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EMSA/OP/10/2013

Risk Level and Acceptance Criteria for Passenger Ships. First interim report, part 1: Risk level of current fleet.

European Maritime Safety Agency

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DNV GL AS DNV GL Maritime
BDL Newbuilding
P.O.Box 300
1322 Høvik
Norway
Tel: +47 67 57 99 00
NO 945 748 931 MVA

Task and objective:
In this report the risks of the current Cruise and RoPax ship fleet are quantified and discussed.

Prepared by:	Verified by:	Approved by:
Rainer Hamann	Apostolos Papanikolaou	Odd Karsten Olufsen
Rolf Skjong		
Eleftheria Eliopoulou		

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0	2014-04-29	First issue	Rainer Hamann Rolf Skjong Eleftheria Eliopoulou	Apostolos Papanikolaou	Odd Olufsen

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1 PREFACE

This report is a deliverable according to the Framework Service Contract Number EMSA/OP/10/2013. This is the third study commissioned by EMSA related to the damage stability of passenger ships. The previous studies focused on ro-ro passenger ships.

This study aims at further investigating the damage stability in an FSA framework in order to cover the knowledge gaps that have been identified after the finalization of the previous EMSA studies and the GOALDS project.

The project is separated in to 6 studies:

- Identification and evaluation of risk acceptance and cost-benefit criteria and application to risk based collision damage stability
- Evaluation of risk from watertight doors and risk based mitigating measures
- Evaluation of raking damages due to groundings and possible amendments to the damage stability framework
- Assessment of cost effectiveness or previous parts, FSA compilation and recommendations for decision making
- Impact assessment compilation
- Updating of the results obtained from the GOALDS project according to the latest development in IMO.

The project is managed by DNV-GL and is established as a joint project which includes the following organisations:

Shipyards/designer:

Euroyards representing: Meyer Werft, STX-Finland, STX-France and Fincantieri

Knud E. Hansen AS

Operators:

Royal Caribbean Cruises

Carnival Cruises

Color Line

Stena Line

Universities:

National Technical University of Athens

University of Strathclyde

University of Trieste

Consultants:

Safety at Sea

Software manufacturer:

Napa OY

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4 ABBREVIATIONS

A: Attained index calculated in accordance with SOLAS 2009. Ch.II-1

ALARP: As Low As Reasonable Practicable

CN: Collision

CT: Contact

FD: Foundering

FSA: Formal Safety Assessment

FX: Fire/Explosion

GOALDS: **GOAL** based **D**amage **S**tability

GR: Grounding

GT: Gross tonnage

IACS: International Association of Classification Societies

IMO: International Maritime Organisation

LMIU: Lloyds Maritime Investigation Unit

POB: Persons on board

R: Required Subdivision Index

SAFEDOR: Design, Operation and Regulation for Safety (EU FP6 project)

WOD: Water on deck

5 EXECUTIVE SUMMARY

This report contains part 1 of the first interim report on the task of “Risk acceptance criteria and risk based damage stability” in the EMSA/OP/10/2013 project. This part includes the investigation of individual and societal risk to which passenger and crew are exposed. Part 2 identifies the risk acceptance and cost-benefit criteria of various transport modes and industries and recommends CAF values for further use.

Based on the risk models developed in project GOALDS for the accident categories collision and grounding, which were amended by the risk models for contact, fire & explosion and flooding (RoPax only) developed in the SAFEDOR FSAs, the risk for the passenger ship types Cruise (cruise and passenger) and RoPax (RoPax and RoPax-Rail) is estimated.

The risk models are updated by newly calculated initial accident frequencies for the period 2000 to 2012 and additional information derived from casualty reports. The investigation on the development of casualties in the different accident categories showed for ship type Cruise an increase in accident frequencies for the period 2000 to 2012 for collision and contact compared to the period 1994 to 2012. For ship type RoPax such an increase is observed for collision, contact, fire & explosion. As already mentioned in GOALDS project, various potential causes for the observed increase exist, for instance changes in and stricter reporting/collecting casualty data by database providers. In general, this development is appreciated because the amount of information will increase in future and it is expected that this will improve the basis for this kind of investigation. However, the number of reports may also change the relation to accidents with significant impact on passenger safety and as to those with smaller impacts. Therefore, a carefully revisiting of existing risk models is necessary. Furthermore, as far as possible and meaningful, the effect of SOLAS 2009 damage stability requirements is included in the updating of the risk models.

For each of both ship types under consideration the risk to person on board for three reference ship size categories is estimated in terms of FN-diagram, PLL, fatalities per hour, fatalities per journey, fatalities per billion passenger hours and fatalities per billion passenger kilometres. The human risk is calculated considering actual occupancy information.

The risk results are summarised and discussed in section 8.3.4 of this report. The discussion considers the updated thresholds for the FN diagram as well as selected results from the analysis of risks for other modes of transport. More detailed information can be found in part 2 (Appendix A and B) of this report.

For cruise ships the main risk contributors are collision and grounding, whereas for RoPax they are collision, grounding and flooding. The supporting investigations, when reviewing the risk models from GOALDS and SAFEDOR FSAs, showed that estimated risks are sensitive with respect to a small number of casualty scenarios (e.g. loss of water tightness – slow/fast sinking) and therefore estimations for the probability of slow/fast sinking as well as the percentage of fatalities have a significant influence on the risk level.

Evaluation of risk as recommended in the FSA guidelines by FN diagram showed that the risk for cruise ships is in the ALARP region[1], where cost effective measures need to be considered for implementation. For RoPax the risk in terms of FN diagram appears partly in the

[1] Risk in ALARP region means that this risk is tolerable but not acceptable and therefore ALARP process should be applied to make it as low as reasonable practicable.

intolerable risk region. However, not all the effects of possible compliance with the Stockholm Agreement provisions on this risk pattern have been herein considered. For both ship types the evaluation by FN diagram is significantly influenced by the updated thresholds for the risk regions (negligible – ALARP – intolerable) which are a factor of eight lower than the thresholds specified in MSC 72/16 (2000) typically used in risk evaluation of previous FSAs. In this context it is mentioned that the boundaries used for distinguishing between intolerable, ALARP and negligible risk should be regarded as benchmarks and not as strict criterion. This is also supported by the comparison to other means of transport based on billion passenger kilometres and billion passenger hours, which show that RoPax vessels do not deviate considerably from other means of transport.

6 ABSTRACT

This reports summarises the work for determining the risk of passenger ships using already existing risk models. In order to determine the risk, the risk models for ship types cruise (including passenger ships that is not RoPax or HSC) and RoPax (including RoPaxRail) as developed in GOALDS or in SAFEDOR were updated with latest IHS Fairplay data on casualties and fleet development until 2012 in order to determine the risk for persons onboard (POB) of ships built in accordance with SOLAS-2009 (SOLAS damage stability) requirements. It is noted that relevant fleet at risk is not trivially compliant with the Stockholm Agreement provisions regarding the water on deck effect (WOD) on the damage stability of RoPax.

Risk is calculated in terms of potential loss of life (PLL) per ship year for reference ship sizes (three cruise and three RoPax) using updated risk models and initial accident frequencies equal to the average of the above ship types for the period 2000 to 2012. Additionally, the risk is calculated in terms of fatalities per hour, fatalities per journey, fatalities per 10^9 passenger hours and fatalities per 10^9 passenger kilometres.

The results are summarised and discussed in section 8.3.4 of this report. Evaluation of risk as recommend in FSA guidelines by FN diagram showed that the risk for cruise ships is in the ALARP region. For RoPax the risk in terms of FN diagram is partly in intolerable risk region. However it should be noted that not all the effects of possible compliance with the Stockholm Agreement provisions on this risk pattern have been herein considered. For both ship types the evaluation by FN diagram is significantly influenced by the updated thresholds for the risk regions (negligible – ALARP – intolerable) which are a factor of eight lower than the thresholds specified in MSC 72/16 (2000) typically used in risk evaluation of previous FSAs.

7 INTRODUCTION

The risk of persons on board of passenger ships was in focus of different investigation for intance the FSAs carried out on cruise ships and RoPax vessels within the research project SAFEDOR. Additionally, studies of single risk contributors are carried out in order to determine and evaluate risk mitigating measures considering limited number of causes, for instance GOALDS which was dedicated to damage stability.

This task of EMSA III project is focused on determining the risk of passenger ships using already existing risk models. In order to determine the overall risk of persons on board of the ship types Cruise (including passenger ships) and RoPax(including RoPaxRail), the risk models as developed in GOALDS or in SAFEDOR were updated with latest (2012) IHS Fairplay data on casualties and fleet development in order to determine the risk for people onboard of ships built in accordance with SOLAS-2009 (SOLAS damage stability) requirements. The investigation is carried out using a statistical sample of ships of the IHS Fairplay database that follows the same selection criteria, for instance with respect to ship size, year of construction etc., as specified in GOALDS project (see section 8.1 for the selection criteria).

For determining the updated initial accident frequencies, the historical evolution of casualties over the last decades was investigated and proper time intervals were specified for the present investigation, which are regarded to be representative for the fleet status today. In this respect, the risk is calculated for reference ship sizes regarded to be representative for the current world fleet (three cruise ships and three RoPax) using updated risk models and initial accident frequencies equal to the average of the period 2000 to 2012.

For discussing the risk, we are introducing and determining various risk terms like potential loss of life (PLL) per ship year, FN diagram, fatalities per hour, fatalities per journey, fatalities per billion passenger kilometres or fatalities per billion passenger hours. Risk is dicussed by comparing it with respect to tolerability using the FN diagram and updated values for specifying the regions of intolerable, ALARP and negligible risk. Furthermore, the risk in terms of fatalities per billion passenger kilometres and fatalities per billion passenger hours is compared to the risk of other transport means.

8 MAIN PART OF THE REPORT

8.1 Basic Information

In order to determine accident frequencies representative for pure passenger ships (Cruise and Passenger ships) as well as RoPax vessels, casualty reports were selected from the IHS Fairplay casualty database for the following ship types identified in (Table 8.1). Casualty reports have been selected using the same filtering criteria specified for the GOALDS (2009-2012) project:

- Accident categories collision (CN), contact (CT), grounding (GR) (also designated Wrecked/Stranded), fire & explosion (FX) and foundering (FD);
- Ship types: Cruise (representative for cruise and passenger ships) and Ro-Pax (representative for RoPax and RoPaxRail);
- GT ≥ 1000 – most ships below GT 1000 operate on non-international voyages;
- ≥ 80 m length (L_{OA}) - most ships below 80 m in length operate on non-international voyages;
- Built ≥ 1982;
- Accidents in the period 1994-01-01 and 2012-12-31;
- IACS class at time of accident – to reduce the potential effect of under reporting;
- IACS class for determination of ship years;
- Froude No. ≤ 0.5 – to eliminate High Speed Craft (HSC) from the study.

