credited in the acknowledgements section of this report.

Lloyd's and Cambridge then worked with marine experts, marine underwriters and the Lloyd's Market Association, who provided invaluable knowledge that helped overcome the problem of limited observations in the historical record for certain vessel types. This process also addressed the fact that historical records may not accurately reflect current or future risks due to the rapidly changing nature of the marine industry.

This subjective expert knowledge was combined with objective statistical information (for example historical incident rates) in the model.

To further develop the model the Marine Model Development Working Group comprised of actuaries and exposure managers was created by the Lloyd's Innovation team during the final phase of the project. The working group used GitHub as a collaborative project platform and it focused on backtesting, incorporating liability limitation and strengthening the R version of the model (R is a language and environment for statistical computing and graphics).

Key characteristics of the new model

- This model provides a first analysis of the exceedance probability of marine vessel severe loss escalation.
- The report and model focus on three of the main shipping classes: container vessels, tankers and passenger cruise ships. Tankers are also split into oil-carrying and non-oil carrying vessels to take into account liability limitations.
- The model considers losses from almost all of the main causes of a constructive total loss to a ship, including allision (hitting a stationary ship), collision (hitting another ship), grounding, wrecking and stranding, foundering in open sea, and fire and explosion. These causes account for 92% of all shipping losses.
- The Lloyd's-Cambridge Marine Risk Model is based on an event-tree framework. Type, size and jurisdiction are categories which determine the incident probability, followed by 14 factors that lead to the event economic loss. This approach allows a formal inclusion of all the various ways that losses might occur to today's fleet and insurance portfolios to inform understanding of the 'tail risk' of potential losses that a managing agent might experience in their current portfolio of marine exposure.
- The model presented here generates large numbers of individual scenarios, each with a specific combination of factors from an event tree with different values, with a resulting cost distribution for each of the cost parameters for damage, salvage and cargo.
- Each scenario has an estimated and explicit likelihood for those permutations of factors to occur. By ranking all the scenarios by severity of loss, insurers can assess the probability of exceeding a certain level of loss for a vessel of that type. They have a loss 'exceedance probability' distribution – also known as an EP curve for each vessel type.
- The total economic loss is then obtained by the sum of multiple head of claims, specifically hull damage, cargo loss, wreck removal, human liability and environmental pollution liability to enable different elements of the loss to be costed separately and to consider payouts for different lines of business within the marine insurance operation.

- For each vessel type, the event tree model generates an estimation of how likely it is that the loss severity from a total loss will exceed a certain value: a loss EP distribution curve.

- Because the loss is broken down by different coverages, there is a specific EP curve for each coverage and Lloyd's managing agents who have different exposures can assess their own loss profile as a result. This suggests methods by which insurers can construct a portfolio-specific estimation of their tail risk.

- The likelihood of losses at different annual probabilities and return periods are set out for different types and classes of vessels. Marine insurers can include these metrics in their estimates of the risk to their portfolios from severe loss events.

- International treaties significantly limit marine liabilities and are therefore incorporated in the calculations of the model.

- The initial model results were compared to back-testing information and the parameters were further refined to achieve reasonable agreement with this past data and empirical probabilities.

Conclusion

- The risk landscape has changed, and there are a number of trends that will influence the likelihood and severity of marine events in the coming years.

- This report presents a model for severe economic losses resulting from marine insurance risks.

- To quantify the likelihood of costs escalating in a marine vessel total loss, Lloyd's and Cambridge have developed a logic process model that captures the likelihood of different steps combining to cause a severe loss pay out in different categories: hull loss, wreck removal, cargo loss, liability for injuries, liability for environmental pollution and total pay-outs.

- Cyber-attacks on marine navigation equipment are considered more likely to cause relatively low levels of loss compared with other scenarios, though the likelihood of cyber-attacks against marine vessels in general may become more of a risk in future compared with the other scenarios described such as explosion in a major world port or terrorist attack on a cruiseship.

- International treaties can dramatically cut the potential for marine insurers to incur severe liabilities from marine incidents, but do not reduce the full economic effect of these scenarios on society. They do, however, help keep premium levels affordable, reducing costs that would otherwise be passed on to customers.

- This project concluded that the current marine scenarios in the Lloyd's RDS are extreme, but plausible and they remain appropriate for Lloyd's oversight.

Next steps

The Lloyd's-Cambridge Marine Risk Model has been developed as a first step towards the probabilistic assessment of global marine disaster tail risk. This research may be further developed in several directions:

- The model could be extended to cover all vessel types and marine incident types. The model would then provide a comprehensive view of global marine disasters.
- The analysis could be extended to include all marine casualties, not just those resulting in total loss.
- Counterfactual analysis as described in Lloyd's 2017 publication 'Reimagining history, counterfactual risk analysis' could be used to factor in data from historical near misses that would enrich the current model.
- The model provides EP curves for single-vessel marine losses across the global fleet. The model could be trivially adapted to create bespoke EP curves for a marine insurer's fleet profile, including consideration of the insurance, re-insurance and the structure of P&I club reinsurance participation.
- Use of additional data sources such as Lloyd's List Intelligence database, satellite automatic identification systems and machine-learning algorithms could automate the identification and interdependency of critical variables.
- For a given vessel the routes it takes could be modelled to allow more detailed outputs and more bespoke portfolio analysis. Liability limitations could be implemented in a more sophisticated way.

Broadening approaches to modelling marine insurance risk

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1. Broadening approaches to modelling marine insurance risk

A review of the Lloyd's marine RDS

Since 1995 Lloyd's has managed its collective exposure to extreme marine losses by monitoring the losses that managing agents could suffer in a hypothetical shipping catastrophe defined in terms of the loss of one or more large vessels - a Realistic Disaster Scenario (RDS). Since the scenarios were originally developed, shipping volumes have doubled, the largest vessels are three times the size and there are four times as many ships at sea (*World Shipping Council, 2016*). For this reason Lloyd's strengthened its marine RDS in 2016 and it now requires managing agents to report their losses from a hypothetical collision in US waters between a cruise vessel with 2,000 passengers and 800 staff and crew, and a fully laden tanker of greater than 50,000 DWT with 20 crew. Lloyd's also requires losses to be reported in a second scenario of involving the sinking of a US-owned cruise vessel with 4,000 passengers and 1,500 staff and crew (*Lloyd's, 2016*). Variants of these two scenarios, inspired by the Exxon Valdez catastrophe of 1989, have been used since their inception as Lloyd's Marine RDS events *(Lloyd's, 2004)*.

As part of the RDS review we undertook to carry out an external project to explore the changing nature of global shipping risks and this report presents the conclusions of the project. Here, we present a model which provides an alternative method of quantifying the risk of marine catastrophes to assess the likelihood and costs of scenarios.

A marine loss severity likelihood model

The techniques of risk analysis have broadened since the original Lloyd's RDS was developed. Probable Maximum Loss (PML) assessments in many other lines of insurance business are now derived from analysis of loss exceedance probabilities, which adds an assessment of the likelihood of scenarios to the assessment of severity. Insurance risk management requires capital that explicitly covers a certain level of severe loss, typically in the range of one in 50 a year (a 2% chance of being exceeded in a given year) to one in 500 a year (a 0.2% chance). They are also known as 50 year return period or 500 year return period respectively. Solvency II requires a calculation of a one in 200 balance sheet impact over all lines of insurance and other relevant risks. Scenarios remain a useful method, however, to explore detailed hypothetical events and assess the variation or volatility of claims patterns year on year widen the view of the risks.

Although there are several centuries of marine loss historical experience available, assessing the probability of a severe loss for today's maritime industry cannot easily be derived from statistics from an age when safety standards and shipping patterns were very different. Instead, an updated and useful analysis requires consideration of all the various ways that losses might occur to today's fleet and insurance portfolios, and to assess these in a formal process of combinations of conditions that could cause losses to become severe. This report proposes a Lloyd's - Cambridge Marine Risk Model that can inform understanding of the 'tail risk' of potential losses that a managing agent might experience in their portfolio of marine exposure.

Severity of loss of a vessel

Compared with some other lines of insurance business, marine insurance has much less aggregation or concentration risk. Most losses usually involve a single vessel, and the severity of the claim for a complex, individual casualty is a more common and pressing concern than the possibility of multiple minor losses occurring from the same cause, although both need to be considered when assessing the risk capital required to support this line of business, in particular in light of the breath of cyber-attacks.

Major losses on marine (re)insurance policies arise principally from the following heads of claim:

- Loss or damage to hull and machinery
- Loss or damage to cargo
- Salvage and wreck removal
- Compensation for loss of life and personal injury
- Third party liabilities, most notably for pollution clean-up costs and loss of life and injury

Examples of extreme historical losses for each of these exposures are considered in the next section of this report, which examines the potential cost severities for each of these main coverage categories. The worst disasters involve combinations of several or all of them, but it is possible to have a severe loss driven predominantly by just one of these lines of business, such as cargo loss. There are catastrophe models available for marine cargo stored onshore, for example, that can help quantify the severity of loss that might be expected at certain levels of probability for this specific coverage. Estimating the likelihoods of severe loss to other coverages is less well established.

Portfolio-specific loss exceedance probability

Each insurer has its own portfolio of marine risks with different numbers, types and sizes of vessels, and the vessels will be operating in different parts of the world. There will be different degrees of exposure in each of the main coverage categories according to the policy terms on those vessels.

Each insurer's portfolio has a different risk profile, which reflects its own likelihood of experiencing a severe loss. Insurers have their own participation and retention of different levels of the risk, with their own co-insurances, reinsurance arrangements and possibly P&I club excess of loss reinsurance participation. This report suggests methods by which insurers can construct a portfolio-specific estimation of their tail risk.

Containers, tankers and cruise ships

This report focuses on three of the main classes of shipping: container vessels, tankers and passenger cruise ships. We also split tankers into oil carrying and non-oil carrying tankers. Each has its own risk characteristics and needs to be considered separately. Each class of shipping has a wide range of different sizes. We take three example size categories in each of the main types (see Table 1), with more focus on the larger size categories that drive the potential for severe losses, to provide analysis for representative vessel. The model does not include bulkers as the most significant claims are less likely to arise from this class of vessel.

We describe a model that explores the key factors that can escalate the losses from a marine total loss event for a single vessel in each of these vessel types as an event tree of compounding factors, generating many thousands of scenarios that combine multiple factors. The model considers loss from almost all of the main causes of a constructive total loss to a ship, including allision (hitting a stationary object), collision (hitting another ship), grounding, wrecking and stranding, and foundering in open sea, fire and explosion. These causes account for 92% of all shipping losses. The remaining 8% of total losses are from causes that are not modelled, such as machinery damage, missing and overdue vessels, and piracy *(Allianz, 2016)*. However, since these causes are independent from the main causes and they typically have smaller loss values their omission will not materially affect the tails of the loss distribution. We parameterise the analysis from worldwide statistics applied to the global shipping fleet.

Loss breakdown by coverage

The model presented here generates large numbers of individual scenarios, each with a specific combination of factors drawn from an event tree with different values, with a resulting cost distribution for each of the cost parameters for damage, salvage and cargo.

Each scenario has an estimated and explicit likelihood for those permutations of factors to occur. By ranking all the scenarios by severity of loss, insurers can assess the probability of exceeding a certain level of loss for a vessel of that type. They have a loss 'exceedance probability' distribution – also known as an EP curve for each vessel type. Because the loss is broken down by different coverages, there is a specific EP curve for each coverage and Lloyd's managing agents who have different exposures `can assess their own loss profile as a result.

Using with a portfolio of multiple ships

The greater the number of ships in a portfolio, the more chances there are in a given year of experiencing an event like one of the more severe scenarios from the distribution. In section 5 of this report, we consider a range of scenarios that could cause multiple vessel losses or severe losses beyond those incorporated in the Lloyd's-Cambridge Marine Risk Model, and which could be added in the future to improve the estimation of tail risk for a portfolio of vessels. The foundation for assessing the return period for an extreme loss in a portfolio, however, is the vessel-specific loss exceedance probability distributions published in this report.

Lloyd's, in partnership with Cambridge, believes that this analysis provides an evolution in the methodology of managing the insurance risk of severe losses in a portfolio of marine insurance and is an important starting point to further develop models with marine insurance experts.

Box 1: Terminology, annual probability, and return periods

The insurance industry uses terms like Probable Maximum Loss (PML), which means the maximum loss that has a given probability of occurring within a specified time period.

It is possible to define the likelihood of a loss occurring that exceeds a certain value, but it is not meaningful to put a probability on the exact circumstances that could give rise to one specific scenario. An individual hypothetical scenario has features and a narrative that illustrates the causal processes of a loss, but the narrative and features of a scenario cannot easily be described as having their own 'return period'. For example, an explosion at a port might occur somewhere in the world on average once every 20 years. The chance of a specific explosion of a certain explosive yield at one selected port with the blast damaging five ships is almost impossible to quantify because the more specific the scenario, the smaller the likelihood of that exact set of conditions occurring. Instead, we consider the losses that might occur from all causes, represented by combinations of scenarios that are suggested from worldwide occurrence rates, and assign a probability to the level of loss being exceeded.

The term 'return period' is commonly used to refer to the annual probability of a loss. The return period is the reciprocal of the annual probability (1/annual probability). Although the term can be taken to imply that there is a period of time that might elapse between one event of this type and the next, this is not what is meant. It is a measure of likelihood, and it is possible that two events of this severity could occur in rapid succession, but with even lower likelihood.

Marine losses and large loss precedents

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2. Marine losses and large loss precedents

This section reviews the history of loss in the marine industry and highlights some case studies of severe losses that have occurred. These are not all severe insurance losses, but they illustrate the ways that shipping losses can occur. Shipping loss data is compiled by Lloyd's Register, and analysed each year in Allianz SE's annual marine risk report and by the International Union of Marine Insurance (IUMI), which draws data from its members *(Allianz, 2016)*. This data includes statistics for all 'large vessels' i.e. vessels over 100 tons and from it we can see the trends and total loss rates across the shipping fleet. Variables such as location, route, a ship's size and age, weather conditions and accessibility all contribute towards the risk of loss and incident severity. Data is also available over a longer time period from the Lloyd's Register World, Casualty Statistics 1900-2010.

On average 127 large ships (over 100 gross tons) have been lost per year over the past decade. The number of ships lost per year has been declining, as shown in Figure 2, with only 85 total vessels lost during 2015. Greater safety and stricter regulations on shipping, improvements in the design and construction of ships, and advances in navigation, radar, communication, and weather forecasting accuracy have contributed to a steady decrease in the number of total marine losses over the past century, even though the worldwide fleet is steadily growing *(Allianz, 2016)*. Between 2006 and 2014, there was a 45% reduction in the annual number of vessels lost. In March 2016, however, IUMI observed that 2015 was the first year for some time not to see a year-on-year decline in total losses *(IUMI, 2016)*. The worst year for global shipping losses in the past decade was 2007 when 171 total ships were lost during the worst year for catastrophe losses since 2000 *(Allianz, 2016)*.The worst year for global shipping losses in 20th century was 1960, when almost twice as many ships were lost as in an average year for that period.

For each ship lost, a great many more suffer accidents. In 2015 there were 2,602 shipping incidents causing repairable damage in addition to the 85 ships that were considered total losses. Allianz reports that increasingly large and more valuable vessels coupled with escalating penalties for injury and pollution, meaning that a single incident can trigger particularly severe losses. Moreover, loss costs to insurers can inflate significantly if there is political interference in the commercial decisions of salvage agents and incident managers.

