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# Safety assessment for a cruise ship terminal

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**Key words:** cruise ships, safety assessment, degree of risk, hazards, ship terminal

**Abstract**

Cruise ships arriving in the port of Koper carry approximately 1000 to 3000 passengers and crew members. Such a concentration of people presents a high degree of risk in the event of a major disaster, because it is difficult to control, due to limited space, the dynamics of people in the event of a general panic, the presence of large amounts of fuel, proximity of the city center and other vessels and cargo at the port.

To avoid the possibility of hazard events, a good safety assessment must be done prior to a ship's arrival. One of the methodologies for systematically assessing the risk is a Formal Safety Assessment, a tool for determing and evaluating the risk of potential hazards at a cruise ship terminal. This paper discusses the diverse aspects of safety analysis.

## Introduction

Cruising is an important element of maritime commerce, as it is on the cruise ship where tourism and transport come together [1]. Cruises also appear to be gaining in popularity; in 1999 cruise ships carried almost 9 million passengers, while in 2006 at least 17 million passengers took vacations on cruise ships. In Slovenia's port of Koper authorities are struggling with the need to adapt to the growing cruise ship trade, which includes the need to accept larger ships. Safety analysis is also necessary, for while in general cruising offers a safe vacation and has a good overall safety record, hazards do exist: from fire, collision, and grounding.

While the international shipping community has long been concerned with maritime safety, in the last decade or so the safety of cruise ship has become more of a concern. Cruise ships are not only subject to various local, national and international rules and requirements relevant for safe operation and construction, they must also comply with the safety standards set by the International Maritime Organization (IMO) enforced through the International Convention for Safety of Life at Sea (SOLAS).

The Formal Safety Assessment (FSA) is a tool for risk evaluation developed by IMO to enhance the safety of ships, passengers and crews, and the environment. The FSA uses five steps: hazard identification (HAZID), risk assessment, risk control options, cost benefit assessment and decision-making recommendations. Its goal is a systematic approach to safety in all aspects regarding particular vessels. This paper examines the FSA in relation to a cruise terminal and the existing safety plan of a cargo seaport.

We should add that the US Coast Guard and Passenger Vessel Association published a manual for safety risk assessment of passenger ships at sea and in ports (PVA Risk Guide – A Guide to Improving the Safety of Passenger Vessel Operations by Addressing Risk). This manual helps improve the process of risk (hazard) identification, to plan how to reduce risk levels and protect ship or ports from possible hazards. It is a tool which could be adapted for different operations or environments where risk assessment is needed. They divided risk handling activities (risk assessment, risk management and risk communication) into ten steps: problem definition, expert gathering, hazard identification, probability assignment, consequence assignment, calculation of relative risk, development of counter measures, estimation of benefit, estimation of cost and cost-benefit analysis [2].

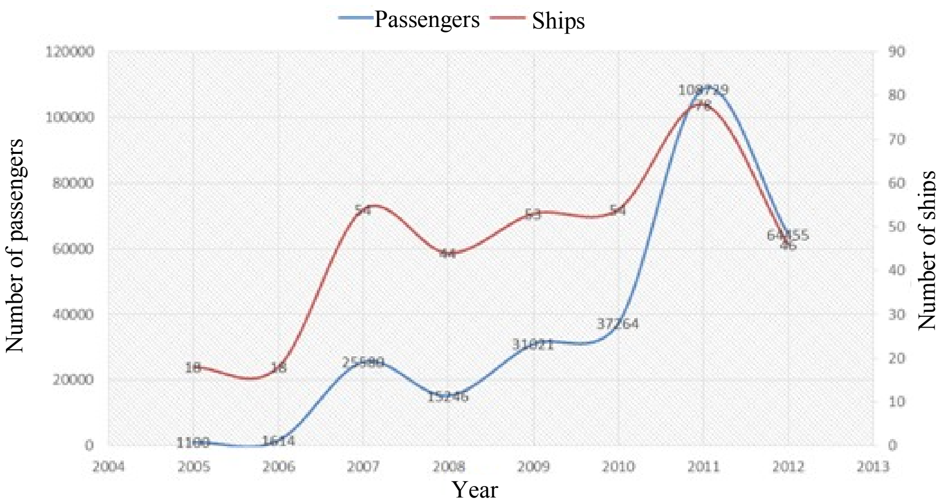


Fig. 1. Passenger vessels and passengers calling Port of Koper

## Risk evaluation criteria

Risk evaluation begins with the conception of appropriate risk acceptance criteria. Port and terminal operators identify potential hazards strictly related with ship hazards, when the ship is approaching or leaving the port or is moored at a terminal. The following quote is taken from MSC 72/16: "The term risk acceptance is established in many industries and regulations; however, it is worth noting that the term itself can be misleading. The risk is not acceptable, but the activity might imply the risk to be acceptable because of the benefits." It is therefore important to make the distinction between risk tolerability and risk acceptability [3].