Deviating from the previous investigation in GOALDS, accidents of the category *contact* have been considered for further review due to the fact that the accident of the *Costa Concordia* was assigned to this category[2]. These casualty reports were reviewed and re-assigned to accident categories if necessary in order to have a consistent consideration of accidents in the risk model. Furthermore and with the objective to determine the total risk of persons on board of ship types under consideration casualty reports of the accident categories fire & explosion, hull machinery and foundering were considered in order to update the risk models considered for this investigation.

All casualty reports collected for CN, CT and GR were carefully reviewed and formed the basis for the development of a database suitable for the risk analysis of the present investigation (see Annex A of this report).

[2] As an alternative to grounding

Table 8.1: IHS Fairplay Statcode and ship type description for ship types considered in this investigation

Ship type	Level5Decode	Description	IHS StatCode
Ro-Pax	Passenger/Ro-Ro Ship (Vehicles)	A ro-ro cargo ship with accommodation for more than 12 passengers	A36A2PR
Ro-Pax-Rail	Passenger/Ro-Ro Ship (Vehicles/Rail)	A ro-ro cargo ship for the additional carriage of rail-vehicles and with accommodation for more than 12 passengers	A36A2PT
Cruise	Passenger/Cruise	A vessel certificated to carry more than 12 passengers, all of whom may be accommodated in cabins	A37A2PC
Pax	Passenger Ship	A vessel certificated to carry more than 12 passengers, some of whom may be accommodated in cabins	A37B2PS

8.1.1 Fleet at Risk

In order to characterise the fleets of both ship types under consideration, some basic analyses of fleet data are summarised in the following for the different fleets at risk and the sample used for the subsequent determination of accident frequencies in the investigation period. For instance, such characteristics are the number of ships or the annual growth rate (indicating the introduction into world fleet of recent changes in regulations). It should be mentioned that for later risk analysis two ship type categories will be used, one consisting of Cruise and passenger ships, the other consisting of RoPax and RoPaxRail, and therefore relevant data will be merged.

8.1.1.1 Cruise Ships

In total 266 cruise ships (≥ 1,000 GT; ≥ 80 m, built after 1981, no HSC) were reported to be active between 1982 and 2012. Of these 258 vessels are classed by an IACS society. The development of the Cruise ship fleet in terms of number of ships and annual relative growth rate is shown in Fig. 8.1 using the criteria summarised above. As shown the Cruise ship world fleet grew continuously in the observation period (doubling its number every decade after 1990) and today comprises nearly 250 ships or about five times the number of 1990. In the same time the fleet size in terms of gross tonnage grew by a factor of 13 and in terms of passenger capacity by a factor of 12 (Fig. 8.2). The average ship size in 1990 was about 26,000 GT with number of passengers of 1,000; until 2000 the average ship size increased by nearly 70% and of passenger capacity by 50%. Between 1990 and 2012 a similar growth with respect to gross tonnage and passenger capacity is observed yielding a total passenger capacity of nearly 490,000. Finally, the number of ship years plotted versus year is shown in Fig. 8.3 providing also detailed data for each year. The cumulative number of ship years over the reporting period 1990-2012 is 3404 considering ships complying with selection criteria. Compared to FSAs of other ship types this number of ship years is relatively small, for instance for containerships the number of ship years for this period is about 15 times higher.

In this context it is therefore mentioned that such small number of ship years has an influence on the certainty of the results which has to be considered when interpreting the results.

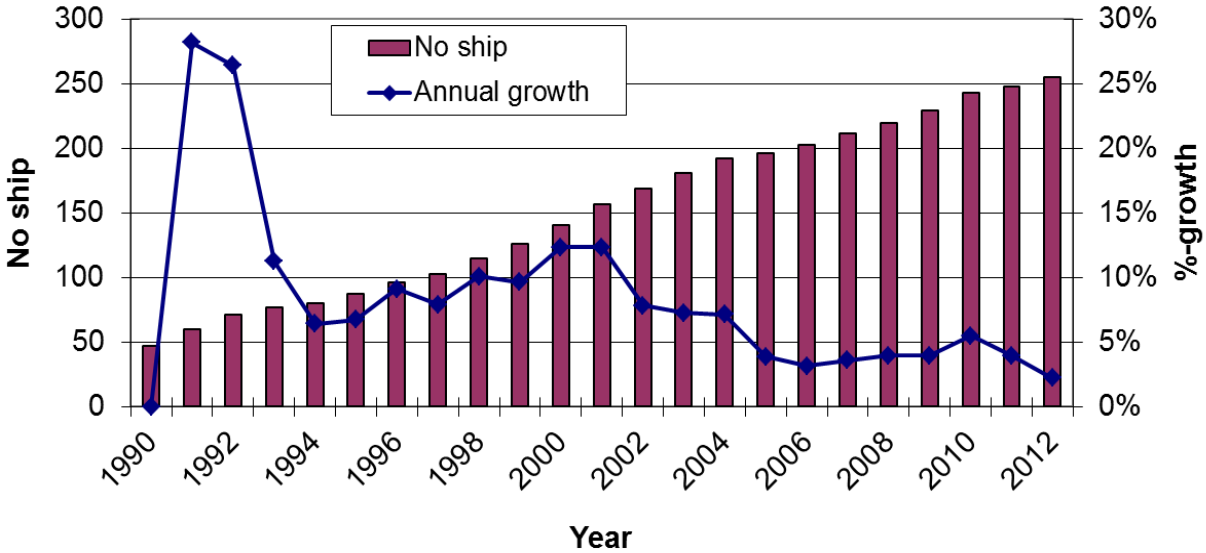


Fig. 8.1: Development of Cruise ship fleet considering ships ≥ 1,000 GT; ≥ 80 m, built after 1981 (excluding HSC) and only IACS class in terms of number of ships vs. year and annual growth rate.

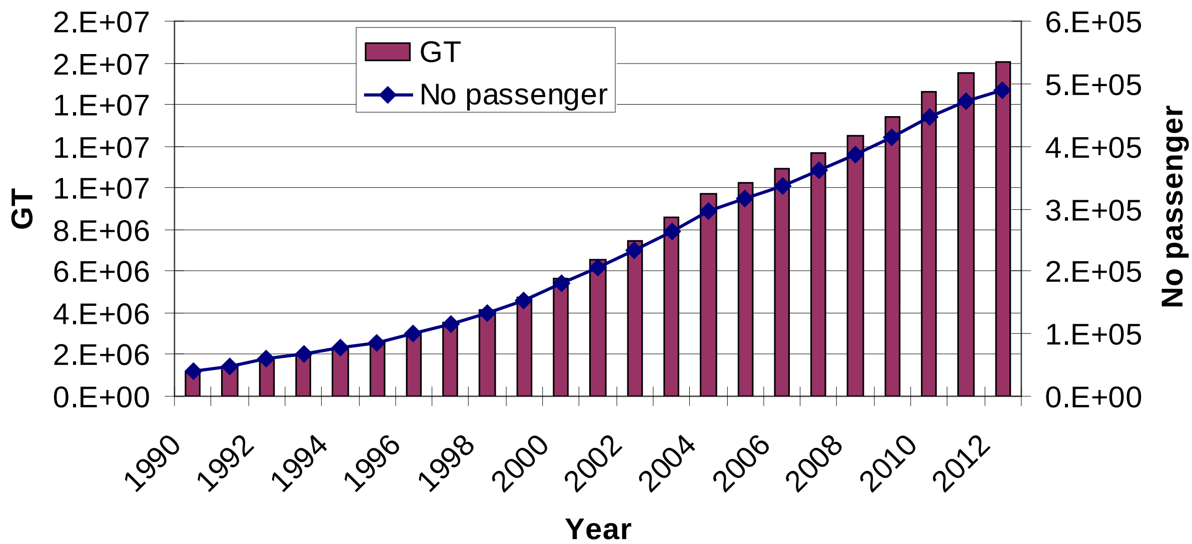
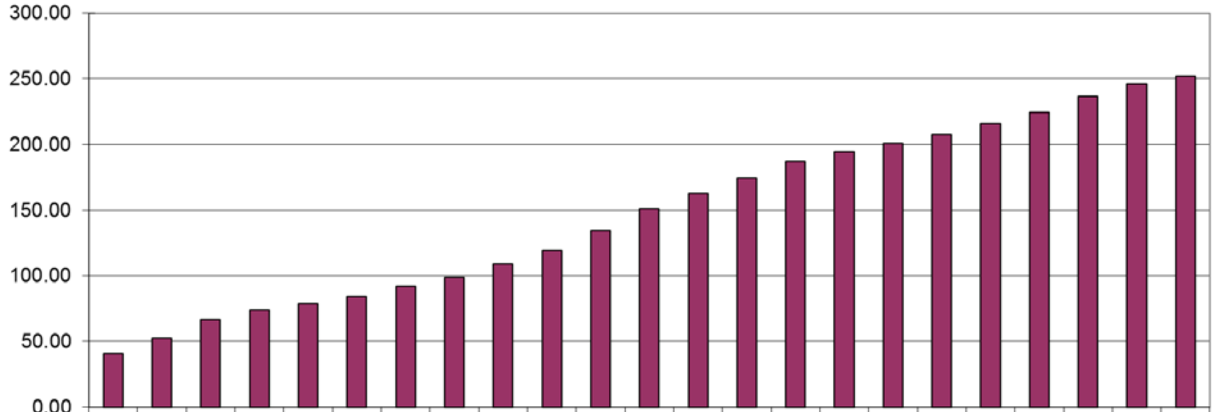


Fig. 8.2: Development of Cruise ship fleet with respect to gross tonnage and passenger capacity (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ship years	41.09	52.67	66.59	74.08	78.84	84.16	91.83	99.08	109.0	119.5	134.3	150.9	162.7	174.5	187.0	194.3	200.5	207.6	215.9	224.5	236.8	246.2	251.7

Fig. 8.3: Number of ship years per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising Cruise ship fleet by ship's nominal passenger capacity, the following can be observed (Fig. 8.4, Fig. 8.5 and Fig. 8.6):

- The larger part of Cruise ship fleet is coming from ships having a passenger capacity of 1,500-2,500 persons.
- Cruise ships carrying 2,500-3,500 passengers are the second largest part of Cruise operational ship fleet.
- Cruise ships with passenger capacity larger than 4,500 persons appeared after 2009 thus the particular capacity presents the higher percentage of growth.