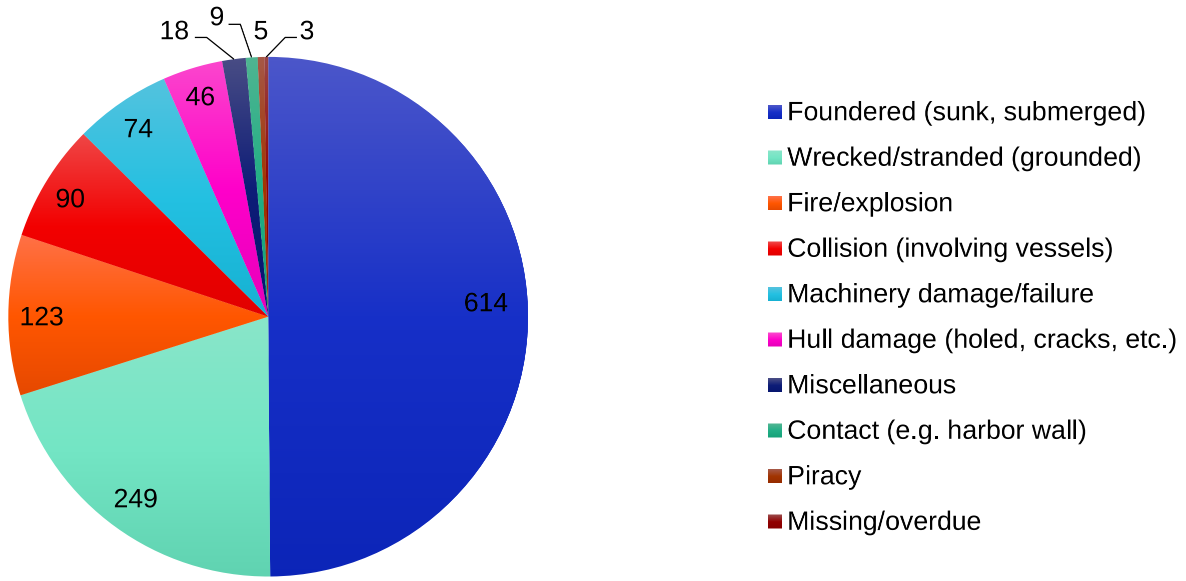
The reported data includes several different categories of total loss, including constructive total loss where the cost exceeds the recoverable value of the vessel:

- **Foundered** - Sunk or submerged, the largest category of ship loss and includes ships in distress where the crew can be rescued
- **Wrecked** - Ship hits rocks, shoreline or is unable to float off an underwater obstacle
- **Fire or Explosion** – Ship is sunk as a result of fire in the engine room, or spreading to the engine roomc
- **Collision** - Ship collides with another vessel
- **Lost** - Ship is classified as missing or overdue, most likely sunk in open water

Figure 1 summarises the causes of total ship losses in the last decade. Foundering (sunk or submerged) accounts for roughly half (614) of all losses, followed by wrecking/stranding (grounding), which accounts for one in five shipping losses. Over the decade there has been a significant fall in the number of losses due to fire, explosion and collision, and there were no losses as a result of piracy for four consecutive years.

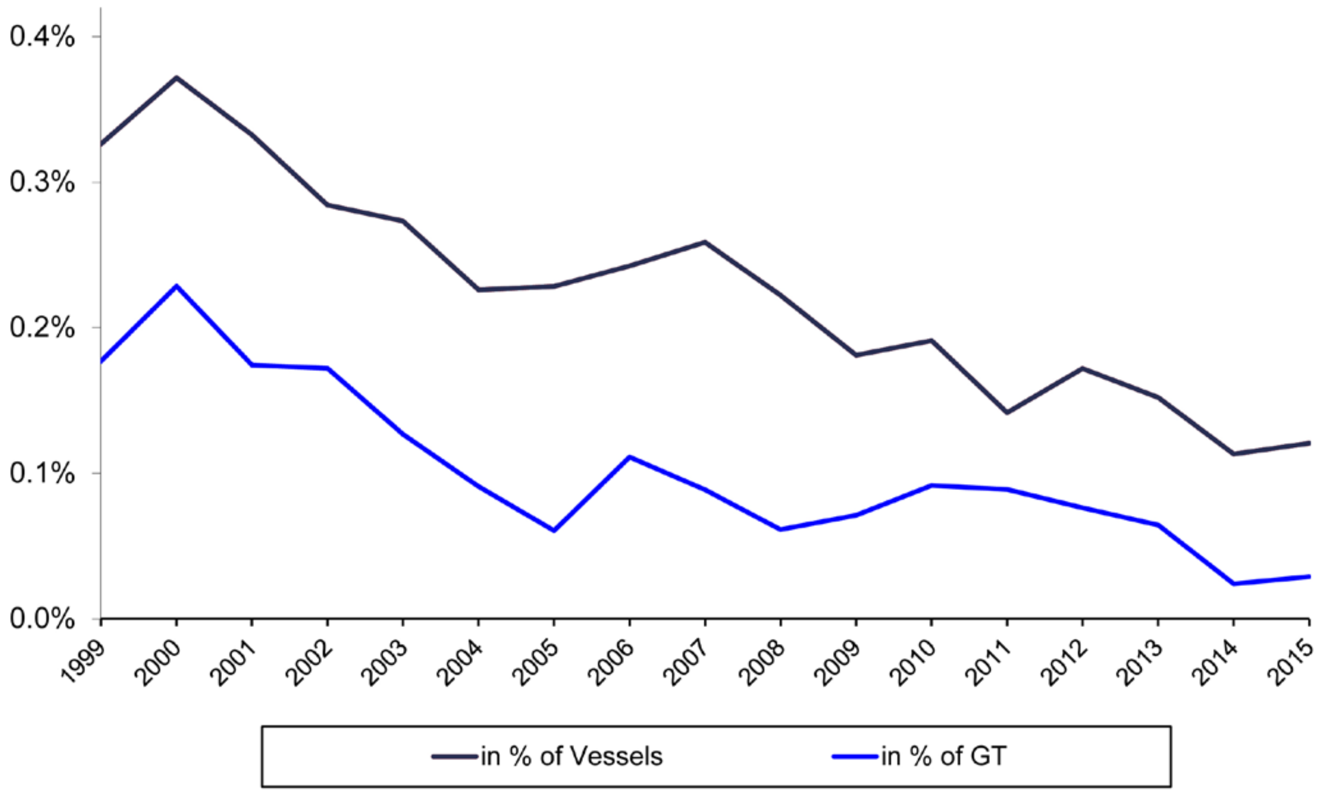
Cargo vessels form the largest category of lost ships, as shown in Figure 3. Figure 4 summarises the largest losses in the marine industry by region in the past decade.

Figure 1: Causes of constructive total ship losses 2006-2015



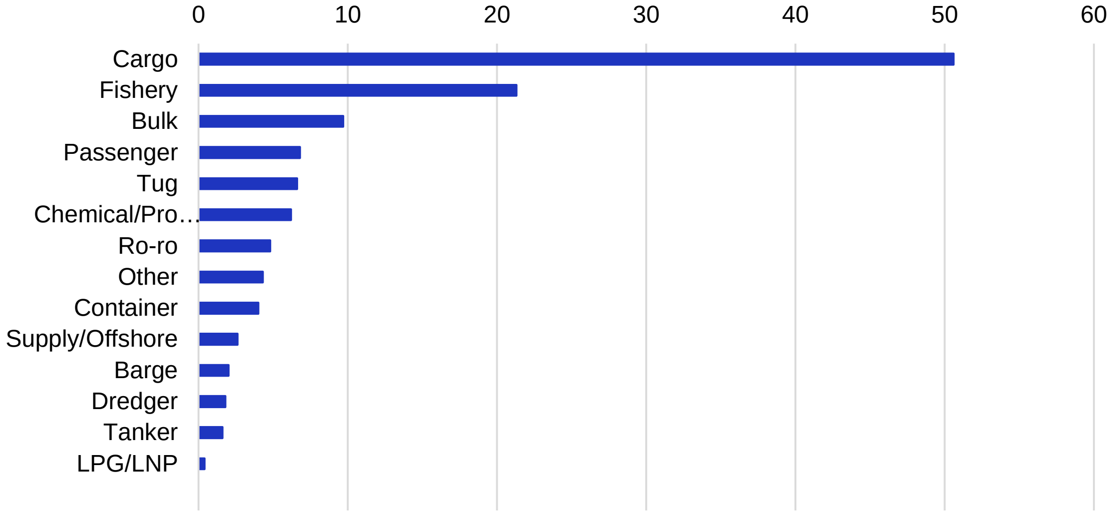
Source: Allianz, 2016

Figure 2: Total losses 1999-2014 as percentage of world fleet (vessels >500GT)



Source: IUMI, 2016

Figure 3: Total average losses by type of vessel 2006-2015



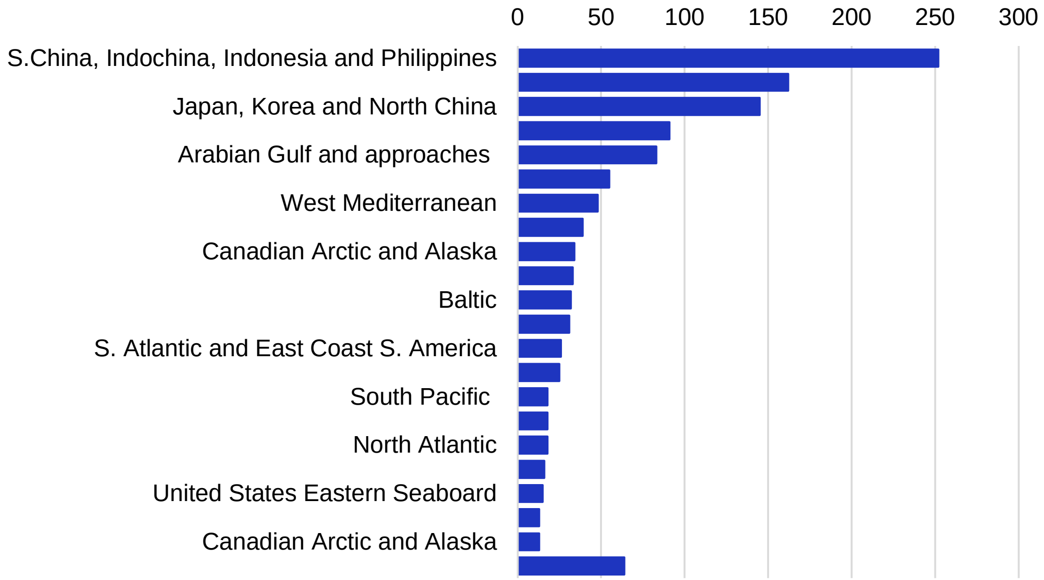
Source: Allianz, 2016

Regional variation in marine loss risk

More than a quarter of recent shipping losses have occurred in the South China, Indochina, Indonesia and Philippines regions. The increase in the number of events in these areas reflects the increase in shipping activities in these waters.

The 2015 Port of Tianjin explosion (see Box 2) and the capsizing of the *Dongfang zhi Xing* (*Oriental Star*) river cruise ship during a storm with the loss of 442 people, also in 2015, are notable examples of major marine incidents local to these areas. The overall cost of accidents and losses in these regions has also increased in recent years *(Zhang et all, 2013)*.

Figure 4: Total marine losses by region between 2006 and 2015



Source: Allianz, 2016

Figure 5: Timeline of large marine events in the past century

1912

Sinking of the RMS Titanic

The sinking of *R.M.S. Titanic* in 1912, with 1,517 fatalities, is arguably the most infamous maritime disaster.

1913

The White Hurricane

In 1913, the White Hurricane destroyed 19 ships and stranding 19 others on the Great Lakes.

1917

Halifax Explosion

The explosion on the fully laden French munitions ships Mont-Blanc in Halifax, Nova Scotia, Canada in December 1917 killed about 2,000 people on the shore and in Halifax, as a result of the blast, falling debris, fires, and collapsing buildings. More than 9,000 people were injured. This is the largest ever accidental explosion of conventional weapons.

1944

Typhoon Cobra

The most ships lost in a tropical windstorm occurred in Typhoon Cobra in 1944, when an unexpected hurricane hit the US Navy Third Fleet in the Philippine Sea. Three destroyers capsized and sank with the loss of 790 men. Thirty ships were damaged, nine warships were badly damaged and 100 war planes were destroyed or washed off the decks. The tragedy led to the establishment of the Joint Typhoon Warning Centre for the Pacific Ocean. Second World War navy warships are very different to today's commercial vessels, but the precedent demonstrates the potential for a large marine loss from a hurricane if appropriate security measures are not taken at sensitive times.

1945

MV Wilhelm Gustloff

The largest loss of life recorded from a ship sinking is 9,400 people lost when a Soviet Navy submarine torpedoed the German transport ship *MV Wilhelm Gustloff* during an evacuation voyage in January 1945.

1987

Doña Paz Ferry Collision

The 1987 collision of the *Doña Paz* passenger ferry with oil tanker Vector in the Philippines, caused an estimated 4,386 deaths. This is the largest death count in a non-military shipping accident in recent history.

MS Herald of Free Enterprise

On 6 March, 1987 the Herald of Free Enterprise car passenger ferry turned over on its side outside the port of Zeebrugge, Belgium, killing 193 of the 459 passengers, and half of the crew of 80.

1989

Grounding of the Exxon Valdez

On 24 March 1989, *Exxon Valdez* grounded on Blight Reef, Prince William Sound, near Valdez, Alaska, spilling about approximately 258,000 barrels (10.9 million gallons) of crude oil (Box 4).

2011

Tohoku Earthquake

The Tohoku earthquake in 2011 triggered a tsunami of up to 10m that impacted ports and shipping activities all along the Sendai coast in Japan. The event damaged the LNG terminal at the Port of Sendai, putting it out of action for a month, and damaged several large vessels, including cargo ship *China Steel Integrity* (175,775 DWT), a bulk carrier, CS Victory (32,285 DWT) and a cargo ship, *Asia Symphony* (6,175 DWT).

Rena Grounded

On 5 October 2011, the Rena ran aground on Astrolabe Reef, offshore from Tauranga in the Bay of Plenty, New Zealand resulting is a spill of oil and loss of cargo (Box 3).

2012

Super Storm Sandy

Super storm Sandy in 2012 caused a storm surge flood that damaged cargo at many ports storage areas around New York, causing marine insurance losses, principally cargo loss pay outs. Total insured losses from Sandy across all lines are estimated at US$25bn (*Allianz*, 2013).

Costa Concordia

Cruise ship *Costa Concordia* grounded off the coast of Italy in 2012. *Costa Concordia* cost insurers over US$2 billion.

2014

Sinking of the Sewol

The Sewol (Box 5) was carrying 476 people when it sank off the southwest coast of Korea on 16 April 2014. 304 people died (*CNN, 2014*).

MS Norman Atlantic

The *MS Norman Atlantic* caught fire on 28 December 2014 in the Strait of Otranto Sea resulting in 30 casualties.

2015

Tianjin Port Explosion

A port explosion in Tianjin, China in 2015 caused one of the largest marine insurance with losses estimated between US$1.5 billion and US$6 billion (*World Maritime News, 2016*).