The term "risk evaluation criteria" rather than "risk acceptance criteria" is perhaps more appropriate to risk assessment. "Risk evaluation" is the official term at IMO (FSA Guidelines) and reflects organization's position that risks are not acceptable; yet decisions involving risks are accepted because their benefits are deemed to outweigh the risks. Risk evaluation criteria use the following categories: unacceptable, tolerable and broadly acceptable. These are further described below:

Intolerable: – Risk level is intolerable. Risks must be reduced irrespective of costs.

Tolerable (ALARP):
- Risk level is tolerable provided that risks are managed to ALARP (As Low as Reasonably Practicable).
- Risks shall be reduced as long as the risk reduction is not disproportionate to the costs.
- Need only to implement cost beneficial Risk Control Options (RCOs).

Partially acceptable: – Risk level is negligible. Not necessary to consider RCOs.

In the following the modelled risk level for cruise ships and ship terminal will be evaluated using risk evaluation criteria concerning individual risk and societal risk.

### Individual risk

Individual risk is the frequency for an individual fatality per year, the likelihood that the most exposed crew member or passenger will die as a result of an accident or event on board a cruise ship. This report only considers events related to ship operation. Accidents due to leisure activities and occupational risks are not within our scope.

The criterion accepts that higher risk is tolerable for crew members than for passengers, as they have "volunteered" to take on whatever risks may be involved in sailing and also benefit financially from operating the cruise ship. We should stress, too, crew members are more aware of their risks and have been trained to carry out their job responsibilities safely and effectively. It should also be noted that the basis on safety regulation in the UK is encapsulated in the Health and Safety at Work Act [4] which requires the duty holder to ensure and demonstrate that risk to employees, part time employed persons and the general public is As Low As Reasonably Practicable (ALARP). The Health and Safety Executive (HSE) publishes from time to time the risk levels it considers as intolerable or tolerable under certain circumstances and while these risk levels cover all industrial activities in the UK, the primary instrument for risk control is ALARP dynamics. Trbojevic [5] has emphasized the individual risk criteria based on existing European standards and guidelines.

Table 1. Individual risk evaluation criteria

| Risk criteria | Value |
|---|---|
| Maximum tolerable risk for crew members | $10^{-3}$ per year |
| Maximum tolerable risk passengers | $10^{-4}$ per year |
| Negligible risk | $10^{-6}$ per year |

**Societal risk**

A societal risk criterion takes the possibilities of catastrophic accidents of major societal concern into account to ensure that the risks imposed on the society from the activity are controlled. Depending on the system under consideration, both individual and societal risk evaluation criteria might apply. Societal risk posed by a cruise ship terminal facility is measured by the exposure probability of a group of people to risks, and where a large number of people are affected by possible accidents and would be exposed to a hazardous level of harm (fatality) due to all types of potential accidents at the facility or through its activity. The societal risk is dependent on both, the density of people in the vicinity of a hazardous terminal (e.g., LNG, Chemical or oil terminal) and the location of the population in relation to the facility. The societal risk is generally presented in the form of an FN curve, expressing the relation between the annual probability (F) of exceeding a given number of fatalities and the number (N) [5]. In most countries the risk assessment is performed on the basis of potential fatalities to the exposed population. Different countries use slightly different criteria for risk acceptability. In the UK, the Health and Safety Executive (HSE) guidelines are to use the individual risk as the principal measure, but also to use the societal risk criteria for land use planning. The acceptability criteria levels for risks for facilities in the UK are specified by HSE (1989). Facilities are permitted only when these (published) criteria are met. In the Netherlands, however, both the individual risk criteria and the societal risk criteria must be met when considering those events whose hazardous effects extend to such distances at which the conditional probability for lethality is higher than 1% [6, 7].