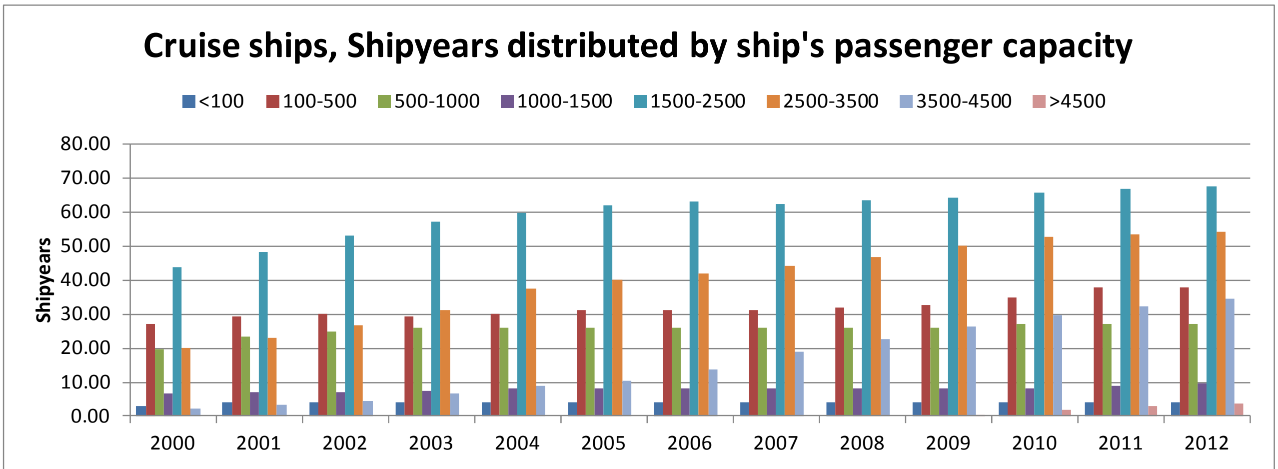


Fig. 8.4: Number of ship years per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

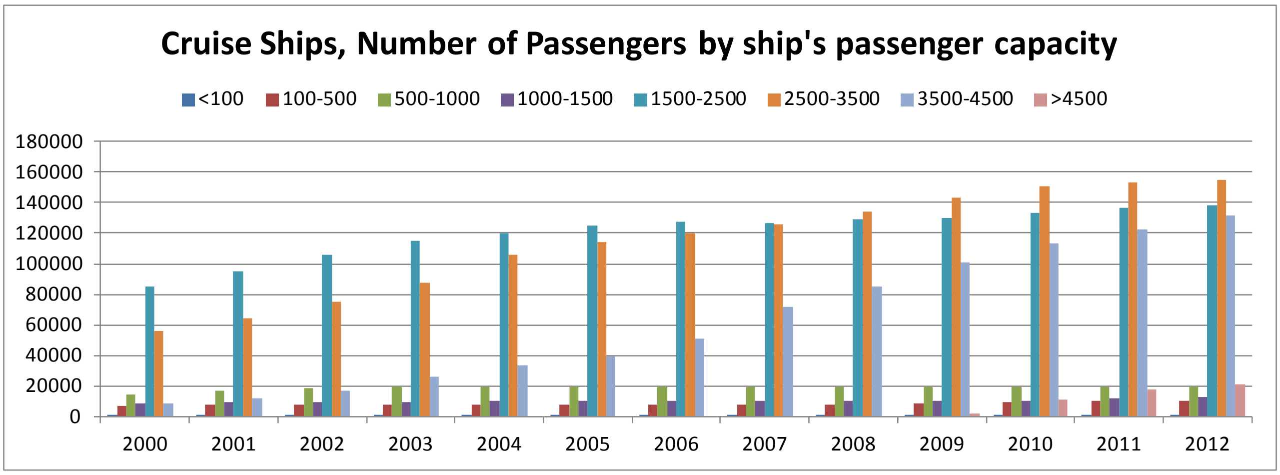


Fig. 8.5: Number of Passengers per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

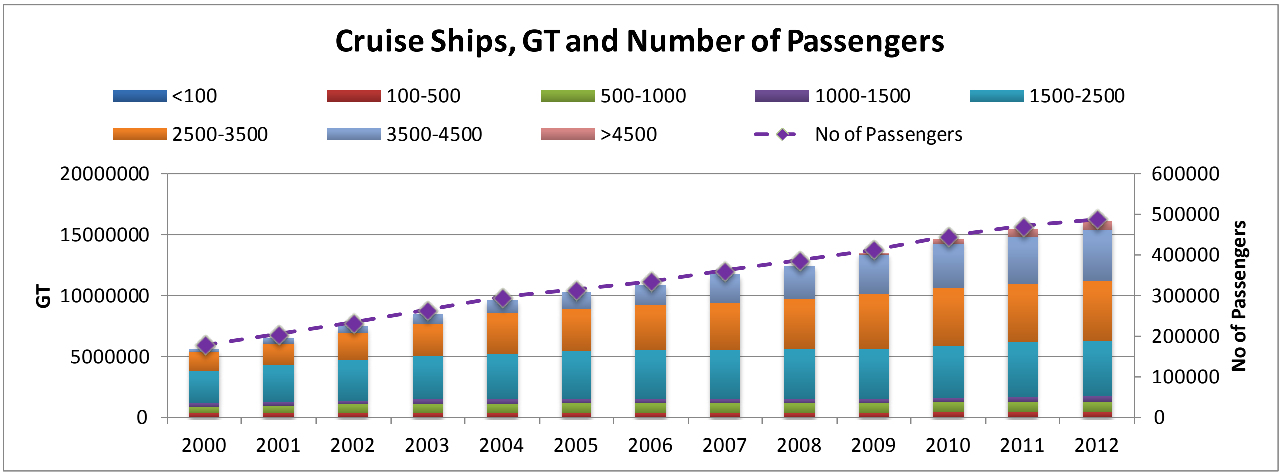
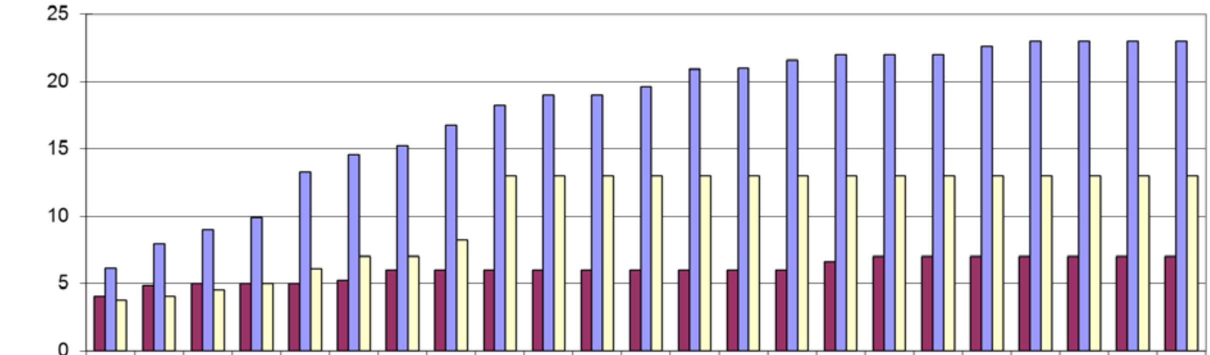


Fig. 8.6: GT and Number of Passengers per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

8.1.1.2 Passenger Ships

The number of pure passenger (no High Speed Craft, no cruise and RoPax) ships built after 1981, ≥ 1,000 GT, with a length ≥ 80 m, is 32 and thus significantly smaller than that for Cruise ships. Majority of this small world fleet is classed by non-IACS societies (22) or other organisations (7). With respect to gross tonnage (< 14,000) and passenger capacity (< 1,750) IACS passenger ships are smaller than IACS Cruise ships. Similar observations were made with respect to ships in other subsets. All ships are below 150 m of length. For the period 1990 to 2012 the number of ship years has been plotted in Fig. 8.7 considering subsets "IACS", "Non-IACS" and "Empty". The cumulative number of ship years for 1990 to 2012 is 139 ship years ("IACS" class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	4	5	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7
Non IACS	6	8	9	10	13	15	15	17	18	19	19	20	21	21	22	22	22	22	23	23	23	23	23
EMPTY	4	4	5	5	6	7	7	8	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13

Fig. 8.7: Number of ship years versus year for Passenger ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).

The comparison between Cruise and passenger ships fleet shows that the latter will contribute only marginally to a merged category.

8.1.1.3 RoPax Ships

In total IHS-Fairplay shipregister contains 735 vessels built after 1981, ≥ 1,000 GT and an L_{OA} ≥ 80 m of which 485 currently classed by an IACS society and 48 for "Non-IACS" society and 202 for "other organisations". The development between 1990 and 2012 of world RoPax fleet in terms of number of ships is shown in Fig. 8.8. Additionally the annual growth rate is plotted.

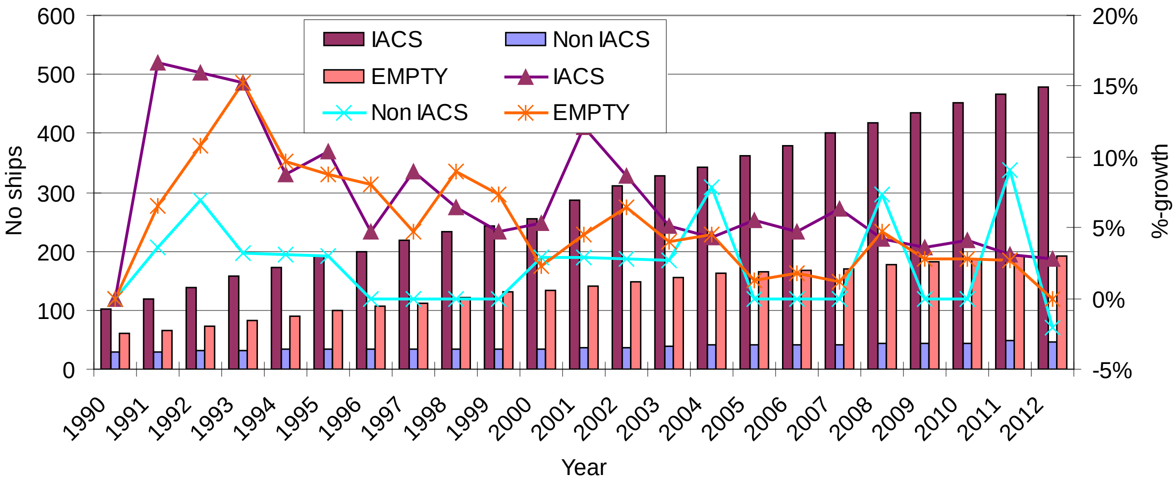


Fig. 8.8: Development of world RoPax fleet classified in categories "IACS", "Non-IACS" and "EMPTY[3]" (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, no HSC).

Since 1990 the RoPax fleet classed by IACS societies has grown by about 370 vessels (~370%) which is higher than the growth (total and relative) of the other subsets of "Non-IACS" and "EMPTY" (~210%; ~70%). The average annual growth rate for IACS classed ships is about 5%

[3] EMPTY, mean no information with respect to class is being given in the IHS-Fairplay ship register

since 2003 which is equivalent to an annual newbuilding rate in the last decade between 14 and 24 vessels.