Grounding of the Hoegh Osaka

The roll-on/roll-off car carrier ship *Hoegh Osaka* (51,770 GT) was deliberately grounded in the Solent in 2015 (BBC, 2015). The cargo consisted of 1,450 cars (323 damaged, 52 total loss) and 183 high and heavy (33 damaged, 28 total loss.) (*MAIB, 2016*).

Box 2: Port Explosion in Tianjin, China, 2015

Event

On Wednesday, 12 August 2015, two explosions in a storage and logistics area of Tianjin port killed 173 people *(The Guardian, 2015)* and injured more than 700 *(CBC News, 2015).* There was widespread damage to surrounding property and infrastructure, although the shipping terminals were largely unscathed and port operations resumed within a week *(Reuters, 2015)*. The cause of the explosion was the ignition of hazardous materials, which were either improperly or illegally stored at the site *(Hernandez, 2016)*. The largest port explosion prior to Tianjin was the 1947 explosion of over 2,000 tons of ammonium nitrate being loaded onto the *SS Grandcamp* in the Port of Texas City *(Minutaglio, 2003).* At least three ships were rendered total constructive losses and another seven were damaged. Dozens of oil storage tanks and chemical tanks were set alight. 581 people died and over 5,000 people were injured *(Stephens, 1997)*. It is still considered the worst industrial accident in US history.

Losses and claims

Nick Derrick, Chairman of the Cargo Committee at The International Union of Marine Insurance (IUMI) reported that estimated cargo losses from the Tianjin could raise from at least US$1.5 billion to as high as US$6 billion *(World Maritime News, 2016)*.

Swiss Re sigma in March 2016 made a working estimate of the total insured property loss of the Tianjin explosions at around US$2.5 billion to US$3.5 billion, subject to revision *(Reuters, 2016).* Damage to the thousands of new vehicles parked at and near the blast site would make up most of the insurance claims. The total number of affected cars was estimated over 20,000 *(Asia Insurance Review, 2016).* Contamination was also difficult for adjusters to estimate, but it might have triggered cargo claims *(Marine Executive, 2016)*.

Six months after the event losses could be broadly classified in the following categories according to Marine Insurance Bulletin of April 2016 *(HFW, 2016):*

- residential, industrial and warehousing property damage, including contamination
- Business Interruption (BI), Contingent Business Interruption (CBI) and Supply Chain Disruption
- Thousands of brand new cars
- Containers of all shapes and sizes
- Liability policies
- Reinsurance

Coverage issues

Swiss Re Sigma explained the uncertainties with respect to the types of cover that could be triggered by the event, depending on whether the damaged vehicles were in transit or at their final port of destination en route to a point of sale in China *(Asia Insurance Review, 2016)*.

Container insurance

Mutual insurer TT Club insures 80% of all maritime containers and has an insurable interest in more than 45% of the world's top 100 ports *(TT Club, 2017)*. In its annual report for 2015 the club said that a number of its members had suffered losses and that claims would fall on the Club's reinsurers *(TT Club, 2015)*.

In 2016 Peregrine Storrs-Fox, TT Club Risk Management Director wrote:

'Tianjin provides a spectacular example of how cargo in transit, potentially mis-declared, or packed or handled incorrectly, can cause widespread damage and loss of life. There have, however, been other port-related incidents of a lesser magnitude reported in the last year, at Santos in Brazil and in Vancouver in Canada. Together, these represent the tip of an iceberg that is made up of many less serious incidents that occur each year, resulting in fatalities, injuries and substantial disruption to the supply chain' (TT Talk, 2016).

Box 3: Rena grounding and oil spill, New Zealand, 2011

A complex salvage case and wreck removal in a remote environmentally and culturally sensitive location

Source: NZ Defence Force assistance to OP Rena, 2011

Type: Container ship

Size: 3,032 TEU

Cargo: 1,368 containers, 11 of which contained dangerous goods.

Built: 1990

Flag: Liberia

Owner/operator: Costamare subsidiary Daina Shipping Co.

Event type: Grounding and pollution

Event

On 5 October 2011, the *Rena* ran aground on Astrolabe Reef, offshore from Tauranga in the Bay of Plenty, New Zealand resulting is a spill of oil and loss of cargo *(Costamare Inc, 2011)*. The ship was declared a constructive total loss *(Lloyd's, List 2011)* and it was estimated that more than 200 tonnes of fuel oil were released from the vessel *(The Atlantic, 2011)*.

Subsequently, bad weather widened the cracks in the vessel and following another severe storm in January 2012, the Rena eventually broke into two parts with the loss of a further containers *(The Guardian, 2012)*. In February 2016, the owners of the *Rena* were allowed to abandon the last remaining part of the wreck off the coast of Tauranga *(gCaptain, 2016)*, with strict conditions, including the multi-million-dollar bond to cover continuing costs *(NzHerald, 2016)*.

Claims

On 1 October 2012, Daina Shipping Co., agreed to pay the New Zealand government NZ$27.6m (US$22.7m) in respect of certain matters arising from the Rena's grounding with an additional NZ$10.4m if permitted to leave part of the vessel in place *(World Maritime News, 2012)*.

Costamare Shipping, owners of the Rena, are members of The Swedish Club, one of the world's leading marine liability insurers. The Swedish Club was the Rena's insurers and investigated the environmental, social, cultural and economic impacts of different options for dealing with the wreck (*Maritime New Zealand, 2012)*.

The owner was allowed to limit liability under the *New Zealand Maritime Transport Act* 1994, which incorporates the 1976 Convention on Limitation of Liability for Maritime Claims in respect of claims arising from the grounding *(Magkill, 2011)*.

Following the *Rena* loss, New Zealand updated the *Maritime Transport Act* to increase the limits available under 1996 Protocol to Convention on the Limitation of Liability for Maritime Claims 1976 (LLMC).

Box 4: Exxon Valdez, 1989

Source: NOAA's National Ocean Service, 2014

Type: Very large crude carrier (VLCC)

Size: 214,867 DWT

Cargo: 1,263,000 barrels of crude oil

Built: 1986, single hull type

Flag: US

Owner/operator: Exxon Shipping Company

Classification society: American Bureau of Shipping

Event type: Grounding, pollution

Event

On 24 March 1989, *Exxon Valdez* grounded on Blight Reef, Prince William Sound, near Valdez, Alaska, spilling over 20% of the 200,984.6 m^3) of oil it was carrying. There was extensive damage and loss of animals and birds along the Alaskan coastline resulting in significant clean up costs. In response to the spill the Unite States Congress passes the Oil Pollution Act of 1990 (OPA) to streamline and strengthen United States Environmental Protection Agency's ability to prevent and respond to catastrophic oil spills. The OPA also set a schedule for the gradual phase in of a double hull design.

Damage to vessel: The damaged was enough for a discharge of fuel, but the ship was repaired and put back into service. It continued to trade until 2012.

Box 5: Sewol, Korea, 2014, and other ferries

Type: Ro-Pax ferry

Size: 6,825 GT

Flag: Korean

Built: 1994

Owner/operator: Chonghaejin Marine Co., South Korea

Event type: Sinking

Event

The Sewol was carrying 476 people when it sank off the southwest coast of Korea on 16 April 2014. 304 people died *(CNN, 2014)*, many of them students were aged between 16 and 17 on a school trip to the holiday island of Jeju *(Reuters, 2014)*.

Blamed on a combination of illegal redesigns, overloading of cargo, crew inexperience, and lax government regulations, the disaster created a wave of national outrage *(The Korea Herald, 2014)*. The captain was sentenced to a 36 years in prison, and other officials and company officers were prosecuted *(The Guardian, 2014)*.

The *Sewol* Ferry was insured by KSA Hull P&I Club, which covers vessels belonging mainly to operators of ferries and other coastal ships *(Fairlplay, 2013)*. Following Sewol event the Korea Shipowners' Mutual Protection & Indemnity Association (Korea P&I Club) COO Park Bum Shik called for '*greater efforts to prevent accidents' (Fairlplay, 2013)*.

Other ferry disasters

The sinking of the Estonian roll-on/roll off[a] (ro-ro) passenger ship *Estonia* (15,566 GT) in the Baltic Sea during the night of 28 September 1994 is the worst peacetime ship disaster in Europe *(Soomer, Rantan and Penttilä, 2011)*. A total of 852 passengers and crew died. The sea was rough, and the official accident report indicated that the locks on the bow door had failed from the strain of the waves, and the door had separated from the rest of the vessel. Recommendations for modifications of ships of this type followed, along with additional training requirements for crew.

The British ro-ro ferry *Herald of Free Enterprise* sank close to the Belgian port of Zeebrugge on the night of 6 March 1987 with the deaths of 193 passengers and crew *(UK Department of transport, 1987)*. The ferry had left the harbour with its bow door open and the sea quickly flooded the lower deck and destabilised the vessel. It was the highest peacetime death count on a British ship since 1919, and led to major improvements to the design and procedures on ro-ro vessels.

Overloading is often a factor in the high loss of life in ferry casualties in developing countries. This was the case with the worst peacetime shipping disaster, the 1987 loss of the Philippines ferry *Doña Paz.* The same was true for the Senagalese government-owned ferry *Le Joola* (2,087 GT), which capsized off the coast of Gambia on 26 September 2002 during a heavy rainstorm. An estimated 1,863 people died, but the exact number could not be confirmed because the ferry was overloaded and many passengers were unticketed *(BBC News, 2002)*.

[a] vessels designed to carry cars, trucks, trailers, and railroad cars, driven on and off the ship on their own wheels or using a platform vehicle.

Trends in marine risk

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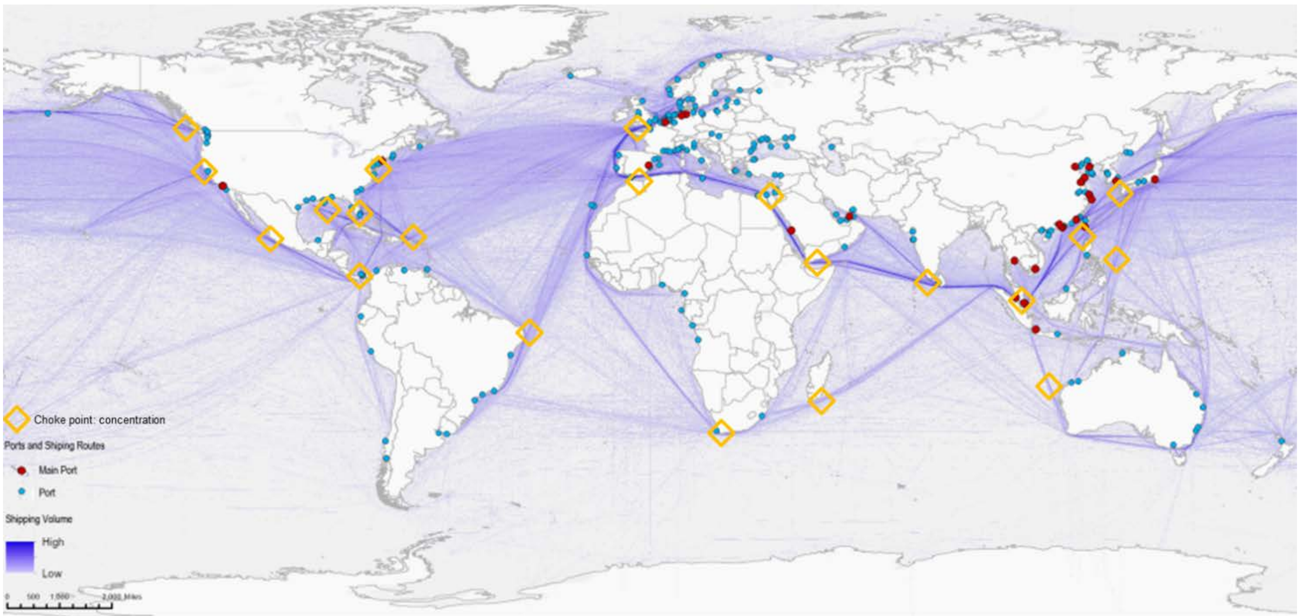
3. Trends in marine risk

There are a number of trends that will influence the likelihood and severity of marine events in the coming years. The number of ships in the world merchant fleet is rising, the vessels are getting bigger and being used more intensively. The average age of the global fleet is increasing as the lifetime of various vessels is extended. Changes in the regulatory and litigation landscape have contributed to increasing compensation pay outs, and practices in dealing with salvage, spills, and wreck removal have implications for cost estimation of future marine catastrophes. Consolidation of the shipping industry and the uncertainty around future economics of shipping all add to a changing pattern of risk.

Growth in shipping activity

Globalisation and the increase in international trade over the past generation have driven huge growth in ship traffic in the world's oceans, with four times as many ships estimated to be at sea today than in the early 1990s *(Tournadre, 2014)*. The large majority of shipping relies on a few strategic routes, shown in Figure 6.

Figure 6: World shipping traffic routes and locations of concentrations of shipping



Source: Cambridge Centre for Risk Studies, 2016 from Halpern, 2008

There are concentration points where the density of ship traffic increases around key ports, canals, or navigation choke points. Insurers' portfolios include shipping companies that may operate regionally or some of these routes more specifically, so each marine underwriter's portfolio is likely to be different in terms of the regional traffic patterns of the insured exposure.

Regional growth in shipping traffic and risk implications

According to China Cruise and Yacht Industry Association (CCYIA), China expects to be the largest cruise market in the world by 2020 with 4.5 million passengers by 2025 *(Marine Executive, 2016)*. In addition to an expanding internal market, international cruise companies, such as Carnival Corporation, have announced the intention to increase their presence in the East Asian market and to have a number of cruise ships homeported in China *(World Maritime News, 2015)*.

Concerns have already arisen in regards to the Panama Canal and its recent expansion opened in June 2016. Doubts have been raised about the viability, future safety and usage of the new canal by post-Panamax ships *(Bogdanich and Mendez, 2016).*

Polar Regions

In the 2012 Lloyd's report 'Arctic opening: opportunity and Risk in the High North' a result of regional climatic warming, new or underused passages are opening up in the Polar Regions, viable to larger cruise ships and tourist exploration.

In 2016, the *Crystal Serenity* became the largest commercial cruise liner to sail the remote Northwest. Some 1,000 passengers were required to purchase $50,000 in evacuation insurance prior to the 28-day journey, which was completed in September 2016*(Nunez, 2016)*.

Should an event arise in such locations the chances of the loss being significant is thought to be greater than in a more benign location. Polar regions are extreme and remote environments, and it takes longer and is more difficult to rescue people and salvage damaged vessels. There has already been an increase in the number of marine incidents, up by 30% year-on-year in 2015, with 415 incidents in Arctic waters in the last decade, including 18 total vessel losses *(Allianz, 2016)*.

There is the potential for severe pollution liabilities resulting from a spill in the ecologically fragile Polar regions. The International Tanker Owners Pollution Federation (ITOPF) has warned of the complexity and costly nature of cleaning up oil spills as, in the case of Arctic conditions, the temperature will *"affect spilled oil behaviour in a number of ways, some aiding and some hindering [the] ability to respond. Standard oil spill rate and trajectory models do not apply in icy waters… in the highly dynamic pack ice zone [,] oil drift may be considerable and unpredictable." (ITOPF, 2016)*.