Societal risk criteria is more complex a concept than individual risk and there is continual debate as to whether the methodologies adopted are suitable. FN curves are, however, a common way of presenting societal risk and are considered by some parties the best way of illustrating this data. The method of deriving societal risk evaluation criteria in this report is based on IMO MSC 72/16 – Decision parameters including risk acceptance criteria [8]. The risk level is plotted as a cumulative function of consequence and frequency on a log-log graph:

$$F1 = \frac{r \cdot EV}{\sum_{N=1}^{N_u} \frac{1}{N}} \tag{1}$$

where:

- $F1$ – is the frequency of accidents involving one or more fatalities;
- $N_u$ – is the upper limit of the number of fatalities that may occur in one accident;
- $r$ – the number of fatalities due to transportation divided by contribution to GNP by transportation. It can be calculated as $r$ = fatalities/$ GNP;
- $EV$ – is the economic value of the industry. In this case, the EV here is represented by a reference vessel and is derived from the income from cruise voyages.

As presented by MSC 85/INF.2 [3] the ALARP area can now be defined by use of the above formula. The criteria applied in this study are presented in table 2.

Table 2. Limits for societal risk

| Parameters for societal risk criteria | Value | Denomination |
|---|---|---|
| F upper (dotted line between ALARP and Intolerable) | $6.9\cdot10^{-1}$ | fatalities |
| F lower (dotted line between ALARP and Negligible) | $6.9\cdot10^{-3}$ | fatalities |

**Cruise ship accident statistics**

In order to perform safety analysis, whether qualitative or quantitative, it is essential to obtain reliable failure data. Qualitative risk analysis requires less detailed statistical failure data compared to Quantitative Risk Assessment (QRA). A ship year is defined as one ship sailing for one year. Given the increase in the number of large ships in recent years it is necessary to distinguish between “smaller” cruise ships and “large” cruise ships; the following tables have been split into two groups (20–60,000 GRT and > 60,000 GRT).

The graph shows an increasing accident trend. The data takes into account the significant increase in the number of cruise ships that have entered the market during the previous decade – particularly for vessels > 60000 GRT.

Most claims involved with accidents were personal injury-related, 50% being for passengers or third-party property and 27% for injury to crew [9]. However, passenger ships were eight times less likely to collide than the average and much less likely to cause third-party damage or pollution.

Related to the study conducted there is no particular event when the accident inside a port, at a cargo terminal led to passenger fatalities at a cruise ship terminal. Accidents usually occur due to the cruise ship itself and its nautical operations. Events that usually lead to accidents are listed in table 3.

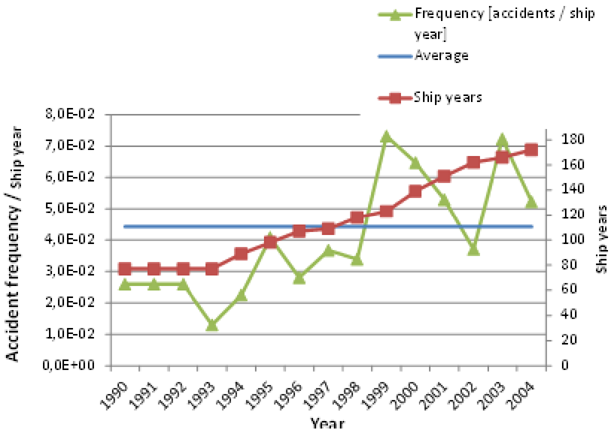


Fig. 2. Accident frequency, year-by-year (per ship-year)

Table 3. Hazardous events during operation phases

| Operation phases | Possible hazardous events |
|---|---|
| Passenger embarkation | Passenger and crew injuries while alongside<br>Passenger violence<br>Fire/explosion in terminal<br>Noise<br>Overloaded gangway/collapse<br>Injuries to unattended children |
| Getting underway (arrival and departure) | Lifting injuries while loading wheelchairs<br>Fall in water/man overboard<br>Collision with another vessel<br>Loss of control (ice, wind, restricted visibility)<br>Slips, falls at gangway<br>Fire during fuelling |
| Cruise | Injuries due to machinery failure<br>High speed collision, grounding<br>Situational management (loss of awareness, distraction, multiple events)<br>Electric shock<br>Exposure to elements<br>Medical emergency/evacuation<br>Vessel fire<br>Engine failure<br>Noise due to conflicting groups |
| Docking | Squish injury<br>Dock fire<br>Contact with unknown/hidden objects<br>Complacency (hard docking) |
| Disembarkation | Sewage spills<br>Injuries due to overloaded gangway<br>Slips and falls while disembarkation<br>Careless attendance to handicapped passengers |
| Outside events (accident on ship neighbour) | Spills at neighbouring cargo terminal<br>Gas or chemical release at neighbouring cargo terminal<br>Fire or explosion at neighbouring cargo terminal |

The threat to humans depends on the type of accident. The accidents registered for cruise ships from 1990 to 2004 are presented in figure 3.