As shown by Fig. 8.9 the subset of Non-IACS ships contains mainly vessels smaller than or equal to 10,000 GT (77%), whereas for IACS ships 63% are between 10,000 and 40,000 gross tonnes. An investigation of the average ship size of the fleet with respect to gross tonnage showed that the gross tonnage per ship increased since 1990 by about 30% or by 5,000 GT to ~20,000 tonnes in 2012.

This difference was also determined for the ship length in terms of L_{OA} (Fig. 8.10). In the IACS subset the majority of ships have a length between 150 m and 200 m, whereas for the other subset nearly 80% are shorter than 150 m. With respect to number of ships in different passenger categories both subsets showed only minor differences (Fig. 8.11). All three subsets show no change in average ship size in terms of passenger capacity between 1990 and 2012 ("IACS" ~ 1000; "Non-IACS" ~ 700; "EMPTY" ~600).

For the average age of the ships an increase from five to six years in 1994 to 14 to 16 years in 2012 was observed. Due to the fact that normal ship life is expected to be about 25 years this observation was expected (considering only ships built after 1981). The average age of the ships in both subsets differ by about two years whereas ships of IACS subset are younger.

The number of ship years per year distributed over the three subsets considered is plotted in Fig. 8.12. IACS classed ships contribute more than 60% of all ship years with slightly increasing percentage towards the end of the observation period (~67% in 2012).

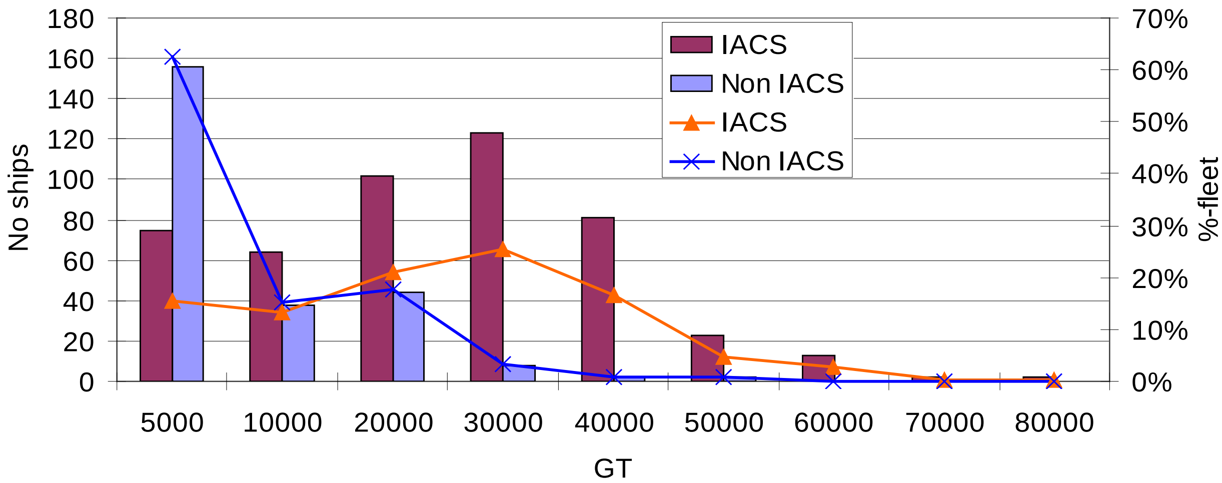


Fig. 8.9: Number of RoPax ships in different size categories (GT) and relative distribution for each subset for "IACS" and "Non-IACS" class ships.

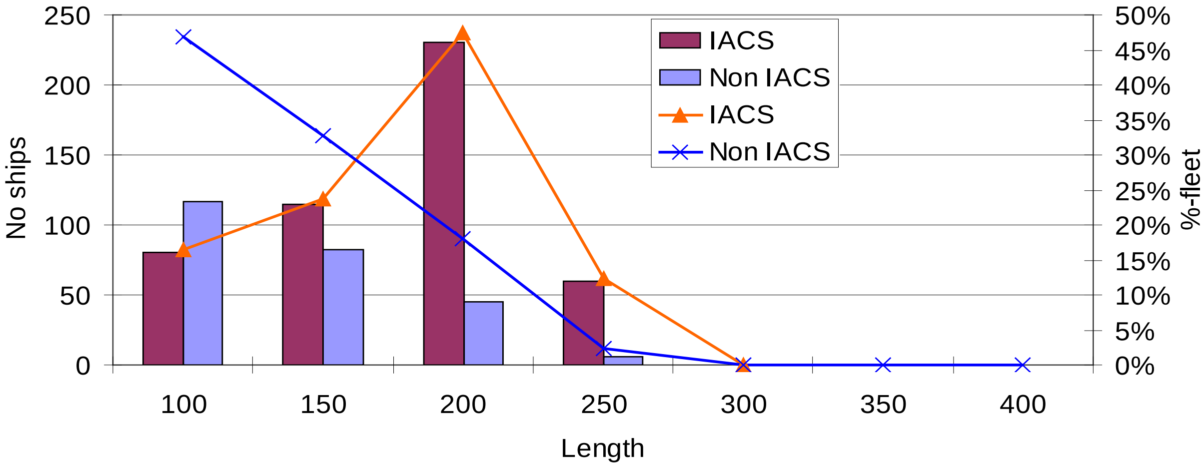


Fig. 8.10: Number of RoPax ships in different size categories (LOA) and relative distribution for each subset for "IACS" and "Non-IACS" class ships.

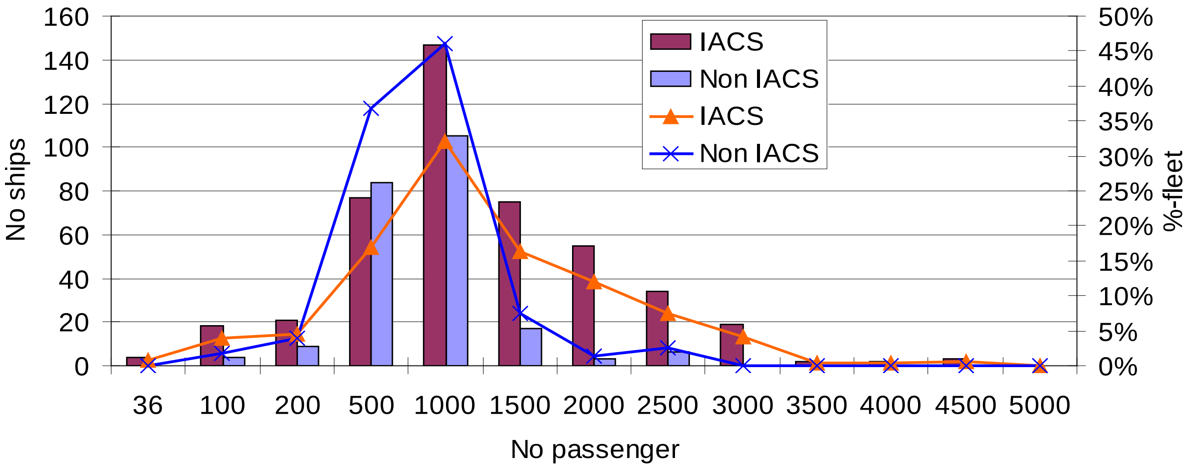
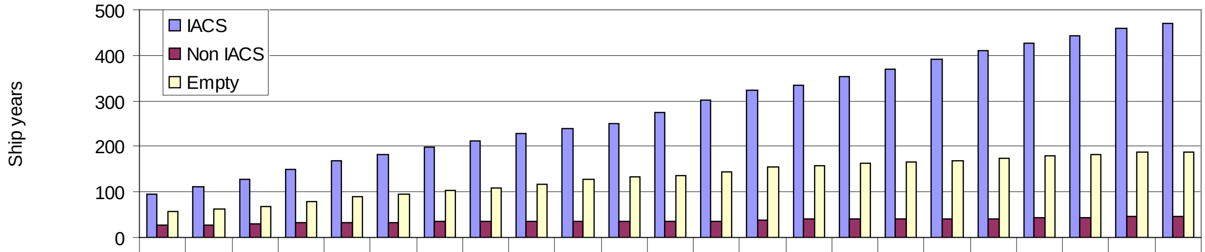


Fig. 8.11: Number of RoPax ships in different size categories (no passenger) and relative distribution for each subset for "IACS" and "Non-IACS" class ships.

The development of the fleet with respect to ship years considering "IACS" and "Non-IACS/EMPTY" class as well as the values for each year are summarised in Fig. 8.12. The cumulative number of ship years between 1994 and 2012 for RoPax ships is 6520 ("IACS" class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	94	112	129	150	168	182	198	211	228	238	249	275	302	322	334	353	371	392	411	426	443	459	471
Non IACS	27	28	30	32	33	34	34	34	34	34	34	35	36	37	40	41	41	41	42	44	44	47	47
Empty	58	64	68	80	88	95	103	109	118	127	133	137	145	154	159	163	167	168	174	180	183	187	189

Year

Fig. 8.12: Number of RoPax ship years for each subset for "IACS" and "Non-IACS" class ships.

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising RoPax fleet by ship's nominal passenger capacity, the following can be observed (Fig. 8.13, Fig. 8.14 and Fig. 8.15):

- The larger part of RoPax fleet is coming from ships having a passenger capacity of 500-1,000 persons and it is continuously increasing over the years.
- RoPax ships carrying 1,000-1,500 passengers is the second larger part of RoPax operational ship fleet.
- Growth rates vary up to 10% after year 2005 with respect to the ships up to 2,500 passengers.
- In annual base, the largest number of passengers is carried by RoPax ships with passenger capacity in the range of 1,500-2,500.