In response to increasing safety concerns, the International Maritime Organisation (IMO) has worked on introducing mandatory guidelines (the "Polar Code") for ships operating in polar waters. This work includes a series of amendments to three existing Conventions: The International Convention for the Prevention of Pollution from Ships (MARPOL), The Safety of Life at Sea Convention (SOLAS) and The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers. The "Polar Code" came into force in January 2017. Lloyd's of London and Lloyd's Register, in close cooperation with the Arctic Council, worked actively to ensure an industry-led approach that could enable to underwrite risks in polar waters with strong safety and training standards in place.

The aim is to make shipping in Arctic and Antarctic safer by laying out strict rules and regulations relating to ship design, construction and equipment, operational and training, and search and rescue operations *(Bai and Yin, 2015)*.

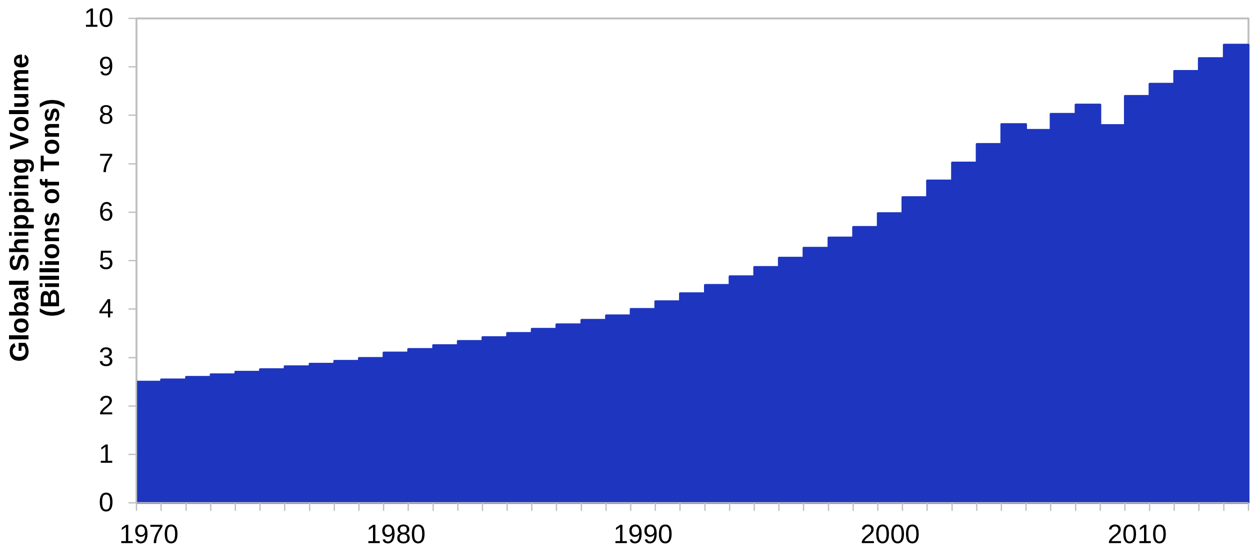
Increasing ship size

Vessels have grown in size as the economics of marine transportation have continued to favour larger cargo shipments. In 2000, the biggest container ship could carry about 8,000 containers. Now, the largest ships carry over 19,000 containers, and this trend seems likely to continue. See Figure 7 for the growth of global shipping volume for the past 45 years.

The increase in size is not limited to container ships. Cruise liners, tankers, bulk carriers, and other classes of vessel have also seen the introduction of larger ships. The largest cruise liners have increased from 18,400 GT in the 1970s to 226,963 GT in 2016. The *Harmony of the Seas* made is the biggest cruise ship in the world with a capacity of 8,880 (passengers and crew) and a length nearly equal to the height of the Eiffel Tower *(World Maritime News, 2016)*.

After the 1973 oil embargo, the booming tanker market collapsed and many new ULCC (Ultra Large Crude Carriers) ships, purchased on speculation, were broken up and replaced with VLCC as the tonnage of crude oil fell 30% to 1985 *(Stopford, 1997)*. Though this slump was briefly relieved in 1979, the average size of oil tankers declined until 1988. Between 2000 and 2013, the overall capacity of the global tanker fleet rose by 73% to roughly 2.85 billion DWT, trespassing new long-haul routes in greater numbers in order to satisfy developing market demand *(UNCTAD, 2013)*. BIMCO projects a global fleet increase of 3.4% in 2016 *(BIMCO, 2006)*. As of 2011, the largest oil tankers in circulation are two double-hulled TI class 'Super Tankers', each with a capacity of 441,500 DWT. The longest ULCC ever was the *Seawise Giant*, measuring 458 meters (scrapped in 2010), but no existing ULCC or VLCC is longer than 400 meters.

Figure 7: Growth in global shipping volume over the past 45 years



Source: World Shipping Council, 2016

The maximum size of such ships is constrained by the physical dimensions of modern docking facilities and canal transit routes. The Panama and Suez canals limit the maximum size of vessels that can transit through them, with size classes named after them. Growing pressure for larger and more economical ships triggered the construction of a wider and deeper Panama Canal in order to accommodate larger vessels – 'post-Panamax ships' – which was completed in June 2016 after nine years of construction *(Nix, 2014)*.

The change in the maximum size of ship has altered the liability profile of the most severe conceivable losses possible. The costs of salvage, wreck removal, and liabilities from ecological or political consequences are 'non-linear' with the size of the vessel – i.e. the scale up to greater costs is disproportionate to the increased dimensions. In addition to having more value to lose in a single accident, or more spillage to create bigger environmental disasters, bigger ships in distress garner greater political attention and higher fines for mismanagement. Larger ships also pose significant logistical challenges for carrying out repair, salvage, and wreck removal.

On 3 August 2016, the Iranian oil tanker *Dream II* (333m long, 32,000 DWT) – a 'Mega Tanker' by this report's vessel typology - collided with a container ship *Alexandra* (366 m long, 14,000 TEU) – a 'Mega Container' in this report's classification - in the Singapore Strait. The tanker's bow hit the *Alexandra*'s port quarter resulting in damage to its hull and some of the containers on board. The incident caused no injuries or oil pollution, but it is one of the first examples of sea collisions between very large 'Mega' vessels. Formal analysis of the event and asking counterfactual questions about this 'near-miss' could help underwriters to get significant additional insights of extreme losses and reduce future market surprises *(Lloyd's, 2017).*

Types of cargo

In addition to the accumulation of exposure from high value electronic and luxury cargoes, the non-declaration or illegal storage of hazardous or dangerous materials is a significant risk at sea and in port, despite new regulatory efforts to monitor incidents that occur as a result of freight content.

The TT Club has stated that ship-board fires are regularly reported, and that charcoal, along with calcium hypochlorite, poses the greatest risk. "*It is estimated that some 10% of cargo carried by sea is declared as dangerous and what should be declared, but is not, increases that proportion. Examples include declaring 'calcium hypochlorite' as 'calcium hydroxide', 'lithium-ion' or 'lithium metal' batteries as 'rechargeable batteries', or scrap engines destined for a recycling facility as 'car parts' all place people at serious risk.*" *(TT Club, 2015*).

Salvage operations and wreck removals

The rising cost of wreck removals concerns the International Group of P&I Clubs and with it, the group's excess of loss underwriters. The *Costa Concordia* costed over US$2 billion to insurers.

As noted in our 2013 report: "The Implications and Challenges of Dealing with Shipwrecks in the 21st Century".

"Analysis of the most costly wreck removals from the past decade by the Large Casualty Working Group of the International Group of P&I Clubs suggests that the following factors are central to the cost of wreck removal: location; the contractual arrangements; cargo recovery from container ships; effectiveness of contractors and the vessel's special casualty representative; the nature of bunker fuel removal operations; and the influence of government or other authorities. Of all these factors, government influence, reflecting public concern, appears to be the dominant factor in rising costs."

Citing the rising costs of salvage operations, Lloyd's also reported that casualties may be determined as total losses simply by the diminishing incentives for removal firms to bid competitively on salvage jobs *(Lloyd's 2013).*

Maritime regulation

While the International Maritime Organisation (IMO) is responsible for setting standard safety regulations for international shipping practices, it is the flag state, or a vessel's country of registration, that maintains the ultimate control over the enforcement of these regulations.

This adds an additional layer of complexity in aggregating the risk of total losses in maritime incidents as flag states introduce further measures over a registered fleet. Significant changes to the marine regulation landscape may shape and influence marine risk in the future. Enforced standards for maintenance, freight rate and safety that aim to decelerate the rate shipping losses overall may ultimately increase the costs of marine incidents that do occur.

For example, the US has introduced stricter liability requirements on ship owners (for example The Oil Pollution of 1990), while the EU has implemented a number of additional safety regulations and some states have subjected registered vessels to national inspections through co-signed memorandums of understanding *(Kristiansen, 2005)*.

Regulatory structures and international agreements

International rules and conventions are typically adopted at the national level and a government department is then responsible for codifying standards. International treaties limit the insurer's liabilities in many waters, and these become key determinants of the upper limits of severe losses for an insurer. Future changes to these treaties could increase the exposure of an insurer to marine loss.

Each country's national maritime administration is responsible for ensuring that rules and regulations are followed. Classification societies, independent bodies that set standards for the construction, maintenance and operation of ships, are responsible for inspecting vessels to ensure they conform to the established safety standards. The societies' responsibilities include hull strength and design, machinery, electrical installations, control systems and safety equipment. The ultimate responsibility in complying with these rules lies with the ship owner.

At international level, new regulations proposed by the IMO have to be agreed by a minimum number of states before coming into effect. The flag state has the responsibility to implement these regulations to ensure safe and efficient control over administrative, operation and maintenance of ships. Some countries may decide not to ratify certain regulations, adding a layer of complexity because of the inconsistency of the regulatory landscape.

A number of important international treaties limit ship owner and insurer liabilities in the event of a marine incident occurring within signatory waters, including:

- **International Convention on Civil Liability for Oil Pollution Damage (CLC)** – Originally adopted in 1969 and replaced by the 1992 Protocol, the CLC applies to all seagoing vessels carrying oil in bulk as cargo (i.e. tankers) and stipulates that shipowners must be insured against oil pollution damage. The convention allows a shipowner to limit liability, according to vessel size, from pollution damages incurred in the territorial waters of a signatory. A maximum liability limit of 89.77 million SDR[b] is currently set for vessels over 140,000 gross tonnage *(IMO, 2016)*.

- **Convention on Limitation of Liability for Maritime Claims (LLMC) –** Adopted in 1976 and replaced by the 1996 Protocol, the LLMC provides a system for shipowners and salvors to limit liability, according to vessel size, by two types of claim: claims for loss of life or personal injury, and property claims. In 2015, new limits were set for the 1996 Protocol *(IMO, 2016)*.[1] We understand that the CLC/FUND and the Athens Convention will typically take precedence over the LLMC and hull and cargo collision liabilities could overlap with the LLMC.

- **International Convention on Civil Liability for Bunker Oil Pollution Damage (BUNKER)** – Adopted in 2001, the Bunker Convention provides compensation for pollution damages caused by bunker fuel. The convention is modelled on the LLMC with limits set according to vessel size.

- **Athens Convention relating to the Carriage of Passengers and their Luggage by Sea (PAL)** – Adopted in 1974 and replaced by the 2002 Protocol, the Athens Convention concerns damages suffered by passengers carried on a seagoing vessel. The 2002 Protocol extends the limit to 250,000 SDR per carriage and stipulates compulsory insurance to cover passengers. If the loss exceeds the limit, the carrier is further liable - up to a limit of 400,000 SDR per passenger on each distinct occasion - unless the carrier proves that the incident which caused the loss occurred without the fault or neglect of the carrier *(IMO, 2016)*.

[b] Special Drawing Rights (SDR) are a supplementary foreign-exchange reserve assets defined and maintained by the International Monetary Fund (IMF). An SDR is essentially an artificial currency used by the IMF and is basket of national currencies.

- **International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND)** – Adopted in 1971 and superseded by the 1992 Protocol, the FUND relieves the shipowner of some of the financial burden imposed by the CLC and provides additional compensation for pollution damage in case of the CLC being inadequate. For a single incident, the FUND has a fixed limit of 135 million SDR (including the CLC limit).

- **Supplementary Fund** - The 2003 Protocol establishing an International Oil Pollution Compensation Supplementary Fund was adopted by a diplomatic conference held at IMO Headquarters in London**.** The aim of the established Fund is to supplement the compensation available under the 1992 Civil Liability and Fund Conventions with an additional, third tier of compensation. The Protocol is optional and participation is open to all States Parties to the 1992 Fund Convention. The total amount of compensation payable for any one incident will be limited to a combined total of 750 million SDR including the amount of compensation paid under the existing CLC/Fund Convention) *(IMO, 2016)*.

- **Small Tanker Oil Pollution Indemnification Agreement (STOPIA) -** provides for shipowners to make payments to the 1992 Fund which are designed to adjust the financial effect of the limitation of liability provisions contained in the 1992 International Convention on Civil Liability for Oil Pollution Damage (1992 CLC) for spills from tankers of less than 29,548 GT.

- **Tanker Oil Pollution Indemnification Agreement (TOPIA)** - provides for shipowners to indemnify the Supplementary Fund for 50% of the compensation it pays under the 2003 Supplementary Fund Protocol for pollution damage caused by tankers in States Party to the Protocol.

The Nairobi International Convention on the Removal of Wrecks, 2007, was adopted by an international conference held in Kenya in 2007. It provides the legal basis for States to remove, or have removed, shipwrecks that may have the potential to affect adversely the safety of lives, goods and property at sea, as well as the marine environment. The Nairobi convention does not introduce liability limitations, but provides the first set of uniform international rules aimed at ensuring the prompt and effective removal of wrecks located beyond the territorial sea *(IMO, 2016)*.

Subsequent action by international organisations and governments following maritime disasters can change the quality of the risk. The *Exxon Valdez* oil spill in 1989 prompted the US Congress to pass the Oil Pollution Act 1990 (OPA ’90) which required a phase-out of single-hulled oil tankers in US waters by 2010. The Act also set up a liability fund and strengthened plans for dealing with oil spills. Following a serious oil spill on the coast of France from the tanker Erika in 1999, and on the coast of Spain from the Prestige in 2002, IMO acted to phase out all remaining single-hulled oil tankers between 2010 and 2015.

Liability and insurance

While Lloyd’s syndicates and marine insurance bodies provide cover for hull, machinery and cargo, the 13 mutual underwriting associations that make up the International Group of Protection & Indemnity Clubs (IGP&I) cover liability risks for about 90% of the entire world’s ocean-going tonnage *(International Group of Protection & Indemnity Clubs, 2016)*. These include personal injury or loss of life to crew and passengers, cargo damage and loss, pollution by noxious substances, wreck removal, and damage to property. In doing so, they are able to provide the high level of coverage that ship owners may need. The clubs operate first through a pooling arrangement and then, together, buy excess-of-loss reinsurance in the market.