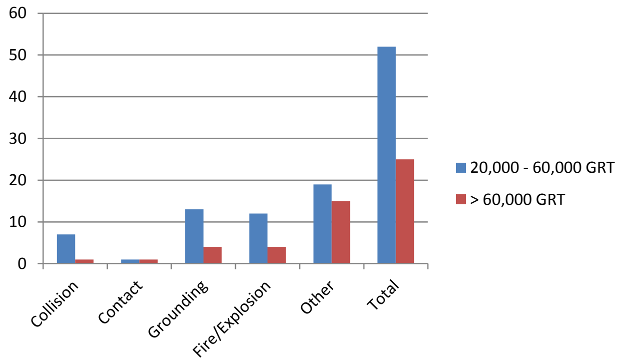


Fig. 3. Cruise ship accidents by type from 1990–2004

"Other" refers mostly to hull and machinery related incidents which have generally been low in fatalities over the years. "Grounding" and "Fire / Explosion" have been the most serious of relevant historical events. The influence or potential consequences of an external accident to a cruise ship and its passengers is not mentioned reports and references. The risk analysis presented below [4] shows how the risk may be quantified on the basis of the simulation of different accident scenarios.

### *Accident frequency calculation*

The exposure during the 1990–2004 period has been 1742 ships years (1222 + 520). 1742 ship years will be used for the accident frequency calculations. The frequency calculations can be summarized as the fraction of accident per accident type and the total number of accidents. However, the number of accidents with fatalities is too few to represent any significant accident trend (Table 4).

## Consequences

The consequence of an accident is defined as the expected number of fatalities if such accident occurs. In order to perform consistent and comparable consequence assessments, fixed bands of expected numbers of fatalities were defined. Bands are defined to suit the reference vessel of 110,000 GRT with a total capacity of 4000 persons. Ten fatality bends cover the full range of accident severities, from a minor scenario to a catastrophic accident resulting in a large number of fatalities. For purposes of accuracy in regard to the current world fleet, the estimated number of fatalities was also estimated for a ship of 75,200 GRT and 40,876 GRT.

Additional risk could occur and influence the safety level for passengers due to other activities conducted in a port area. The literature does not emphasize accidents in ports that have influenced

Table 4. Accident frequency calculations, vessels > 20,000 GRT

| Cruise ship<br>**Ships > 20,000 GRT** | Collision | Contact | Grounding | Fire/Exp. | Other | SUM |
|---|---|---|---|---|---|---|
| LMIS accidents recorded 1990–2004 | 8 | 2 | 17 | 16 | 34 | 77 |
| Ship years 1990–2004 [ship years] | 1742 | 1742 | 1742 | 1742 | 1742 | 1742 |
| **Cruise ship accident frequency [per ship year]** | **4.59E–03** | **1.15E–03** | **9.76E–03** | **9.18E–03** | **1.95E–02** | **4.42E–02** |
| Return period [No. of ship years per accident] | 218 | 871 | 102 | 109 | 51 | 23 |
| Number of fatalities, 1990–2004 | 0 | 0 | 0 | 21 | 1 | 22 |

the safety level of a moored cruise ship or terminal. Therefore, the initial probability could not be defined as possible for collision, contact, grounding and fire accidents. Potential consequences and risks should therefore be calculated applying a deterministic approach.

The occurrence of accidents at cargo terminals with spills of flammable or toxic fluids are risks and require special consideration. Potentially large spills with fire could have a negative influence on a moored cruise ship in a range of 500 m, depending on spill dynamics, weather conditions and several other factors analyzed below. This events have a very small probability, however, because of the potentially severe consequences should be considered and analyzed.

Fig. 4. ERPG 2 zone for a methanol spill in a 11.5 t puddle (Port of Koper)

Figure 4 illustrates the ERPG 2 zone (1000 ppm) for a spill of 11.5 t of methanol in water. Threat zones are calculated applying a heavy gas model. Results indicate that this is a consideration to be implemented in a cruise ship terminal PSA. Second (described in Fig. 5a) is a supposition of a spill and fire of a flammable liquid in a close neighbour to the cruise ship. The initial probability of the spill event is assumed to be $5e^{-5}$/ship year.

A final recognized industrial risk present in the port of Koper is the possibility of a leakage of styrene that may start at the chemical terminal and with north or north east winds a highly poisonous cloud can affect a cruise vessel. The case of expected concentration inside cabins is presented with figure 5b.