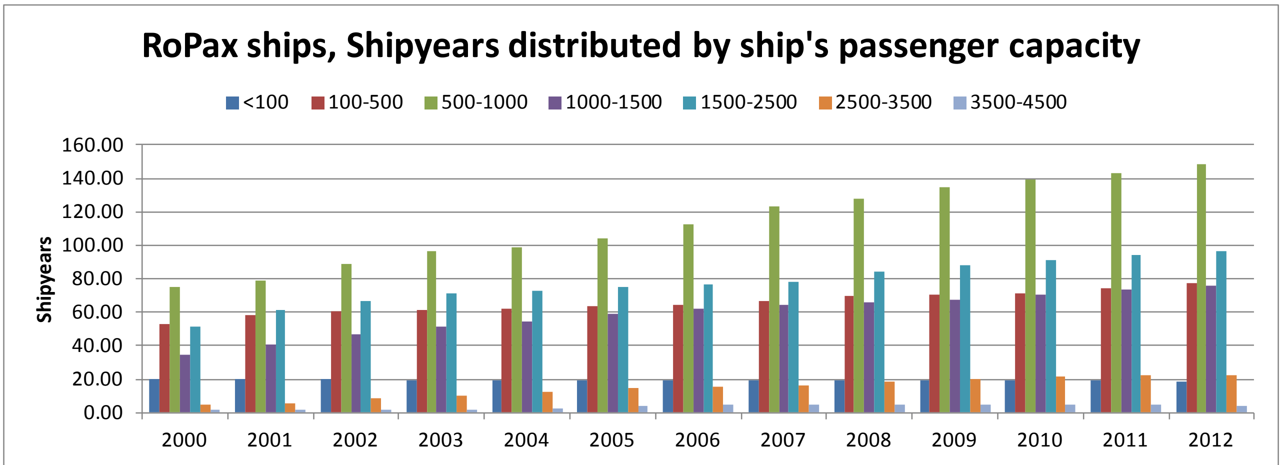


Fig. 8.13: Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

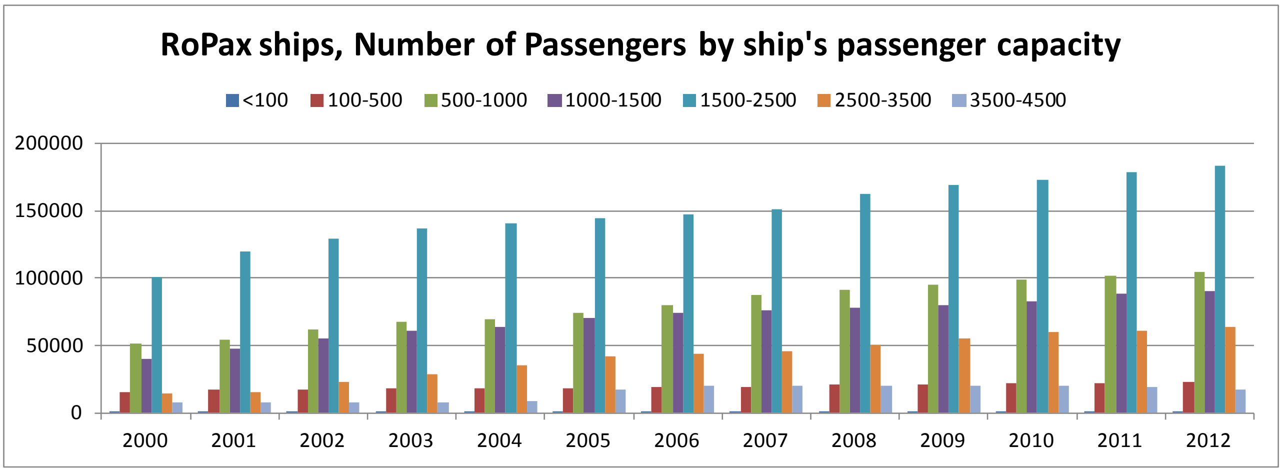


Fig. 8.14: Number of Passengers per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

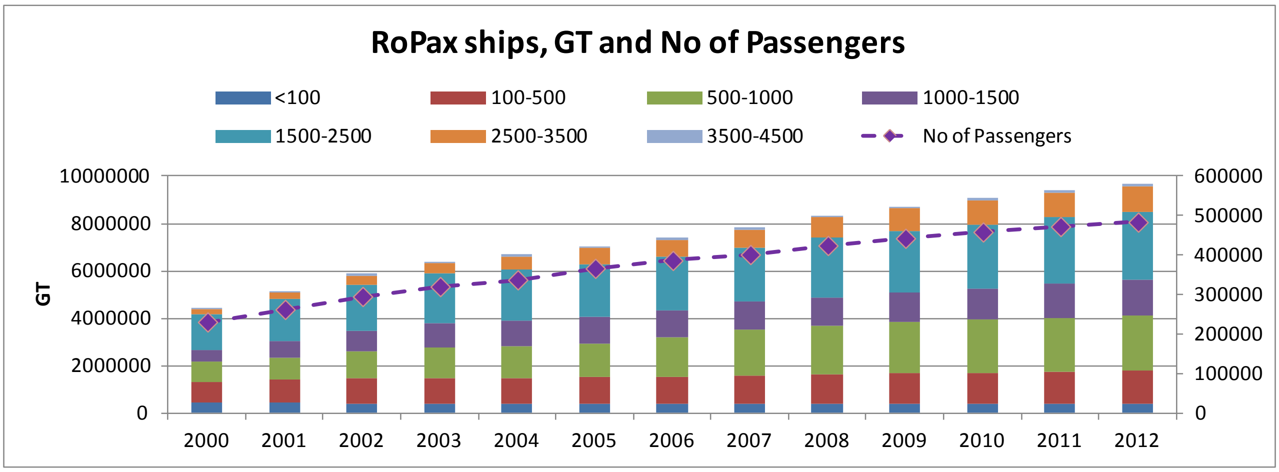


Fig. 8.15: GT and Number of Passengers per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

8.1.1.4 RoPaxRail Ships

The fleet at risk between 1982 and 2012 of RoPaxRail ships satisfying the selection criteria with respect to length, gross tonnage and year of delivery was determined to 47 vessels of which ~94% are classed by an IACS society. The development of the fleet with respect to number of ships after 1990 is shown in Fig. 8.16. Comparison between Fig. 8.8 and Fig. 8.16 shows that RoPaxRail fleet is about one tenth of RoPax fleet (IACS class ships). The annual newbuilding rate of the last decade is between zero and two vessels.

The structure of the fleet with respect to gross tonnage, length and number of passengers is shown in Fig. 8.17, Fig. 8.18 and Fig. 8.19. Compared to RoPax ships(IACS classed), large RoPaxRail vessels with more than 30,000 GT are very few, and like RoPax the majority of vessels (~70%) has a gross tonnage between 10,000 and 30,000 (RoPax 46%). 25% of RoPaxRail ships are smaller than 10,000 GT which is also close to the figure for RoPax ships (IACS: 27%). An investigation of the average ship size of the fleet with respect to gross tonnage showed that it increased since 1990 by about 25% or 3,000 GT to ~16,000 tonnes in 2012.

Also with respect to ship length the fleets of both ship types have large similarities and the typical ship has a length between 150 m and 200 m (RoPaxRail: ~60%; RoPax: ~47%). Finally, passenger capacity of both fleets show similar characteristics and the vast majority of ships can transport between 200 and 1,500 passengers (RoPaxRail: ~80%; RoPax: ~75%).

The number of ship years per year for RoPaxRail ships over the period 1990 to 2012 is plotted in Fig. 8.20. In total 805 ship years were reported which is about 12% of the IACS RoPax fleet.

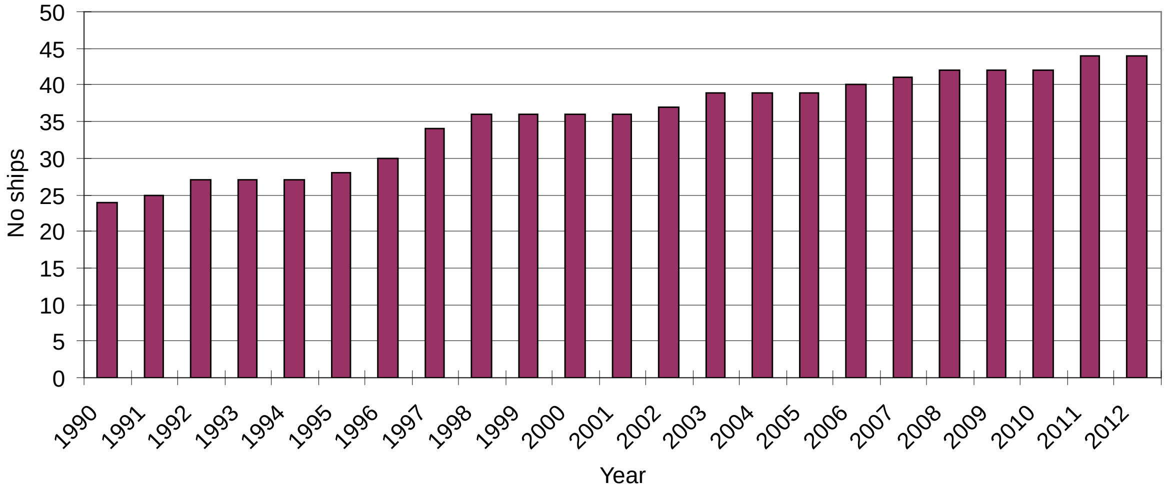


Fig. 8.16: Development of world RoPaxRail fleet after 1990 and IACS class ships only (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, no HSC).

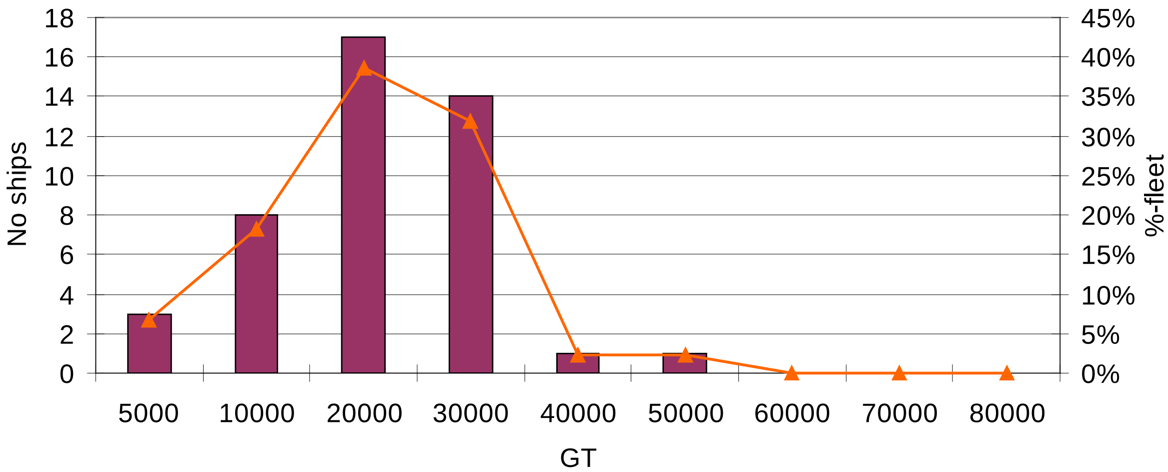


Fig. 8.17: Number of RoPaxRail ships in different size categories (GT) and relative distribution for IACS class ships.