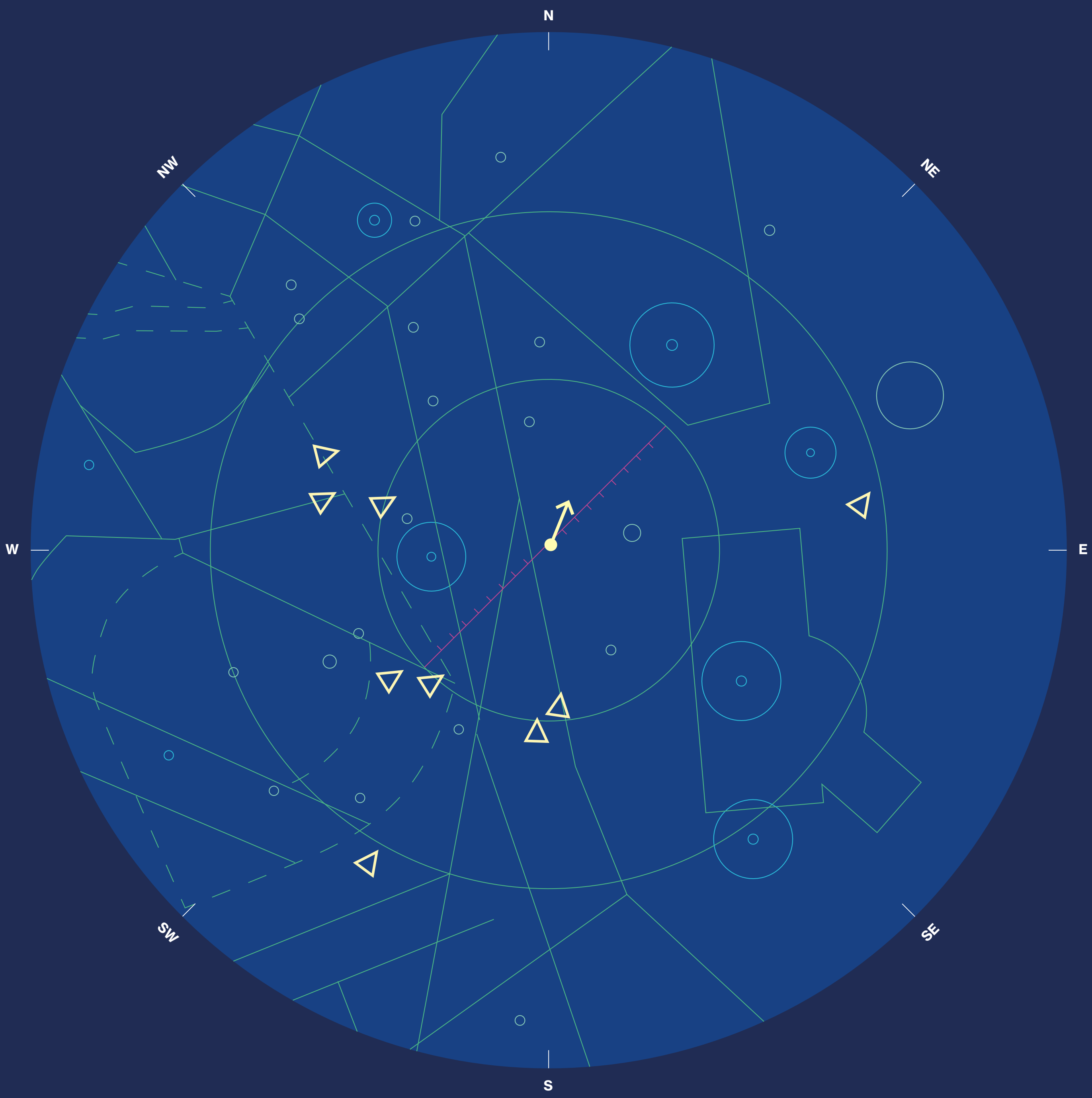
Each group club also provides a number of additional services to its members including claims handling, legal support and loss prevention, and plays an important role in coordinating and management of the response to maritime casualties. The total number of claims notified in 2015 for the UK P&I Club has fallen compared to the previous years due to a smaller number of expensive casualty claims and a lower rate of claims overall, according to the Club *(UK P&I Club, 2016)*.

Other risks

As navigation, radar and communications technologies develop and systems become more interconnected, the threat from a malicious cyber-attack becomes greater to these exposed systems. The Advanced Autonomous Waterborne Applications Initiative (AAWA), managed by Rolls-Royce, has published a 2016 whitepaper outlining the future of autonomous ships, which highlights cyber security risks noting that “*in principle, anybody skilful and capable to attain access into the ICT system could take control of the ship and change its operation according to hackers’ objectives” (Rolls-Royce, 2016)*.

Other challenges include piracy, which has already used cyber surveillance and identification technology to augment attacks; supply chain disruption; damage accumulation; and external geopolitical instability *(Allianz, 2016)*. On 29 July 2013 and 31 August 2013, terrorists attacked ships passing through the Suez Canal using rocket-propelled grenades. Although the damage was insignificant, the Suez Canal represents a target for terror groups seeking to destabilise the Egyptian government *(Mediterranean Affairs, 2014)* and undermine the US$5.3 billion a year that it contributes to the Egyptian economy *(Kirkpatrick, 2015)*.

The Lloyd's-Cambridge Marine Risk Model



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4. The Lloyd's-Cambridge Marine Risk Model

The Lloyd's marine project first considered multiple different scenario types that can lead to major losses. Underwriters were asked to rank these in various dimensions. The results from this process are detailed in section 5. The loss precedents and detailed analysis of future marine loss trends, in combination with the input received from market specialists, suggest that the main risk of severe losses to marine insurers is the escalation of costs from incidents involving large vessels. The conclusion was that Total Loss Risk for single vessels leads to the most probable source of major events that are within the likelihood range that we have chosen to focus on. That is not to say that other disasters cannot happen, just that they are assessed as having lower probability. Therefore, several constraints have been imposed to help simplify the first iteration of the model, these include: the assessment of single vessel payouts only; a focus on Total Loss (TL) casualties; and, a focus on estimating overall loss severity (i.e. the complexities of marine insurance and re-insurance structures are not currently captured). It should be noted that the model also includes the limitation of liability by international treaties.

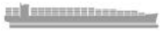
By definition, the largest losses come from incidents causing a total loss, including a constructive total loss. Many factors are acknowledged to influence how losses can potentially escalate. This section provides an overview of how these factors, coupled with expert knowledge, have been incorporated into the Lloyd's-Cambridge Marine Risk Model. The model provides a means of exploring the tail risk of extreme loss potential in marine insurance and has been developed to meet several objectives. The model seeks to assess severity of loss for return periods in-line with other insurance RDSs and PML calculations. The model aims to populate probabilistic event sets or EP curves for the different vessel types, with the potential to be reconfigured for the particular fleet profile of a marine insurer.

The model combines objective statistical information (e.g. historical incident rates) with subjective expert knowledge. The use of expert opinion helps overcome the problem of limited observations in the historical record for certain vessel types and addresses the fact that the historical record may not accurately reflect current or future risk due to the rapidly changing nature of the marine industry. The process of eliciting expert knowledge is described below. The initial model results were compared to back-testing information and the parameters were further refined to achieve reasonable agreement with this past data and empirical probabilities.

Vessel types modelled

The market specialist advisors identified vessels of priority interest as cruise ships, container ships, and tankers. The world fleet of these categories was further subdivided into three sizes of vessel. The vessel types analysed are summarised in Table 1 and with their size ranges, valuations, and numbers in the world fleet. As mentioned, the model does not include bulkers as the most significant claims were considered less likely. In the model the tanker class is split between oil-carrying tanker and non-oil carrying tanker to allow the application the liability conventions, these results in the following vessel types: oil-carrying tanker, no-oil carrying tanker and container (treated as one type) and cruiseship. Based on a sample from Clarkson Research we assumed that 39% of tankers are non-oil carrying.

Table 1: Vessel types modelled

		Vessel Type	Common vessel size classes included	from	to	from	to	Units	from	to	Total No in World Fleet (2016)
A1	Mega Tanker 	Tanker	ULCC, VLCC (Malaccamax), Suez-Max	270m	380m	120,000	550,000	DWT	$75m	$150m	674
A2	Super Tanker 	Tanker	Panamax, Seawaymax, Aframax	180m	270m	60,000	120,000	DWT	$40m	$75m	1,926
A3	Standard Tanker 	Tanker	Vessels greater than 100 GT	10m	180m	19,000	60,000	DWT	$5m	$40m	7,030
B1	Mega Container 	Container	Triple E, New Panamax	330m	400m	10,000	19,000	TEUs	$150m	$300m	366
B2	Super Container 	Container	Post Panamax, Post Panamax Plus	270m	330m	3300	10,000	TEUs	$75m	$150m	1,046
B3	Standard Container 	Container	Panamax, Vessel greater than 100 GT	10m	270m	70	3300	TEUs	$10m	$75m	3,818
C1	Mega Cruise Ship 	Cruise Ship	Oasis, Quantum, Dream	300m	362m	4850	8900	Manifest	$600m	$1200m	27
C2	Super Cruise Ship 	Cruise Ship	Destiny, Grand	260m	300m	3300	4850	Manifest	$200m	$600m	78
C3	Standard Cruise Ship 	Cruise Ship	Vessel greater than 100 GT	10m	260m	70	3300	Manifest	$20m	$200m	285
											15,250

Logical process model of marine loss escalation

For the largest categories of these vessels there are very few loss statistics. There are good statistics on past total losses for some of the different types of vessels and overall frequency of occurrence that can be assumed, but there are, thankfully, very few examples of vessel incidents and not enough to be confident that we have examples of the worst cases that could potentially occur to all these vessel types. Some of them have only been operating in the world fleet for a relatively short period of time.

There have never been total losses for a ULCC, Triple E, Suez-Max, New Panamax, or Oasis class vessels. There are around 1,000 of these mega vessels (see table 1, A1, B1, and C1) currently in the world fleet.

Instead of trying to estimate the likelihood of losses occurring from statistical observations we construct a logical process model of how a total loss can occur and use data from the total losses that we know about, but adapt them for what we know and understand about the performance, superior safety standards, and robustness of these modern types of vessels. We expect that over a long enough time period some of these vessels will have incidents and that the more severe incidents will result in a total loss. The logical process model explores how this could occur and how likely they might result in a severe loss.

Multiple heads of claim

The model analyses each of the following heads of claim to enable different elements of the loss to be costed separately and to consider payouts for different lines of business within the marine insurance operation, including hull, cargo, and liability writers. These are combined into a total loss value for each scenario path.

- Hull Loss
- Wreck Removal
- Cargo Loss
- Third party liability for loss of life or injury (Human Liability)
- Third party liability for environmental damage (Pollution liability)

Causes of total loss for a vessel

The logical process model considers the total loss of a vessel from one or more of the following causes:

- Allision (hitting a stationary ship)
- Collision (hitting another ship)
- Grounding
- Wrecking and stranding
    - Foundering and loss in open sea
    - Fire and explosion

Historically, around 92% of total losses to large vessels resulted from these causes. Annual total loss incident frequencies are set within the model according to the historical rates of loss from these causes. The remaining 8% of losses result from machinery damage, missing and overdue vessels, piracy, and other miscellaneous causes that are not explicitly accounted for in the logical process steps of the model. These would require a different set of modelled steps, but could be accounted for in a similar way. Our estimation is that these non-modelled causes tend to be either similar in severity or less severe than those modelled. Therefore, it is a reasonable and conservative conclude that the model represents the full picture of severe loss outcomes since the incident probability is based on all events in the assessed historical record. Extending the model to cover the causes of all total losses would slightly increase the return period of less severe incidents but not affect estimated return periods of more severe incidents.

An enhanced event-tree conceptual framework

The Lloyd's-Cambridge Marine Risk Model is based on an *event-tree* framework. Event trees and the related, though more sophisticated, concept of Bayesian Networks (or probabilistic graphical models) have previously been employed in the analysis of marine incidents but have tended to focus on specific locations *(Hanninen and Kujala, 2009)*, individual vessel types *(DNV, 2003)*, particular types of incident *(Pedersen, 1995),* or the underlying causes of incidents *(Martins and Maturana, 2010)*. Here, the design considers the event tree to begin with an *initiating event* – the probability of the marine incident itself (for example a grounding or a collision). The size of loss arising from this is then affected by impacting *factors* (such as whether an evacuation fails which will clearly affect the quantum of human liabilities). Each impacting factor has a probability of taking one of a set of mutually exclusive *states*, including binary state sets, such as yes/no, or higher-order sets, such as high/medium/low.

Specifically the event tree framework is enhanced in several important ways:

- First, there are three *categories* to choose from: vessel type (tanker, container and cruise ship) and size (mega, super and standard) and jurisdiction. Like events, categories can take one of a set of mutually exclusive states; these affect the incidence probability directly.

- Second, *event cost* variables are introduced. Again, event costs can take one of a set of mutually exclusive states but do not form part of an event path (i.e. no feedback loops). E*vent costs* are used to estimate the loss severity of a given event path. There are five main sources of loss associated with marine disasters: (1) Hull damage, (2) Cargo loss, (3) Environmental pollution liability, (4) Human casualty and injury liability, and (5) Wreck removal and salvage. Event costs can be conditioned by both events and factors. Event costs are specified as a most likely value (the 'mode') along with upper and lower bound estimates, from which a basic triangular distribution can be estimated. The total cost arising from a path is the sum of the five distributions - this is estimated by using Montecarlo simulation: chosen specified points on this distribution are retained with model outputs.

- Third, the framework accommodates *forward conditioning*, whereby the states of earlier factors can be taken to influence the state probabilities of subsequent, but not necessarily sequential, factors. For example, the likelihood of a vessel starting to sink or capsize is likely to increase if the hull has sustained major structural damage, while a vessel sinking or capsizing will increase the likelihood of significant human casualty. Both the likelihood of sinking and significant human loss could further increase due to adverse conditioning factors, such as weather conditions.

- Finally, the framework allows *scenarios* to be specified by constraining the state of factors. This has the effect of isolating a subset of event paths that conform to a given scenario specification. For example, model results could be compared across two scenarios, one investigating super tankers, the other looking at super containers.

The raw output of the model is a set of event paths, each with an overall estimated likelihood of occurring (the product of event state probabilities) and an estimated distribution of loss severities (overall costs). An EP curve (explained further below) showing the likelihood of exceeding different loss severities for a given scenario, can be derived by rolling up event path likelihoods with the secondary uncertainty associated with their individual costs.

Loss steps

For a specific vessel and type the model consists of 16 steps that influence the costs of the vessel loss. This process, and the dependency between variables, is further illustrated in Tables 2 and 3.

1. Determine vessel/size incident rate based on vessel type and size;
2. Jurisdiction: Potential for the incident to occur in a high-cost legal environment; this is combined with the vessel/size incident rate to create an incident probability;
3. Conditions: Weather and climate, and the potential for the incident to occur in unfavourable weather and climate conditions that significantly increase the severity of the consequences;
4. Location: Potential for the incident to occur in a remote location where access difficulties increase the severity of the consequences of the incident;
5. Occurrence of major hull damage;
6. Potential for rapid sinking or capsize;
7. Potential for a major fire to occur on board;
8. Evacuation required for crew, staff and passengers;
9. Potential for a major evacuation failure, that results in loss of life of the people on board;
10. Proportion of those on board that die;
11. Proportion of bunker (fuel carried on board) lost;
12. Proportion of cargo lost;
13. Potential for the incident to become politicized;
14. Potential for pollution clean-up to be complex;
15. Wreck removal required;
16. Potential for wreck removal to be complex.