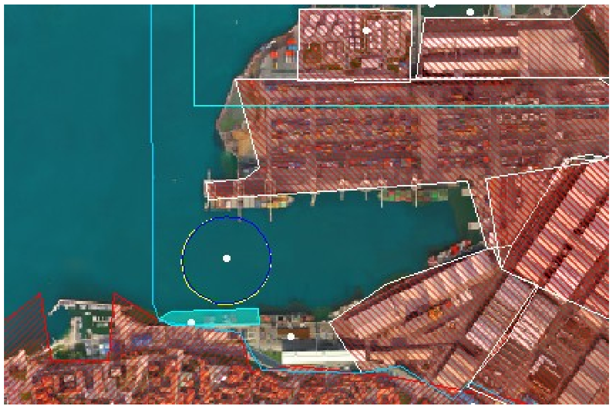

Fig. 5. a) Thermal zones of 12 kW/m$^2$ for ignition of 12 t of gasoline in a pool (Port of Koper)

It is important to note that the identified fatality bands only apply to the reference vessels defined for this study. Each final event is connected to an estimated number of fatalities. The expected number of fatalities is selected from one of the ten possible bands, as defined before. The event tree and probabilities for each event have been carried out together with other participants involved in the Hazard Identification process. The assumption of fatalities is based on the review of the calculated consequences for each event. A further event tree for an oil spill occurring near a cruise ship is presented in figure 6.

The percent value represents the share of the total number of passengers on the analyses ship brand. Most important are levels 2 and 3, which consider intervention by the containment group. Without containment the slick could spread uncontrollably and reach zones with a higher probability of ignition. In the proposed event tree the percent of fatalities on each event is predicted on a qualitative basis, proposed by the HAZID group of expert, in our case the authors. Those values could therefore be enhanced.

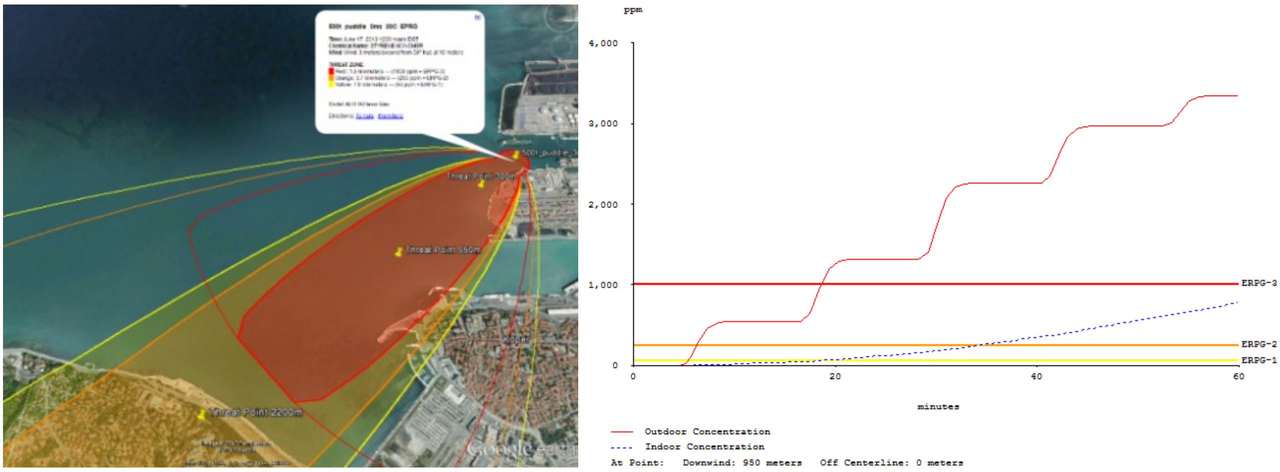


Fig. 5. b: ERPG zones (left) indoor and outdoor concentration passenger terminal for the evaporation of 500 t of Styrene