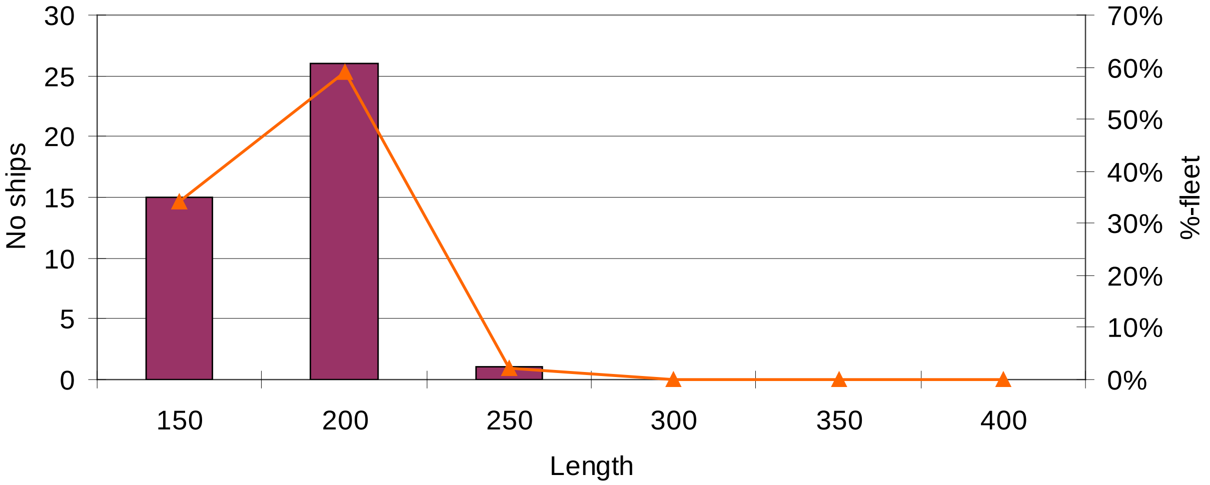


Fig. 8.18: Number of RoPaxRail ships in different size categories (LOA) and relative distribution for IACS class ships.

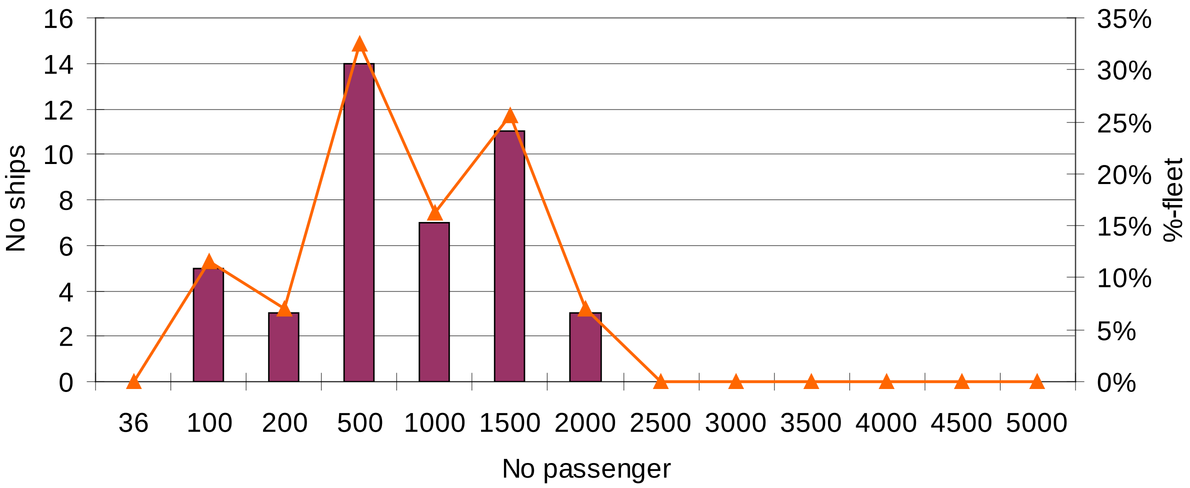
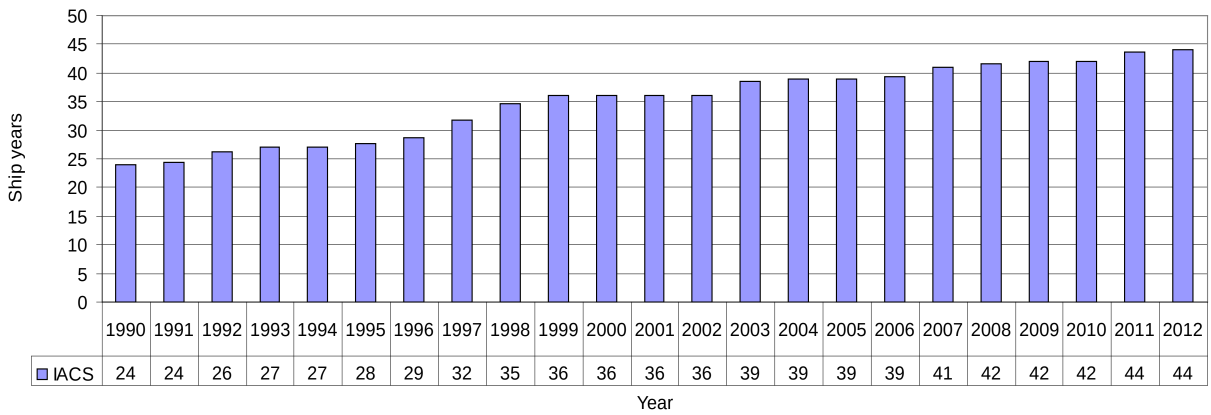


Fig. 8.19: Number of ships in different size categories (no passenger) and relative distribution for IACS class RoPaxRail ships.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	24	24	26	27	27	28	29	32	35	36	36	36	36	39	39	39	39	41	42	42	42	44	44

Fig. 8.20: Number of ship years per year for IACS class RoPaxRail ships.

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising RoPaxRail ship fleet by ship's nominal passenger capacity, the following can be observed (Fig. 8.21, Fig. 8.22 and Fig. 8.23):

- The major part of RoPaxRail fleet is coming from ships having a passenger capacity of 100-500 persons.
- The fleet of RoPaxRail ships carrying 1000-1500 passengers is the second largest part of RoPaxRail operational ship fleet.
- In annual base, the largest number of passengers is carried by RoPaxRail ships having a passenger capacity in the range of 1,000-1,500.