Each step of the analysis has several potential alternative outcomes. To maintain the model within practical limits of calibration and useful outcomes, the number of choices for each step is kept to a minimum. Each vessel type and size has 393,216 possible paths; some of these are zero probability paths, however. Specifically for tankers and containers there are 208,896 positive probability paths for each size and for cruisers there are 52,224 such paths for each size.

An *event path* (or "scenario") describes the full chain of events taking a particular set of states. Figure 8 gives a graphical illustration of such a path. The probability of any given event path occurring – its likelihood – is simply the product of the incident probability and the probabilities of each branch of the path. At the end of a path distributions of loss are determined for the five heads of claim described above, these are conditional on the state of events along the path. The individual heads of claim distributions are finally aggregated to produce a total loss distribution for the path.

The Cambridge-Lloyd's Marine Risk Model

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1. **Type, size and jurisdiction are categories which determine the incident probability. See Table 2, pg. 38.**
2. **They are followed by 14 factors that lead to the event economic loss.**
3. **Event costs are specified as a most likely value (the 'mode') along with upper and lower bound estimates, from which a basic triangular distribution can be estimated.**
4. **The total cost arising from a path is the sum of the five distributions - this is estimated by using Montecarlo simulation. The output of each path is a probability and cost curve.**

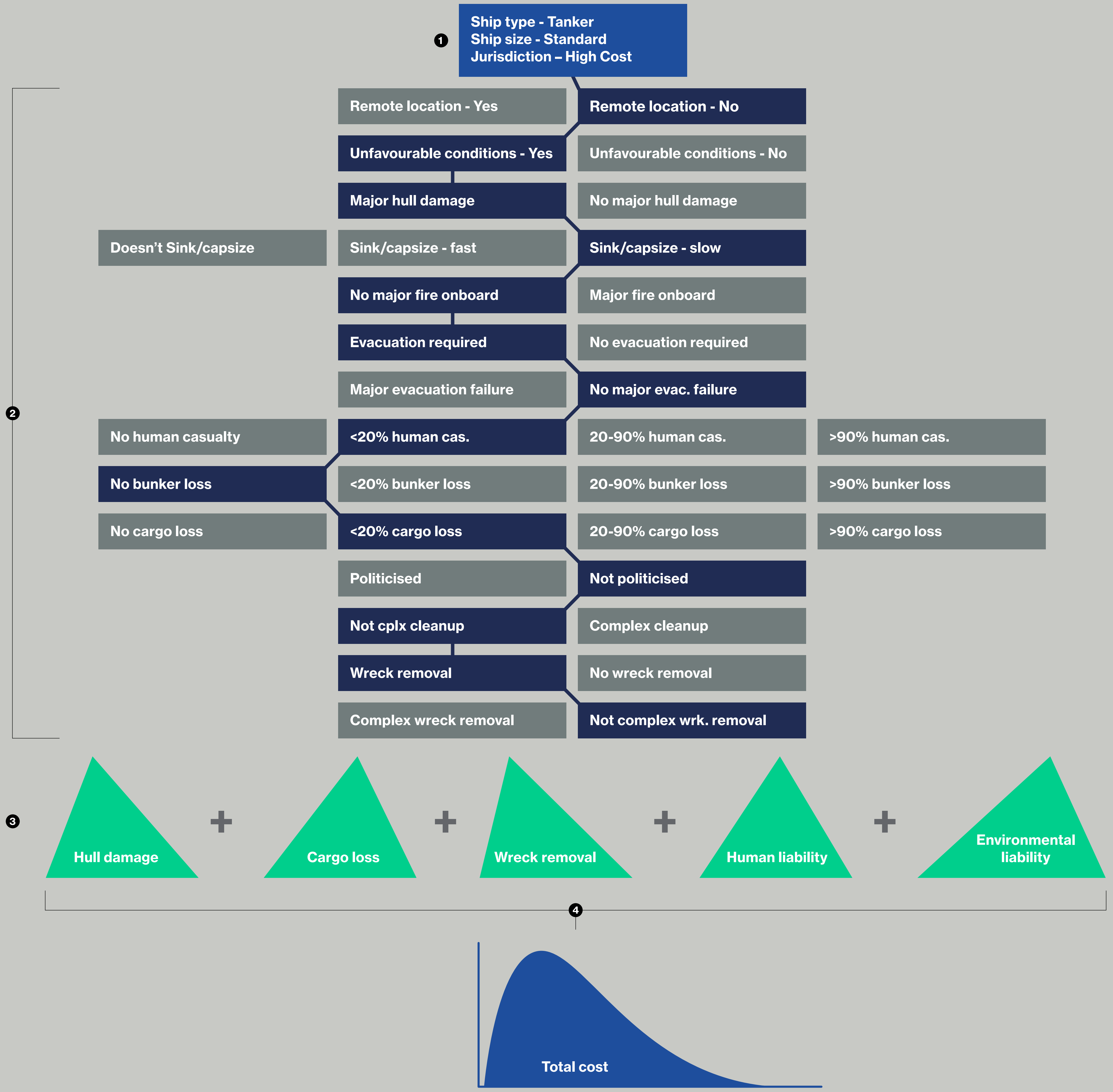

Figure 8: Event path example

Specifying variables

Table 2 shows an example of how the variables have been specified within the model. The variables are listed beginning with categories (1-3) which determine the incidence probability, followed by all factors (4-18) and finally the event costs (19-23). Each variable is given a code (for easy reference in the probability and cost tables) and a longer name. The variable type is identified and the number of states are indicated and individually listed.

Table 2: Example of a variable and state specification table

Variable No.	Variable Code	Variable Name	Variable type	Type code	No. of states	States			
1	Type	Ship type	Category	1	3	Tanker	Container	Cruiser	
2	Size	Ship size	Category	1	3	Standard	Super	Mega	
3	Juris	Higher cost jurisdiction	Category	1	2	Yes	No		
4	Remote	Remote location	Factor	2	2	Yes	No		
5	UnfavCon	Unfavourable conditions	Factor	2	2	Yes	No		
6	HullDam	Significant structural hull damage	Factor	2	2	Yes	No		
7	SinkCap	Vessel sinks / capsizes	Factor	2	3	Yes - fast	Yes - slow	No	
8	Fire	Significant fire onboard	Factor	2	2	Yes	No		
9	EvacReq	Evacuation required	Factor	2	2	Yes	No		
10	EvacFail	Evacuation & rescue efforts fail	Factor	2	2	Yes	No (or not required)		
11	HumCas	Extent of human casualty	Factor	2	4	None	<20%	20% to 90%	>90%
12	BunkLoss	Extent of bunker loss	Factor	2	4	None	<20%	20% to 90%	>90%
13	CargoLoss	Extent of cargo loss	Factor	2	4	None	<20%	20% to 90%	>90%
14	Politicised	Incident politicisation	Factor	2	2	Yes	No		
15	CmplxCleanup	Complex cleanup operation	Factor	2	2	Yes	No		
16	WrkRemReq	Wreck removal required	Factor	2	2	Yes	No		
17	CmplxWrkRem	Complex wreck removal	Factor	2	2	Yes	No		
18	HullCost	Cost of hull damage	Event cost	3	3	Min	Mode	Max	
19	HumanCost	Cost of human casualty	Event cost	3	3	Min	Mode	Max	
20	EnviroCost	Cost of pollution	Event cost	3	3	Min	Mode	Max	
21	CargoCost	Cost of cargo loss	Event cost	3	3	Min	Mode	Max	
22	WrkRemCost	Cost of wreck removal	Event cost	3	3	Min	Mode	Max	

For clarity of exposition, several of the example variables in Table 2 are discussed in more detail below:

Size	*Ship size* – Although several ship size classification systems are in use, they are typically specific to a particular vessel type. Instead, in this example we define ship size according to the classifications detailed in Table 2.
Juris	*Higher cost jurisdiction* – Casualties occurring in certain jurisdictions, such as North America, Western Europe, Japan, Australia and New Zealand, for example, are typically associated with significantly higher loss severity. This may be due to higher fines for environmental pollution, more stringent clean-up or wreck removal requirements, and/or greater liabilities for human death and injury.
Remote	*Remote location* – Casualties in remote locations may incur severe losses due to the additional time and resources required to access vital services and equipment, including search and rescue, clean-up, salvage, and wreck removal infrastructure.
UnfavCon	*Unfavourable conditions* – Casualties and their consequences (e.g., rescue, clean-up, salvage, wreck removal, etc.) during unfavourable conditions are also likely to incur higher loss severities. Unfavourable conditions include weather and climate related factors – such as wave height, wind speed, visibility (due to fog and time of day), air and sea temperature, and the presence of sea ice. Other factors relate to the local geography – such as currents and tides, water depth and the bathymetry of the sea floor.
Politicised	*Politicisation of the incident* – The location of the incident, the extent (or potential extent) of environmental pollution, and the level of human loss and injury can bring casualties to the headlines and the attention of local and national authorities. The politicisation process can lead to severe escalation in loss severity, from, for example, additional pollution fines, more stringent clean-up targets, and interventions requiring exceptional salvage or wreck removal strategies.
CmplxCleanup	*Complex clean-up operation / complex wreck removal* – Environmental clean-up and wreck removal operations can be extremely expensive. Costs can increase when specialist equipment is required, lengthy delays occur (e.g., due to adverse weather conditions or the availability of required equipment), specialist or novel methods are required, or when the operation must take place in a particularly vulnerable environment (for example, a coral reef, polar region, etc.).

Specifying variable interdependency

Having specified the variable set, the next model component considers how the variables relate to each other. As noted above the model permits forward conditioning; the states of earlier events and factors can be taken to influence the state probabilities of subsequent, but not necessarily sequential, events.

An interdependency matrix (similar to an adjacency matrix in network analysis) is used to keep track of how variables condition one another (see Table 3). All variables that have been introduced into the variable specification table are listed along both the table rows – the *conditioning* variables – and columns – the *conditioned* variables.

Table 3: Example of a variable interdependency matrix

Conditioning variables		Conditioned variables																						
	Variable No.	1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Variable Code	Type	Size	Juris	Incident	Remote	UnfavCon	HullDam	SinkCap	Fire	EvacReq	EvacFail	HumCas	BunkLoss	CargoLoss	Politicised	CmplxCleanu	WrkRemReq	CmplxWrkRe	HullCost	HumanCost	EnviroCost	CargoCost	WrkRemCost
1	Type				1					1			1		1	1				1	1	1	1	1
2	Size				1											1			1	1	1	1	1	1
3	Juris				1											1					1			
	Incident							1				1					1		1					
4	Remote							1				1					1		1					
5	UnfavCon							1																
6	HullDam								1					1	1									
7	SinkCap									1	1			1	1			1						
8	Fire										1			1	1									
9	EvacReq											1	1											
10	EvacFail												1											
11	HumCas															1					1			
12	BunkLoss															1						1		
13	CargoLoss															1						1	1	
14	Politicised																1	1						
15	CmplxCleanup																					1		
16	WrkRemReq																		1					1
17	CmplxWrkRem																							1
18	HullCost																							
19	HumanCost																							
20	EnviroCost																							
21	CargoCost																							
22	WrkRemCost																							

For example, reading from the column for the incident (which is not a variable in its own right, hence it does not have a variable number), we see it specified that the likelihood of an incident is influenced by vessel type, vessel size and higher cost jurisdiction.

Similarly, the extent of cargo loss (variable 13) is shown to be conditioned by the vessel type and in addition whether significant structural hull damage has been sustained, whether the vessel has sunk or capsized, and whether there has been a major fire on-board.

The model parameterisation process

The marine loss severity likelihood model must be parameterised before the tool can be used. The parameterisation process consists of four main steps: analysing the global fleet, variable and state selection; estimating probabilities from data; and eliciting probabilities and cost estimates from marine experts. Each step is discussed in more detail below.

At each step of the analysis, we assess the relative likelihood that each outcome of that step could happen. Where there is available statistical data, this can be used in the calibration, for example assigning the likelihood of the total loss occurring in a remote location can be assessed by how many total losses have occurred historically in locations which have made it difficult to deploy standard search and rescue.

Other steps with less evidence to guide the likelihoods of different outcomes are assessed using expert opinions. We interviewed multiple marine insurance specialists in the London Market (credited in the acknowledgements) to use their experience in assessing how likely a consequence would be, given a certain condition, and the relative likelihood of different outcomes. For example if one of the types of large vessels in our analysis were wrecked, how likely would it be that the wreck removal process would be complex, and also would suffer political interference in the process from the jurisdictional government of the waters?
Responses from the market specialists had variation in estimations, but were highly consistent in the relativities and logical dependencies that they proposed to be incorporated in the analysis. These parameters were further refined with reference to back-testing information. The market specialists provided essential guidance on how they would expect certain variables to affect the likelihood of the loss escalation that was incorporated in the logical steps of the model parameters. The market specialist inputs were analysed to derive the average best estimate across the interview survey sample and also a range of higher bound and lower bound, representing the estimation uncertainty across the survey sample of specialists.

Analysing the global fleet
An understanding of the profile of the global marine fleet is required to assess marine casualty incident rates. Various databases, for example, Clarkson Research (made available to Cambridge), provide extensive details of the global fleet, usually focusing on vessels over 100 gross tons. Such databases can be used to evaluate how many vessels there are of different types and sizes.

Annual casualty probabilities can be estimated by coupling data on the global fleet with data on how many casualties occur on average each year for different vessel classifications which was available from the Allianz safety and shipping review using data from Lloyd's list.

Variable and state selection
The choice of variables (conditioning factors, consequential events and event costs) and what states they can take are paramount to a successful model parameterisation. As already noted, there is a challenging compromise between the nuanced characterisation of the real world and the ease with which the model can be parameterised – particularly if it is heavily reliant on expert judgement and is executed on a standard desktop machine. We have found that the use of influence diagrams, drawn with the help of marine experts or following the analysis of marine literature, can greatly help isolate key variables and narrow down the selection process.

Estimating probabilities from data
Some of the conditional probability tables can be populated through the analysis of existing data. This is particularly the case for estimating the annual probabilities of marine incidents for the model's initiating event. A comprehensive database, such as Lloyd's List Intelligence, can be used, for example, to estimate how many casualties there are on average each year for different vessel classifications or locations. Simple sub-models, for example based on scaling factors, can then be developed that use this data analysis to fill out the conditional probability tables (CPTs).

Eliciting probabilities and cost estimates from marine experts
In the absence of detailed data on historical marine incidents (due to data availability or simply a lack of historical events to draw robust assessments), it is likely that the parameterisation process will have to rely heavily on the elicitation of subjective knowledge from marine experts. As with parameterisation based on data analysis, simplifying submodels can be used to reduce the number of 'data points' that each expert is required to postulate.

The expert elicitation process can take many forms, but we used an approach consisting of:

- A set up stage designed to familiarise the expert with the overall process and help fine-tune their sense of probability using known examples.
- Provisioning the expert with estimates for the values requiring parameterisation. The experts were then asked to adjust the values to their best estimate along with upper and lower bounds.
- Eliciting marginal probability estimates to check for overall consistency. in addition to conditional probabilities and costs,
- Weighting experts elicitation values to make a decision about their adequacy.
- Running the model by using the expert's initial parameterisation to generate an EP curve, which the expert can observe and propose modifications to the initial parameterisation.