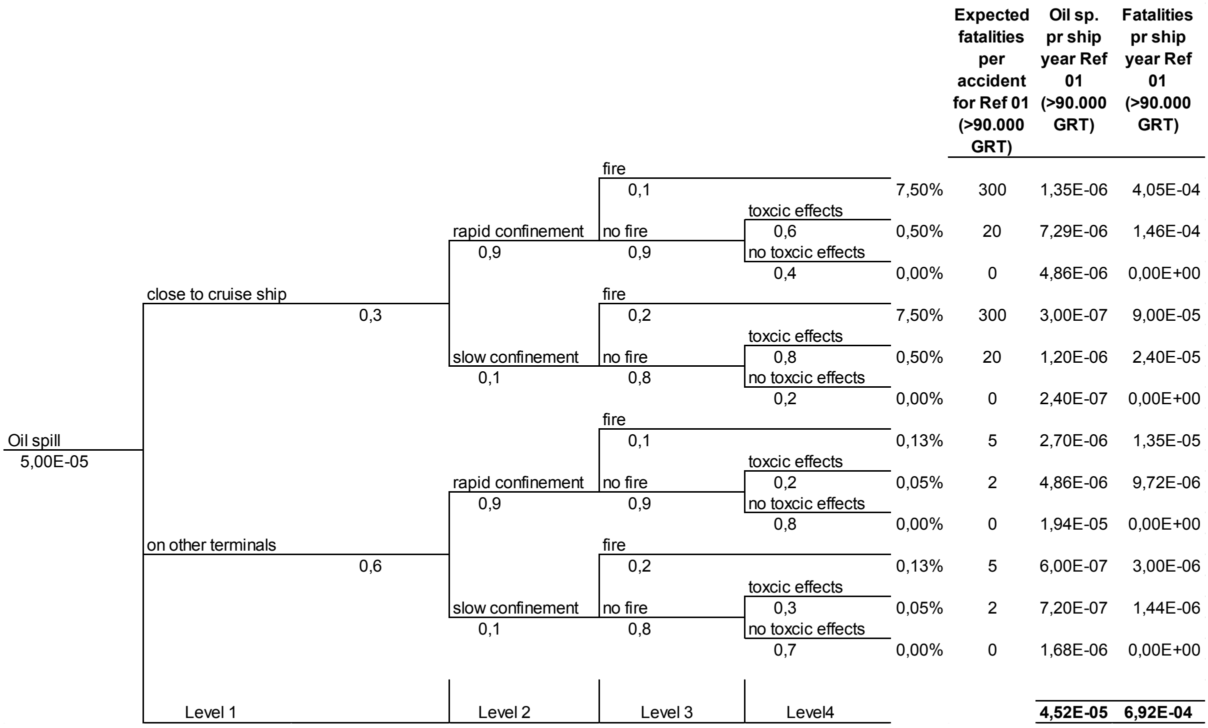


Fig. 6. Cruise ship neighbour oil spill event tree

Table 5. Results for cruise ship neighbour oil spill event tree

| **Cruse ship neighbour oil spill** | | | |
|---|---|---|---|
| Ships in Band | Number of ships in band | Theoretical Fatalities per ship year | Theoretical Number of Fatalities per year |
| Ref 01 (>90,000 GRT) | 30 | 0.00069 | 0.02 |
| Ref 02 (60,000–90,000 GRT) | 53 | 0.00047 | 0.03 |
| Ref 03 (20,000–60,000 GRT) | 89 | 0.00036 | 0.03 |
| **Total** | **172** | | **0.08** |
| Theoretical predicted fatalities per year in current world fleet | Theoretical predicted average number of fatalities per ship year | Theoretical predicted average number of ship years per fatality (current fleet) | |
| **0.08** | **4.53E–04** | **2209.4** | |

– Large scale incidents (sinking, flooding and rapid capsizing) with an estimated 80% casualty rate shape the results for the oil spill event tree.

This is because the estimated numbers of fatalities is large and the estimated frequencies are not low enough to compensate. Any change in the estimated likelihood or consequence of these large scale incidents will have a direct effect on the results of the risk modelling.

– A return period of 2209.4 ship years per fatality (due to oil spill).
– 0.08 fatalities (due to oil spill) per year for the cruise fleet (172 Ships).

The estimated numbers of fatalities for the two other sizes of vessels are also representative of today's fleet and have also been derived and are used later in the results section to provide an overall average number of fatalities that could be expected. The method required establishing the particulars of a reference vessel and determining the likely outcome in terms of fatalities for all scenarios. The total number of persons on board is assumed to make an impact on the total numbers of fatalities only when whole ship events are modelled. Evacuation is indirectly factored into the event tree analysis by assuming a normal distribution of evacuation. It was assumed that, on average, evacuation will work according to procedures.

## Risk level

Individual risk levels can be derived from the ship risk level when the number of crew and passengers is known. The table 6 details the number of passengers and crew on board the three different reference vessels. From the table, an estimated number of persons on board the world cruise fleet (1990–2004) can be calculated and an estimated number of persons on an average size cruise ship can be derived.