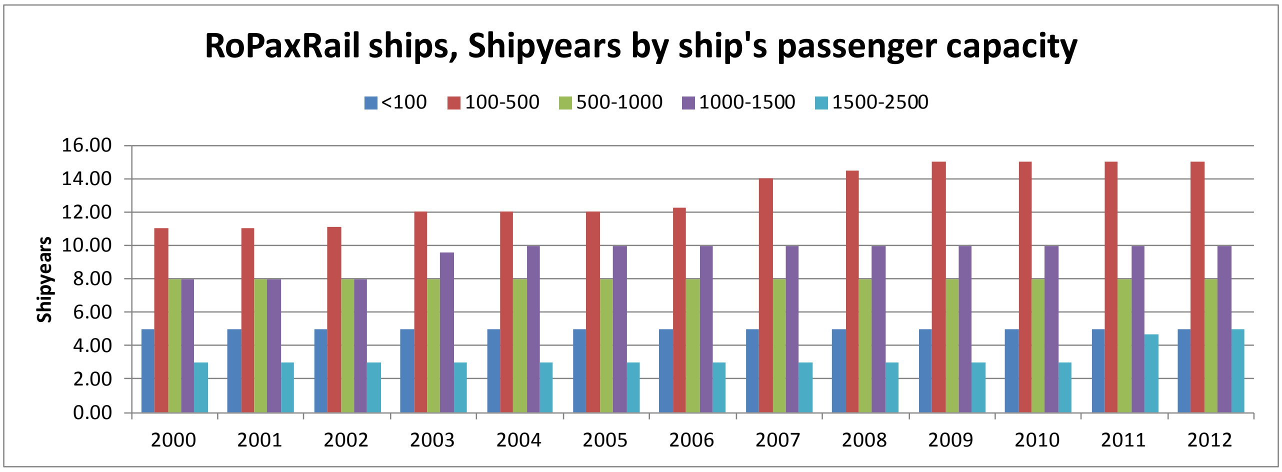


Fig. 8.21: Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

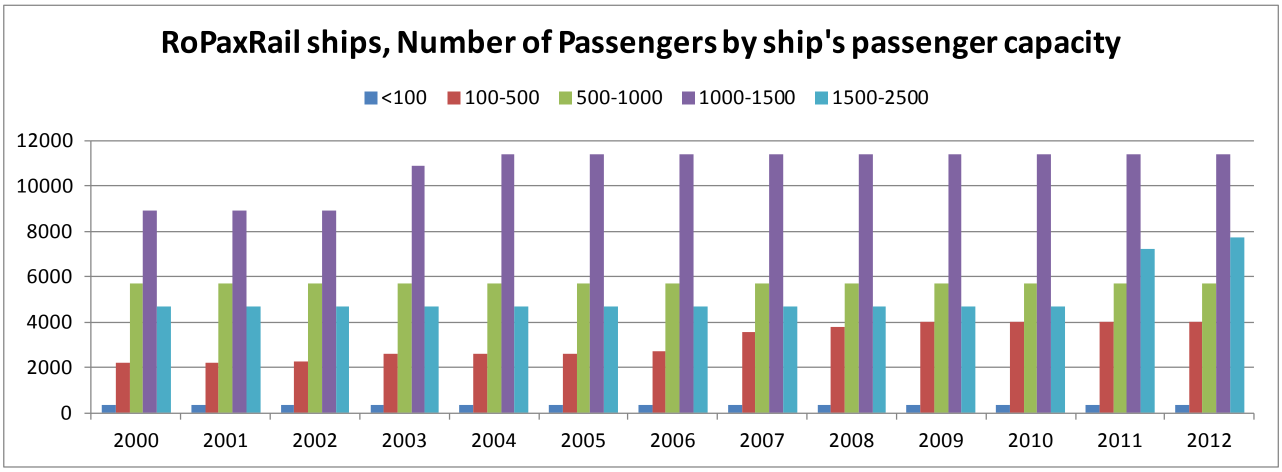


Fig. 8.22: Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

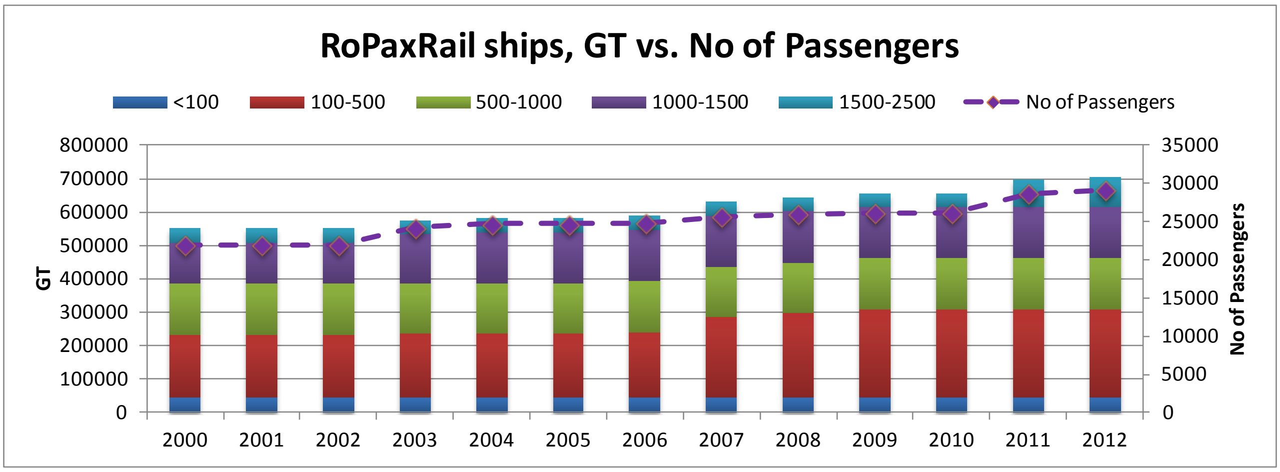


Fig. 8.23: Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

8.1.2 Casualty Reports

In the following some basic analyses of the casualty reports are summarised, focusing on the development of accident frequencies in the investigation period. The last analysis carried out in GOALDS project started with year 1994 and therefore the focus for collecting and investigating casualty reports was put on the period 1994 to 2012. The investigation considers characteristics like number of casualty reports, distribution of years, distribution over “IACS”, “Non-IACS” or “serious” and “not-serious”. It should be mentioned that the classification of casualties into serious and not-serious accidents strongly depends on the database used; for instance, in the LMIU database an event is considered serious if one of the following situations applies:

- Serious structural or machinery damage likely to result in a vessel being declared a constructive total loss
- Structural or machinery damage rendering a vessel unseaworthy or requiring extensive repairs
- Disablement or breakdown, resulting in a vessel requiring assistance of salvors or the abandonment of the voyage or a vessel being taken out of service for a reasonable period
- Any other incident resulting in damage considered serious enough to prevent a vessel from continuing in service.

Whereas the criteria in Lloyd Register Fairplay (today IHS Fairplay) use:

- Structural damage, rendering the ship unseaworthy, such as penetration of hull underwater, immobilization of main engines, extensive damage, etc.
- Breakdown
- Actual Total Loss
- Any other undefined situation resulting in damage or financial loss which is considered to be serious.

Furthermore, it was already observed in the GOALDS project that the ratio between serious and not serious casualties in LMIU be about 1:4, whereas the IHS Fairplay database contains more serious than not serious casualties. This difference is caused both by the approach of collection of casualty data, as well as by the different definition of the two categories.

The number of casualty reports and representative periods used for the risk analysis will be specified in section 8.3 below.

8.1.2.1 Cruise

Collision

For Cruise ships 23 collision accidents were reported consisting of 18 serious and 5 not serious classified accidents. All except one accident (not serious) were reported for IACS class ships. The distribution of accidents over the period under consideration is shown in Fig. 8.24. As shown by this plot nearly all accidents were reported for the period 2001 to 2012[4]. Vast majority of collision accidents (75%) occurred during operation in port/harbour/dock areas. Also, close to 79% of the recorded serious collisions happened in the last 6 years of the reporting period.

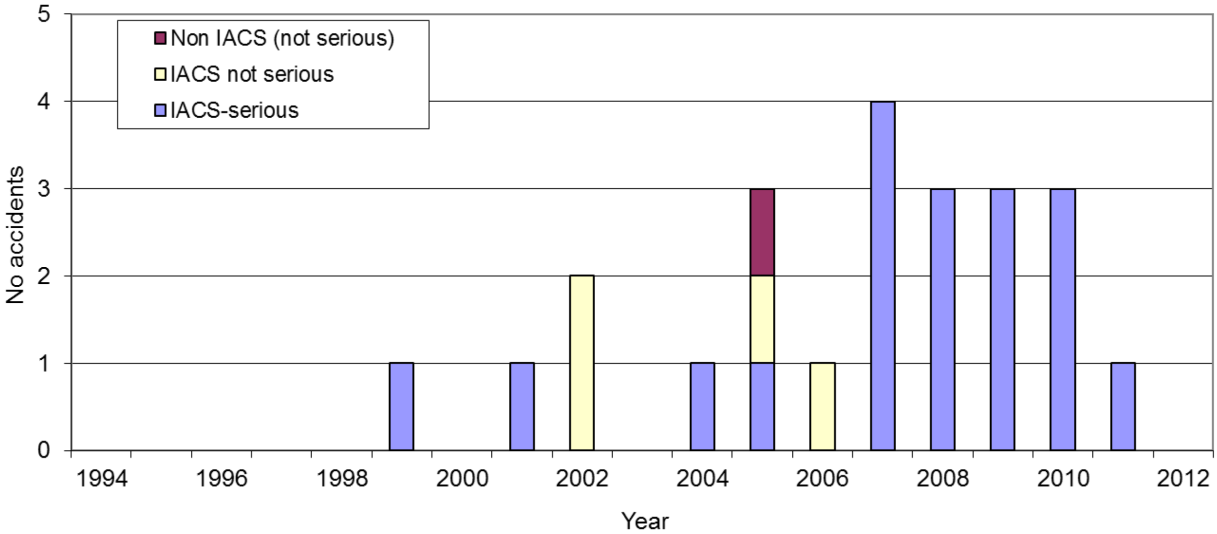


Fig. 8.24: Distribution of CN (serious and not serious collision) accidents between 1994 and 2012 distinguishing IACS and Non IACS cruise ships.

Contact

In total 33 contact accidents are considered of the IHS Fairplay database reports of which 24 were classified serious. Note that 17 (68%) of the serious contacts happened in the last 5 years of the reporting period [4]. Again the majority of accidents (24) occurred in port/harbour/dock areas. Like for the previous accident category the reports pertain to the period 2001 to 2012 (Fig. 8.25).

[4] The reasons for the recent increased number of *serious* CN and CTs may be attributed to increased traffic; however, there may be also some effect of different recording practice by the IHS Fairplay database provider, as observed in similar type of statistical analysis for other ship types (e.g. recent FSA on containerships)

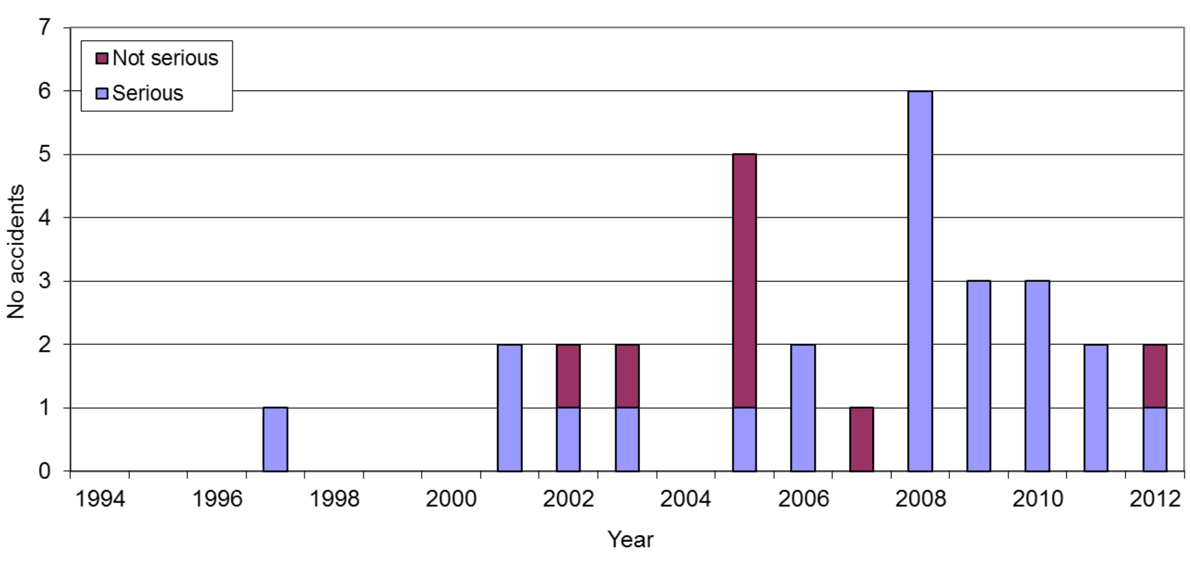


Fig. 8.25: Distribution of CT (serious and not serious contact) accidents for cruise ships between 1994 and 2012.

Grounding

For grounding IHS Fairplay database contains 30 reports of which 29 are for IACS class ships and 24 are serious (IACS 23). In contrast to collision and contact accident the accidents are more equally distributed over observation period (Fig. 8.26).

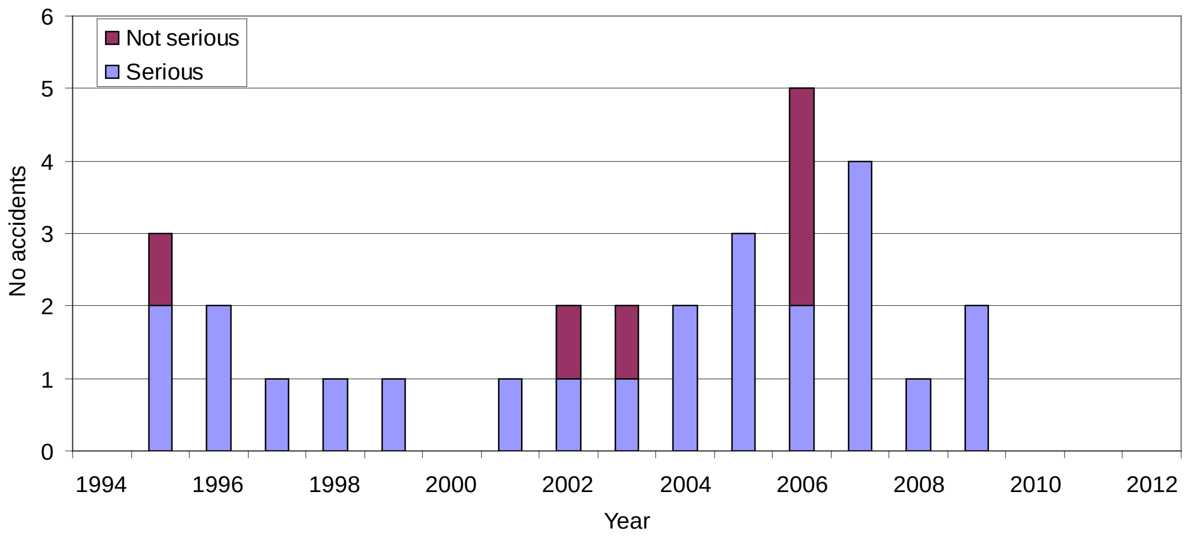


Fig. 8.26: Distribution of GR (serious and not serious grounding) accidents between 1994 and 2012 for cruise ships. One accident in 2008 was for a Non IACS ship.