Finally the model outputs were compared to back-testing and the parameters were further refined to achieve a realistic fit with lower return periods consistent with observed losses.

Loss limitations provided by international treaties

The value of marine liabilities being limited by international treaty are so important that they have been incorporated in the calculations of the model. These limitations dramatically cut the potential for marine insurers to incur severe liabilities from marine incidents, but do not reduce the full economic effect of these scenarios on society; they do, however, help to keep premium levels affordable, reducing costs that would otherwise be passed through to customers.

In jurisdictions where some losses are not capped by international treaty, such as United States, there is potential for liability losses to be well over an order of magnitude larger than those where treaties apply. This clearly has very significant implications for insurers in managing their liability risk appetite by limiting the exposure of the portfolio in terms of the number of insureds and limits to insurance participation in vessels operating in these exposed waters. It emphasises the importance of identifying all the waters where vessels are not covered by the protection offered by different conventions and protocols, along with the need to monitor the likelihood of insured vessels operating in these waters. Insurers should also be aware of the risk of future changes in the landscape of international treaties, and that, under pressure, ship owners might waive limitation or see their right to it forcibly broken by local or national authorities.

Estimating financial impacts

Calculating event path likelihoods and loss severities

When all the CPTs and CCTs (*conditional cost tables*) have been parameterised, it is possible to calculate every possible event path (a unique combination of factor and event states). The likelihood of each event path is calculated as the product of event state probabilities found by looking up the parameterised CPTs. For the example variable specification given in Table 3, there are 1.4 million event paths (the product of the number of states of variables) after removing zero probability paths.

The states of a given event path can then be used to find the path's loss severity distribution by looking up cost parameters in the CCTs. A Monte Carlo method is used to approximate a path's overall severity distribution from triangular distributions (defined by three-point estimates: minimum, most likely, and maximum) representing each category of loss (i.e., hull, human, pollution, cargo, and wreck removal costs). The overall claims cost distribution is then broken down into many components to give a discrete set of likelihood-severity pairings.

Estimating costs of loss scenarios

Costings for each of the heads of claim that made up the components of the overall loss were estimated using valuation data on hull and cargo replacement costs, together with calculations of unit costs, such as reference compensation values per death and injury level, and liability costs for pollution costs per tonne of oil spilt, and average costs of TEU container values from crew and passenger manifests and cargo capacities. We acknowledge the important contribution made to the cost estimation process from the expertise of our Marine Risk Specialist Advisors, particularly on wreck removal costings, hull valuation, calculations using unit costs, costing ranges, and scaling factors for our use.

All cost values were established as most likely values, together with lower and upper bounds to recognize the uncertainties and variation that can arise in the unit costs in the calculations. These enable cost uncertainties and sensitivity studies to be incorporated in the outputs. The suggested values were further adjusted in light of back-testing.

The individual probability of each event path is calculated within the model they are of little value until they are viewed collectively in the form of an EP curve.

Per vessel EP curve

The many paths (for each of the vessel types) represent the range of outcomes that can occur, with likelihoods and costs. They incorporate all the available data on the occurrence frequencies of total losses in each vessel type. The outcome is analysed by assessing all the events as a synthetic set of statistical losses from this type of vessel – i.e. if many tens of thousands of these types of vessels had been operating for hundreds of years under today's conditions, what would we expect the experience of losses to look like by now?

These results are analysed by the distribution of loss severity – how many events would the experience dataset suggest would cost more than a certain value of loss?

The main model outputs include statistics such as expected loss (probability weighted loss value for a total loss), the median value (across the population of loss values, where do half of the losses fall above and below), and percentile distributions (for example what loss value might be exceeded in 10% of the cases we might expect to see).

The probability of exceeding values for the loss of a particular vessel type is anchored on the likelihood of experiencing a total loss, which is taken from recent statistics, combined with this logic path analysis of the distribution of losses that include potential loss escalation from each step in the paths.

The loss frequency and severity distribution from this output set can be presented in the form of an estimated EP curve for each type of vessel. An EP curve shows the probability of any given loss severity being exceeded. It can be read in two directions: starting with, for example, a high severity the EP curve estimates how likely it is that this or any higher severity could be reached; alternatively starting with a given low probability the EP curve estimates the maximum loss we would expect to observe. Although the individual probability of each event path is calculated within the model they are of little value until they are viewed collectively in the form of an EP curve.

Portfolio EP curves

A "portfolio" of vessels is defined as a vector with components being the number of vessels in each of the type and size categories. Specifically let $N_{s,t}$ denote the number of vessels of a type *t* and size *s* and let $P_{t,s}(k)$ be the occurrence probability of a vessel of type *t* and size *s* having a loss exceeding the amount USD***k***bn then the portfolio Occurrence Exceedance Probability is defined as:

$$OEP(k) = 1 - \prod_{t,s}(1 - P_{t,s}(k))^{N_{t,s}}$$

Note that this assumes independence between vessel losses and therefore rules out a second loss, on collision with a second vessel within the same portfolio. Nevertheless, the method allows for the possibility of multiple vessels losses in the year. Aggregate Exceedance Probability (AEP) curves can be created by sampling vessel EP curves.

Limitations of the model framework and current analysis

There are few important limiting aspects to the model framework:

- The product of the sizes of all factor and event state sets gives the total number of event paths In the current model for each vessel and size combined there are 2^{11} 3 4^{3} = 393,216 paths. Adding additional steps rapidly increases the model size and complexity. Such exponential increases quickly start to demand significant computational resource and time. Efforts must therefore be taken to keep the number of variables and states to a minimum.

- The number of variables and states along with the extent of interdependency between variables (i.e., how many variables influence other variables) also determine the size of the CPTs that need parameterising. Wherever the parameterisation process is driven by expert elicitation, rather than by data, the size and complexity of CPTs will have a significant impact on the ease and accuracy with which the tables can be completed. Although the use of submodels, for example based on the use of scaling factors, could aid the completion of CPTs and reduce the overhead placed on experts, the need to parameterise the model restricts the practical scale at which it can be implemented. Again, the number of variables and states should be kept to a minimum. There is a trade-off between the complexity of the parameterised model and its ability to sufficiently capture the nuances and variations in marine disasters and ultimately populate a realistic EP curve. Several variables may need to be rolled into a single, perhaps more abstract, variable. For example, various important conditioning factors such as visibility at sea, wave height, wind speed, and air and sea temperature have been combined within our model into a simple binary yes/no "unfavourable conditions" factor.

- Moreover, this analysis is a simplification of the risk in a number of ways. It assumes that vessel losses occur independently – each vessel encounters perils on its own that determines what its losses might be. For the purposes of this analysis we have ignored the scenarios in which multiple vessels are all impacted by the same event. In the next section of this report, we identified a number of candidate scenarios that could cause this kind of correlated multi-vessel loss, such as a port explosion, hurricane, tsunami, computer virus. We also identified potential extreme cost scenarios that have not been seen in historical loss experience, such as a large scale terrorist attack and a collision between a ship and an oil wellhead. The expert elicitation exercise around these multi-vessel loss scenarios suggested that the likelihood of these is significantly lower than the total loss and cost escalation probabilities that are incorporated into our single vessel loss model here. A more complete marine vessel severe loss model would overlay our individual vessel total loss results with a more sophisticated analysis of the likelihood and costs of these multi-vessel and other extreme scenarios. We believe this would affect the deep tail of the distribution but not have a material effect on the more frequent part.

- The starting probability of a vessel suffering a total loss is an important determinant of the loss escalation probability EP curve. The data on total losses for the Mega classes of vessels is statistically insufficient to make class-specific estimation of the likelihood of total loss. Instead, we have assumed that Mega vessels have the same likelihood of having a total loss as their generic type – i.e. that Mega tankers have the same likelihood of suffering a total loss as all tankers as a vessel class, and similarly for cruise and container ships. This may be conservative if Mega classes are generally safer than Super or Standard classes, but this can be adjusted with improved data or expert judgement in future iterations.

- There are some causes of vessel total loss that have been ignored in this analysis. These ignored causes are responsible for around 8% of vessels becoming a total loss, and they include machinery damage, missing and overdue, piracy, and other miscellaneous attributions. They are independent from the main causes and they typically have smaller loss values their omission, however and will therefore not materially affect the tails of the loss distribution.

- The vessel types considered in this analysis are those of most concern to the insurance underwriters in our steering group. They do not represent all of the vessel types in the global fleet. The analysis could be extended in future using a similar methodology to include bulk carriers, ferries and other vessel types in the fleet.

Additional scenarios of severe losses

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5. Additional scenarios of severe losses

The Lloyd's-Cambridge Marine Risk Model provides a loss distribution that is likely to result from individual independent vessels that have their own chance of suffering a total loss as they travel around the oceans. This is a useful reference framework of the risk to individual classes of vessels, but it may underestimate the risk of insurer payouts in a severe year or combination of circumstances. In this section we explore some of the considerations that insurers should give to supplement the model multiple losses, more severe loss event types, and most significantly the potential for correlated losses to multiple vessels in the same rare catastrophic event. These issues represent features of analysis that could potentially be added to improve the Lloyd's-Cambridge Marine Risk Model.

Losses to multiple vessels

The model presented here produces individual EP curves per vessel which can be combined using the usual rules of probability to model portfolio losses. However, the tail risk for an insurance portfolio which is defined by combining the probabilities of independent loss events such as those in the Lloyd's-Cambridge Marine Risk Model may underestimate the chances of having a loss from a correlated event, where the same cause triggers the loss of more than one vessel. Scenarios where this might be possible are considered below.

We have abstracted the loss cost analysis away from the concept of two vessels colliding. In the modelling, we retain the concept of a vessel suffering a total loss as the result of an impact with another object. That other object could be another vessel. It could even be another vessel that is also in the portfolio of the same insurer. A comprehensive analysis of the risk of a severe loss in a marine insurance portfolio would incorporate this potential.

Identification of other severe loss scenarios

From the review of historical case studies, and with the help of specialists in marine risks and the experience of marine insurance underwriters, we developed a list of the types of scenarios that could cause severe losses to marine insurers in the future, particularly those where correlated losses could occur to multiple vessels in the same incident. This involves a process of constructing hypothetical scenarios and exploring the situations and variables that could make losses unexpectedly severe. This process made use of an advisory panel of marine risks specialist advisors and marine insurance market specialists, credited in the acknowledgements section of this report.

Elicitation of other loss scenarios

To position the various scenarios in context of the likelihood and severity of different types of events we also used our advisory panel in a series of workshops to develop lists of scenario candidates, and to compare and contrast them with the loss severity formulation for an individual vessel.

The first iteration involved the development of a broad candidate list of hypothetical scenarios for extreme marine loss. This was not intended to be exhaustive but involved the consideration of historical precedent case studies, published hypothetical scenarios by others, and general risk issues and concerns.

The second stage entailed the selection of a short list of eight sample scenarios from the broad candidate list, for benchmarking using an elicitation framework.

Candidate list of scenarios

The review of candidate scenarios drew from published sources, stress tests, adaptation of historical precedents, and extrapolation. Scenarios reviewed in published sources included the following:

Lloyd's Marine RDS *(Lloyd's, 2016)*

1. A collision in US waters between a cruise vessel with 2,000 passengers and 800 staff and crew and a fully laden tanker of greater than 50,000 DWT with 20 crew.
2. The sinking of a US-owned cruise vessel with 4,000 passengers and 1,500 staff and crew.

RMS Marine Cargo Scenarios *(RMS, 2016)*

1. Fire and explosion at the Port of Singapore – vapour cloud explosion of LNG tanker.
2. A Mw 9.2 earthquake on the Luzon Arc Subduction Zone with a tsunami impacting ports in Philippines, Taiwan and Macau.
3. Houston, TX area hurricane and storm surge – high winds and inundation of the Port of Houston damage container storage and oil storage tanks.

Allianz Safety and Shipping Review

A listing of key risks to the future safety of shipping identified by the Allianz Safety and Shipping Review 2015 included *(Allianz, 2015)*:

Automation; war risks; misappropriation of cargos; fallen states; cyber attacks and electronic navigation; dangerous cargo classification; ice shipping; LNG as a fuel; piracy; search and rescue challenges; electronic navigation; catalytic fines and criminalization of seafarers; passenger ship safety.

After the significant total loss resulting from Costa Concordia, the review states that a loss event involving a Mega ship and/or political intervention in salvage operations, could lead to more than US$1 billion in total claims.

Other scenarios

Other scenarios considered by the advisory panel, in addition to those selected for benchmarking and specified in the next subsection, included:

- Sinking of a ship in a key waterway or port entrance that prevents other vessels from access, including key choke points of the Panama Canal, Suez Canal, Mississippi River and other locations.
- Sinking of a large cruise vessel in polar waters.
- Development by other regions of the world of environmental and injury compensation liability standards that equal or exceed those in United States, greatly increasing the potential costs of all marine incidents in other jurisdictions.
- Terrorist attack on cruise ship in deep water.
- Terrorist use of one ship to cause a deliberate collision with another.
- Terrorist attack in a port.
- Hazardous cargo leakage, including biological hazards and nuclear waste accidents.
- Significant increase in piracy losses and pirate ship-scuttling, as a result of a change in tactics, increased resources, and proliferation of more organised pirate groups.
- Cyber attack on port facilities causes significant cargo misappropriation losses.
- Unprecedented fire spread scenarios involving materials, finishes, and ship architectural design that could generate very high casualties.
- Systemic design flaws across multiple vessels from the use of new materials, hatch designs, or innovations that become apparent after ships are operational.
- Geopolitical crisis that causes ships to halt their normal journeys and cluster outside the crisis zone, where they are then affected by another event, such as a hurricane or freak storm

The advisory panel selected eight scenarios for benchmarking from the candidate list described next.

Benchmarking selected scenarios

A. Explosion in a major world port

An accident in a cargo ship being offloaded in one of the 10 largest ports in the world triggers a large yield explosion. The blast causes structural damage to ships within 800m (half a mile), and minor damage to ships within 3 km (2 miles). It collapses buildings onshore, triggers fires, and breaks windows for up to 6 km (4 miles) away.

B. Fire on board a container ship

A container ship carrying 14,000 TEU in mid ocean experiences a fire originating in containers below deck, which spreads rapidly to ignite stores of calcium hypochlorite on deck.

C. Cruise ship collides with a Super Tanker

Off the Florida Keys, a cruise ship with 2,000 passengers and 800 crew collides with a fully laden Super Tanker at night. The closing speed is sufficient to pierce the side of the tanker and rupture its double hull and mid-deck, splitting two bulkheads. The tanker sinks in moderate depth water. The collision triggers a major fire on board the cruise ship, with the potential to ignite the spilt oil on the sea surface.

D. Hurricane impacts busy shipping lane

A hurricane in the Caribbean rapidly intensifies and unexpectedly veers into busy shipping lanes at least 250 km (135 miles) away from its predicted track location earlier in the day, before the majority of shipping can get out of its way. A large area of ocean – a region with radius of 100 km (50 nautical miles) – experiences wind speeds of over 70 m/s (150 mph), with significant wave heights of over 17m (60ft), with occasional 36m (120ft) waves for more than two days. A much larger surrounding region experiences severe storm conditions.