The fatality frequencies, calculated from the event-tree(s), are used as input to calculate the individual fatality frequencies for crew and passengers. Risk for crew and passengers have been modelled in a similar way except for the fact that crew is on board for a longer period (higher exposure).

From table 7 it can be seen that the individual risk exposure to a crew member is 7.5E-5 fatalities per crew year. This corresponds to one crew fatality approximately every 13,290 crew years. Similarly, the individual risk exposure to a cruise ship passenger is 5.77E-6 fatalities per year. This implies that a

Table 6. Risk exposure for crew and passengers

| Selection of Representative Ships within 3 size bands | Selected Band for Group of Ships (GRT) | Number of Ships in Band |
|---|---|---|
| Reference Ship 01 | > 90.000 GRT | 30 |
| Reference Ship 02 | 60.000–90.000 GRT | 53 |
| Reference Ship 03 | 20.000–60.000 GRT | 89 |

| | No. of ships in each band | Ships complement (representative ship) | Total carrying capacity of each ship band |
|---|---|---|---|
| Number of persons onboard ships in current cruise fleet | 30 | 4000 | 120,000 |
| | 53 | 2728 | 144,584 |
| | 89 | 2080 | 185,120 |
| | | Total | 449,704 |

| | Total No. of Ships | Total Capacity of Ships | Average No. of persons on each ship |
|---|---|---|---|
| Average number of person on a ship representative of today's fleet | 172 | 449,704 | 2615 |

| | Working period / stay onboard | Total exposure per ship year |
|---|---|---|
| Crew Exposure | Average 6 months onboard | 0.5 |
| Passenger Exposure | Maximum 2 weeks per year | 0.0384 |

Table 7. Individual risk summary

| Hazard | Fatalities [per ship year] | Individual Risk of Pax & Crew [Fatalities Per Year] | Individual Risk for Pax [Fatalities Per Year] | Individual Risk for Crew [Fatalities Per Year] | Return period for passengers in years | Return period for Crew in years |
|---|---|---|---|---|---|---|
| Collision | 2.35E–01 | 8.97E–05 | 3.44E–06 | 4.49E–05 | 290,506 | 22,285 |
| Contact | 7.91E–03 | 3.03E–06 | 1.16E–07 | 1.51E–06 | 8,617,509 | 661,069 |
| Grounding | 1.41E–01 | 5.38E–05 | 2.07E–06 | 2.69E–05 | 484,206 | 37,145 |
| Fire / explosion | 9.67E–03 | 3.70E–06 | 1.42E–07 | 1.85E–06 | 7,050,441 | 540,856 |
| Oil spill | 4.53E–04 | 1.73E–07 | 6.64E–09 | 8.66E–08 | 150,601,788 | 11,553,014 |
| **Sum of all incident causes** | **3.93E–01** | **1.50E–04** | **5.77E–06** | **7.52E–05** | 173,249 | 13,290 |
| Return period in years | 2.54 | 6645 | 173,249 | 13,290 | | |

single fatality occurs approximately every 173,249 passenger years.

The individual risk level for crew and passengers is in the ALARP area, which means that according to the IMO guidelines the risk for crew and passengers should be reduced as long as the risk reduction is not disproportionate to the costs; i.e. only cost beneficial RCOs need to be implemented.

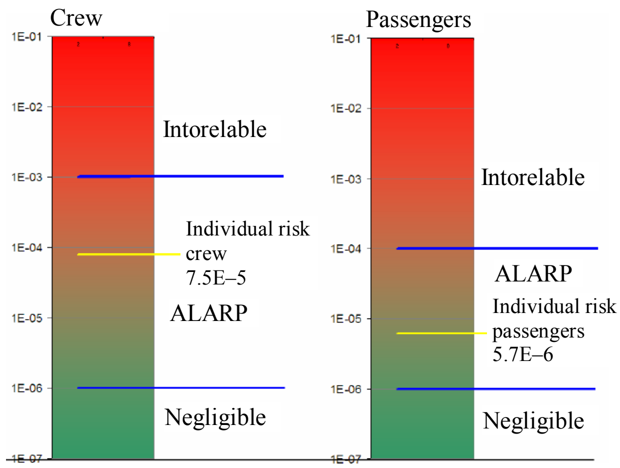


Fig. 7. Individual risk level

The individual risk could also be presented as an area derived from the consequence models and the topography of the populated area together with the assumption of the cruise ship passengers and crew.