E. Electronic navigation devices compromised

A computer virus causes errors in electronic navigation control systems for ships using a particular brand of software. Around 5% of all modern ships use this software. Errors occur randomly and untraceably approximately once a day, introducing navigation errors ranging from 10 metres (32 ft) to 1 kilometre (0.5 nautical miles). Accidents caused by software navigation errors are initially attributed to human error. It takes over a year to diagnose the error and to upgrade the software to eliminate the virus. During this time, the malware is responsible for marine accidents.

F. A container ship hits an oil wellhead

A Post-Panamax container ship carrying a full load of 10,000 TEUs collides with a floating oil wellhead facility in Gulf of Mexico with sufficient force to rupture the wellhead, spilling oil until it can be controlled. The collision badly holes the container ship, which loses power and lists 30 degrees.

G. Terrorist attack on cruise ship

A team of terrorists attack a cruise ship docking in Miami with 5,000 passengers and 2,000 crew. A bomb is detonated from a Zodiac sailed alongside, followed by a team of terrorists boarding the cruise ship and attacking passengers with automatic weapons. The terrorists set fires on board and detonate suicide vests until neutralised by law enforcement response teams. In the case of marine, terrorism is covered by specialised products (e.g. Marine Hull War, Marine Cargo War and Marine Kidnap and Ranson). For the purposes of this scenario, the total damage, consequences and loss of life are considered, irrespective of insurance coverage.

H. Tsunami hits costal port

The Port of Long Beach in Southern California is part of a length of coastline that is hit by a tsunami generated by an earthquake out to sea. A very large tsunami wave impacts San Pedro Bay and a wave washes up the Long Beach Channel into the harbours of the port. Ships berthed at the docks are thrown against harbour walls. Those that lose their moorings are washed inland. Cargo stored on shore is impacted by the wave.

Scoring the scenarios

Cambridge carried out a careful consultation with the advisory panel to estimate the loss and consequences from all the vessels, cargo, and insured personnel potentially affected by the event. The panel members were asked to give each scenario a severity score for each of the following attributes: damage cost, human casualties (number of deaths), environmental impact (amount of oil spillage). They then gave a probability ranking to the occurrence a scenario of this severity.

The scoring scales used for the exercise were quantitative, but categorised. Each respondent was asked to provide his/her best estimate, and a range of minimum to maximum on the given scales for damage cost, human casualties (number of deaths), environmental impact (amount of oil spillage).

Scenario benchmarking results

Figure 9 shows the collated results of the elicitation of the opinions of the advisory panel. These were first collected independently from each of the panellists, then presented and reviewed with the panel as a group, to allow consensus adjustment, as a variant of a Delphi method of expert elicitation.

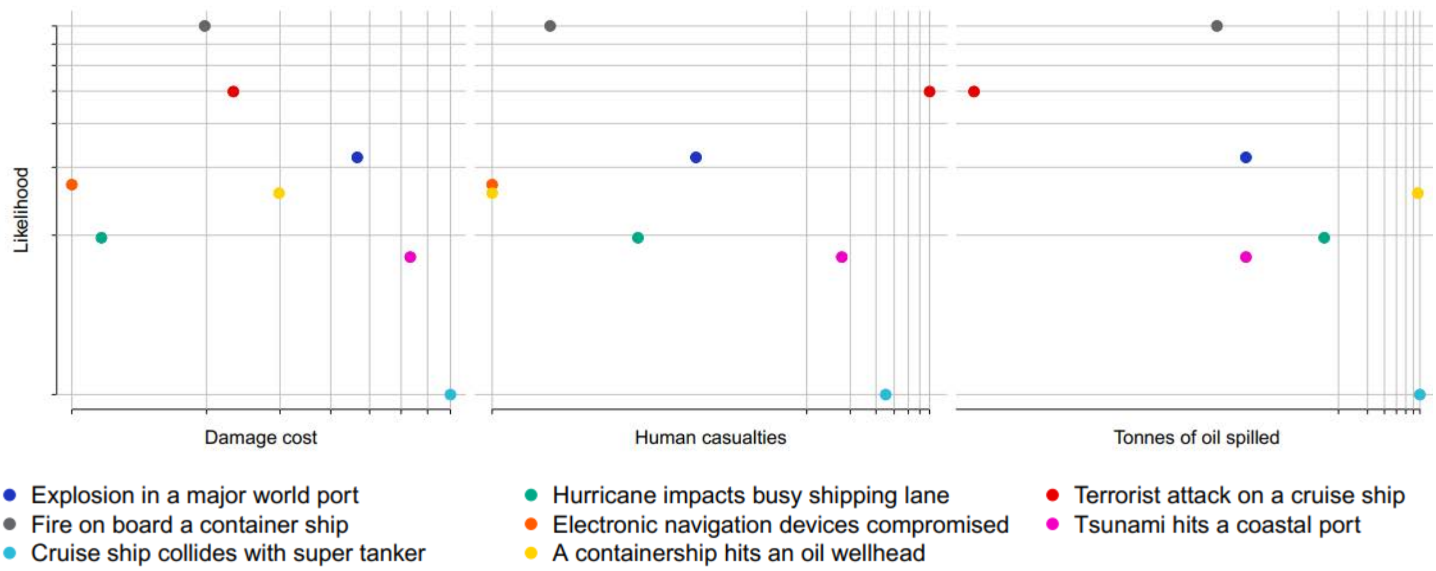
The results are presented as 'best estimates', these are the numerical values of the categories, averaged for all of the respondents and in some cases adjusted by group review.

The advisory panel members were consistent in their views that severe losses from a terrorist attack on a cruise ship (see: Scenario G) was one of the most impactful scenarios likely to occur somewhere in the world within the return period of concern, while acknowledging that terrorism coverage is a specialist line of marine insurance.

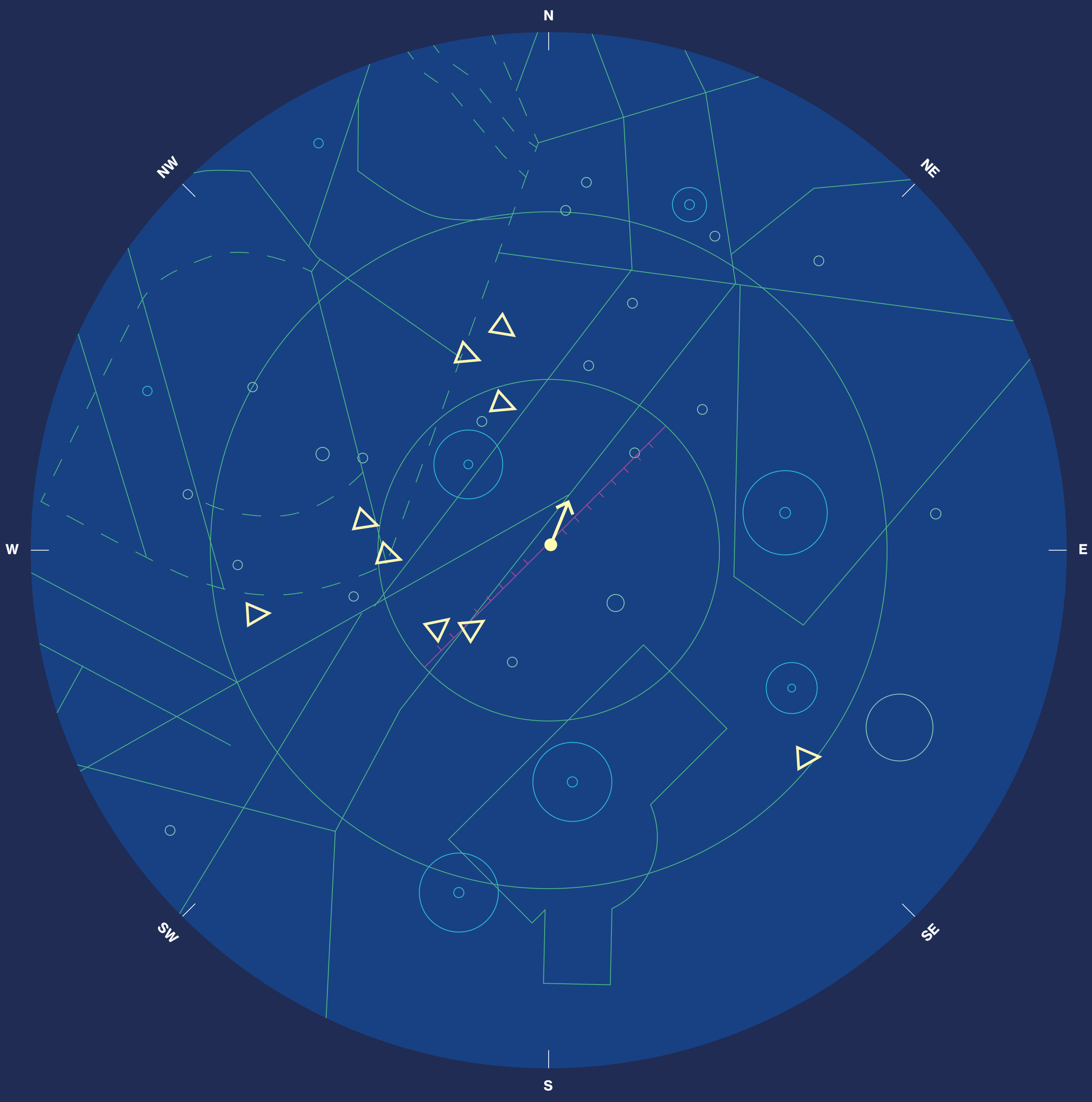
An explosion in a major port somewhere in the world (Scenario A) is considered highly impactful at return periods of concern, mindful of the Tianjin explosion in 2015. Cyber attacks on marine navigation equipment (Scenario E) were considered more likely to cause relatively low levels of loss than other scenarios, though the likelihood of cyber attacks against marine vessels in general may become a greater peril in future than other scenarios described. A severe fire on a container ship is considered one of the most likely events for the insurer to have to deal with. The collision of a cruise ship with a Super Tanker in US waters is considered of low probability demonstrating that the Lloyd's RDS remain appropriately extreme tests.

The scenarios provide the context for the areas of primary concern for the marine insurance professional: the potential for severe cost escalation occurring around a significant marine loss, as parameterised in the Lloyd's-Cambridge Marine Risk Model. This listing of additional hypothetical scenarios above should be recognised by insurers as potential severe scenarios that could affect their tail risk, particularly those with the potential to impact multiple vessels in a correlated event, and potentially estimated more formally through quantified risk assessment in a future version of the Lloyd's-Cambridge Marine Risk Model.

Figure 9: Scenarios benchmarking results



Conclusions and future developments



6. Conclusions and future developments

In this report, we have explored a model for severe economic losses resulting from marine insurance risks. We reviewed the existing literature on marine disasters with regard to three key areas: marine losses over time; current regulation and international conventions applied to the shipping industry; and methodology used to estimate the consequences and losses.

We examined the potential for correlated multi-vessel losses arising from a wide variety of scenarios, and benchmarked the frequency and severity of these. Industry experience, expertise, and the data that is available on these extreme loss scenarios suggest that these multi-vessel loss scenarios are not as much a probable driver of severe costs as the potential for cost escalation in the pay-outs from the more common incidence of a total loss of an individual large vessel.

To quantify the likelihood of costs escalating in a marine vessel total loss, we have developed a logic process model that captures the likelihood of different steps combining to cause a severe loss pay out in different categories of loss: hull loss, wreck removal, cargo loss, liability for injuries, liability for pollution, and total payouts. We have described this for three types of vessels – tankers (split into oil carrying and other), cruise ships, and container ships – in three size categories for each: Standard, Super, and Mega.

Interpreting loss exceedance probability distributions

For each vessel type, the event tree model generates an estimation of how likely it is that the loss severity from a total loss will exceed a certain value: a loss EP distribution curve. We believe this is the first time that a fully probabilistic severe loss model has been applied in this way to marine insurance.

EP distribution curves indicate a characteristic knee-bend curve and have upper limits for cost that become increasingly more unlikely as they are approached. There is an initial phase of the curve where losses rapidly escalate across several orders of magnitude with corresponding likelihoods increasing over only a single order of magnitude. The curve 'hinges' at a knee and is then in a mode of severe cost escalation characterised by a rapid fall in likelihood (i.e. it is much harder to achieve such losses). This is particularly noticeable in the EP curves of tankers.

For any individual vessel, the chances of a total loss are remote in a given operating year, based on statistics of losses to vessels of this type. The curve begins at this starting point of probability with a minimum cost of a total loss to a vessel type, and then shows the full range of loss cost with the likelihood that the cost could escalate to any given level.

Improving the estimation of risk capital requirements

The ultimate aim of this report and its accompanying model is to shed light on existing and emerging risks in the marine industry and to highlight the costliest events that would result in significant insurance losses. In approaching this subject and designing the model, Lloyd's and the research team at the Cambridge Centre for Risk Studies has collaborated with major marine experts and marine underwriters in the industry in order to develop a rigorous methodology for creating a relevant and robust tool for analysing modern marine risks.

This model provides a first analysis of the exceedance probability of marine vessel severe loss escalation. The likelihood of losses at different annual probabilities and return periods are set out for different types and classes of vessels, along with approaches by which these can be used to help marine insurers estimate their own portfolio risk from severe loss cost events.

We provide this analysis to assist marine underwriters in improving their estimation of risk capital required to support this vital line of insurance business.

Opportunities for future development

The Lloyd's-Cambridge Marine Risk Model tool has been developed as a first step towards the probabilistic assessment of global marine disaster tail risk. This research may be further developed in several directions:

- The model is currently configured to evaluate every possible event path determined by the variable and state set. Computational considerations constrain the complexity of the model. An alternative approach would be to use Monte Carlo simulation modelling to sample a subset of possible events paths sufficient to populate a smooth EP curve. This has been implemented here for AEP (aggregate exceedance probability curve), but could be moved earlier in the process. This approach could be suitable if additional complexities were to be added to the model in other respects, thus balancing run time or memory constraints. Alternatively parallel processing could be employed and this model is ideally suited to this.

- The model can be extended to cover all vessel types and marine incident types. The model would then provide a comprehensive view of global marine disasters.

- The analysis may be extended to include all marine casualties, not just those resulting in total loss.

- Counterfactual analysis of near-total loss events could lead to a reassessment of consequential event probabilities. The current model takes the existence of a marine incident as its starting point. The causal events leading up to the incident have not been assessed. Again, the counterfactual analysis of near-misses (as discussed in the Counterfactual Risk Analysis paper published by Lloyd's in October 2017) is likely to lead to a re-evaluation of annual incident probabilities based on historical casualties.

- It may be possible to calibrate historical losses against historical exposure values, and thereby allow future losses to be calibrated against current or projected exposure values.

- The variable and state selection process is currently manual. With greater data availability, including for example the full Lloyd's List Intelligence database and Satellite Automatic Identification System (S-AIS) databases, machine learning algorithms may be able to assist in the identification and interdependency of critical variables. The Lloyd's Data Lab is currently exploring the value of geospatial intelligence and a wide variety of open data sets for maritime and vessel tracking with the Lloyd's Market.

- The model provides EP curves for single-vessel marine losses across the global fleet. The model could be readily adapted to render bespoke EP curves for a marine insurer's fleet profile, including consideration of the insurance, re-insurance and the structure of P&I club reinsurance participation.

- For a given vessel the routes taken could be modelled allowing more granularity of outputs and more bespoke portfolio analysis Liability limitations could be implemented in a more sophisticated way.

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