Fig. 8. Individual risk zones for cruise ship neighbour oil spill

The highest dependence of results derives from the initial probability of the event. In this case the oil spill probability is assumed to be 5E–5. The probability could be calculated from the historical data as has been the case for other accidents. In this case the data were not available for such an event because there are very few events available for the analyzed port. Related to the reason of an oil spill there is a probability it happens as a consequence of collision or grounding from the sea side, but also as a consequence of an industrial accident on the land side. The value 5e–5 is taken as a calculated risk of a land side spill. The calculated probability for collision in the analyzed port is 2E–5 /year and for grounding 5.8E–5. Assuming that 10% of those accidents could lead to a spill the frequencies are ten times lower. In this case the higher probability has been assumed for further calculation.

### Societal risk

Based on the calculated individual risk frequencies the societal risk in computed. Integrate the probability of death for each event over the population specified $N_u$ represents the number of people killed by a given event. Figure 9 illustrates the modelled risk level for cruise ships in an FN diagram. The risk level is calculated as the sum of the frequency per ship year for these accidents. The limits for societal risks are provided in table 2. The risk level is within the ALARP region.

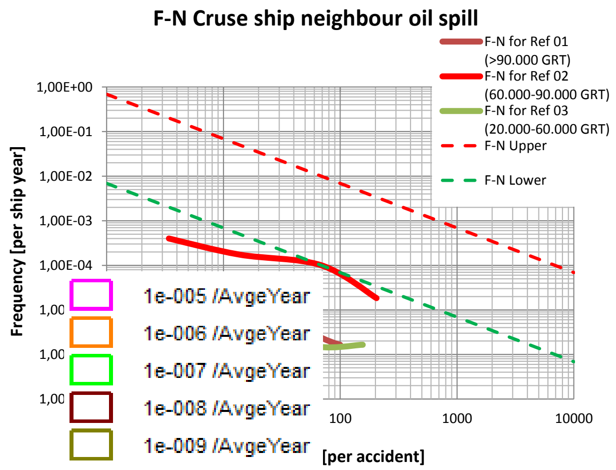


Fig. 9. Societal risk level for Cruise ship neighbour oil spill

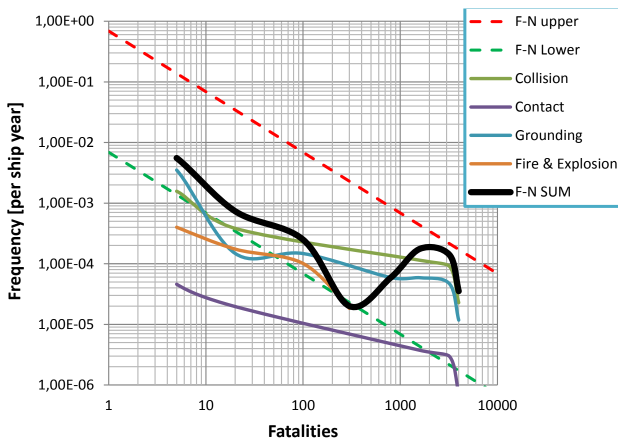


Fig. 10. Societal risk level based on accident type

Figure 10 shows the risk level for other four accident types evaluated for cruise ships over 90,000 GRT. From the figure it is evident that collision and grounding accidents are the main risk contributors, while contact and fire / explosion accidents do not contribute significantly to the overall risk picture.

Table 8. Risk overview per hazard

| Hazard | Accudent frequency [per ship year] | % of all accidents | Fatalities [per ship year] | % of all |
|---|---|---|---|---|
| Collision | 4.59E–03 | 10 | 2.35E–01 | 58.8 |
| Contact | 1.15E–03 | 3 | 7.91E–03 | 2.0 |
| Grounding | 9.76E–03 | 22 | 1.41E–01 | 35.3 |
| Fire / explosion | 9.18E–03 | 21 | 9.67E–03 | 2.4 |
| Others | 1.95E–02 | 44 | 5.81E–03 | 1.5 |

## Conclusions

44% of cruise ship accidents fall into the “other” category. However, the four modelled hazards account for 98% of fatalities. Collision and grounding amount to 94% of fatalities (59% + 35%). Smaller accidents with 2 to 5 fatalities can be expected every year in a fleet of 172 ships. The great majority of risks are within the large scale accident category due to the large numbers of estimated fatalities. Catastrophic accidents with large numbers of fatalities account for 80% of the risk even though the frequency of such events is quite low.

The results are highly dependent on historic incident data and modelling of collisions and to a lesser extent groundings. The data used are not up to date and should be updated for the analysis of the current world fleet of cruise ships. Further research should be initiated to investigate whether our results apply to modern cruise ships.

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