Fire / Explosion

In total 36 fire/explosion accidents occurred in the period under consideration of which were 31 for IACS class ships and five for Non IACS class. The latter were all classified by IHS Fairplay as serious accidents whereas six for IACS class were in the category not serious. The detailed distribution over years is shown in Fig. 8.27. Like for groundings the accidents are mostly uniformly distributed over the whole period under consideration.

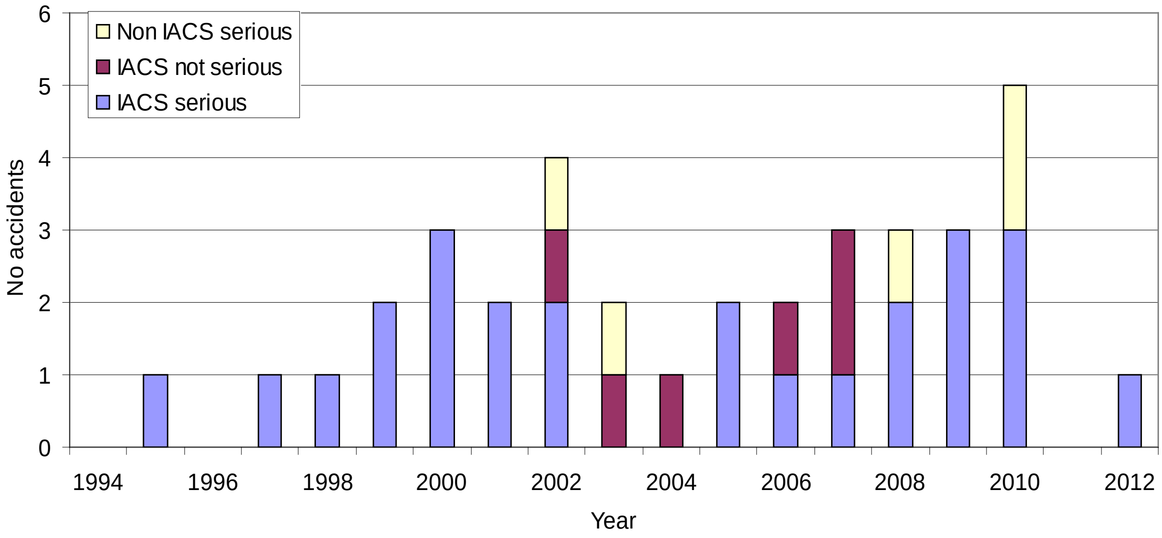


Fig. 8.27: Distribution of FX (serious and not serious) accidents between 1994 and 2012 for cruise ships.

Foundered

Only one report for a foundering accident of cruise ships in 2004 exist, which occurred in dock under construction and therefore is not considered in this investigation.

8.1.2.2 Pax

For the sample of world passenger ship fleet selected using the criteria summarised above only two collisions, one grounding and one fire/explosion were reported. Of these only one collision (1998, serious) and one fire/explosion (2012, serious) were for IACS class ships. The fire/explosion accident was during repair work and therefore is not considered further.

8.1.2.3 RoPax

Collision

In total 92 collision accidents were reported for the period 1994 to 2012 of which 74 were of IACS class ships. As shown, the annual number of accidents significantly increased after 2002 (Fig. 8.28). 65 of all accidents were classified serious (54 “IACS”).

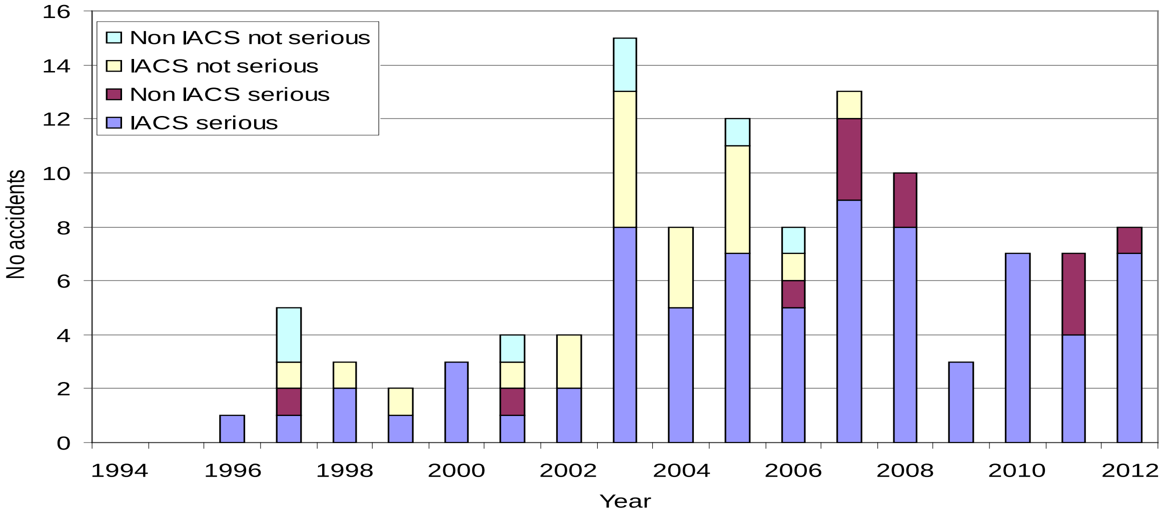


Fig. 8.28: Distribution of CN ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

Contact

IHS Fairplay reported 112 contact accidents between 1994 and 2012 ("IACS": 83) of which 102 were classified serious ("IACS": 75). The distribution over this period is shown in Fig. 8.29. Like for CN accidents significant differences between before and after the year 2000 are observed. For the period 1994 to end of 1999 IHS Fairplay reported only one contact accident, whereas for the following interval 111 were reported, thus the number has significantly increased like with the collisions[5].

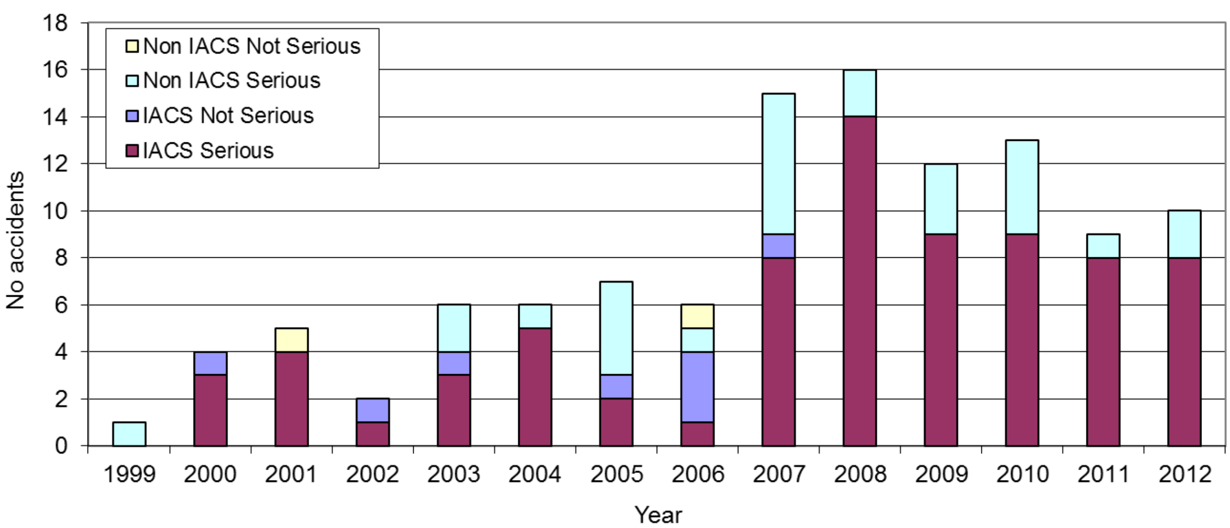


Fig. 8.29: Distribution of CT ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

[5] As mentioned before the reasons for the recent increased number of *serious* CN and CTs may be attributed to increased traffic; however, there may be also some effect of different recording practice by the IHS Fairplay database provider, as observed in similar type of statistical analysis for other ship types (e.g. recent FSA on containerships)

Grounding

55 grounding accidents were reported of which 34 were for IACS class ships (28 serious). For remaining Non IACS class ships 18 serious accidents reports were available. Of the 28 serious accidents only three were in 1990s. Again the number of reported accidents has significantly increased in the last decade.

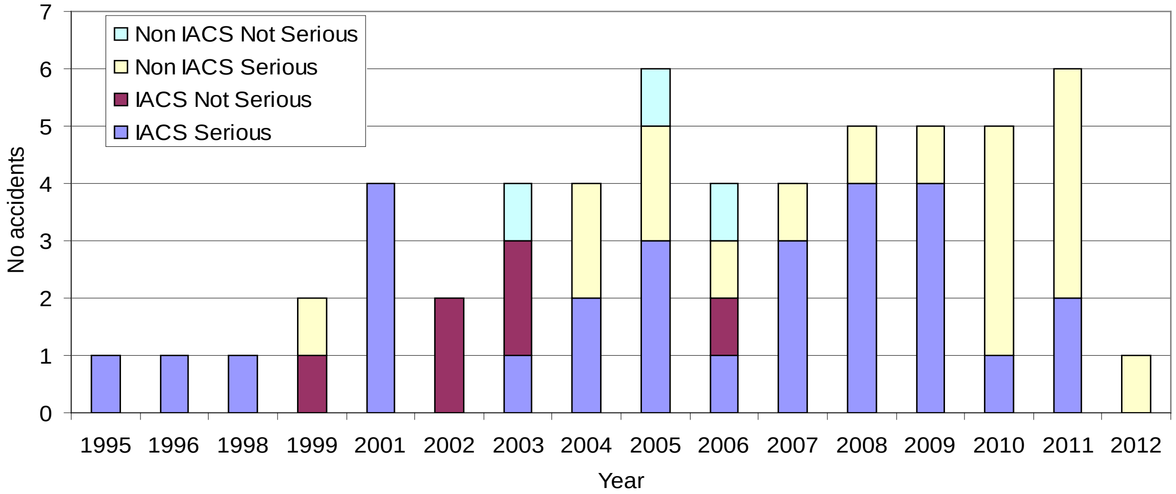


Fig. 8.30: Distribution of GR ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

Fire / Explosion

In total 62 Fire/Explosion accidents were reported for RoPax vessel (IACS and other) of which 51 were for IACS class ships. Vast majority (56) of accidents were classified "serious" by IHS Fairplay. The distribution of accidents between 1994 and 2012 is shown in Fig. 8.31.

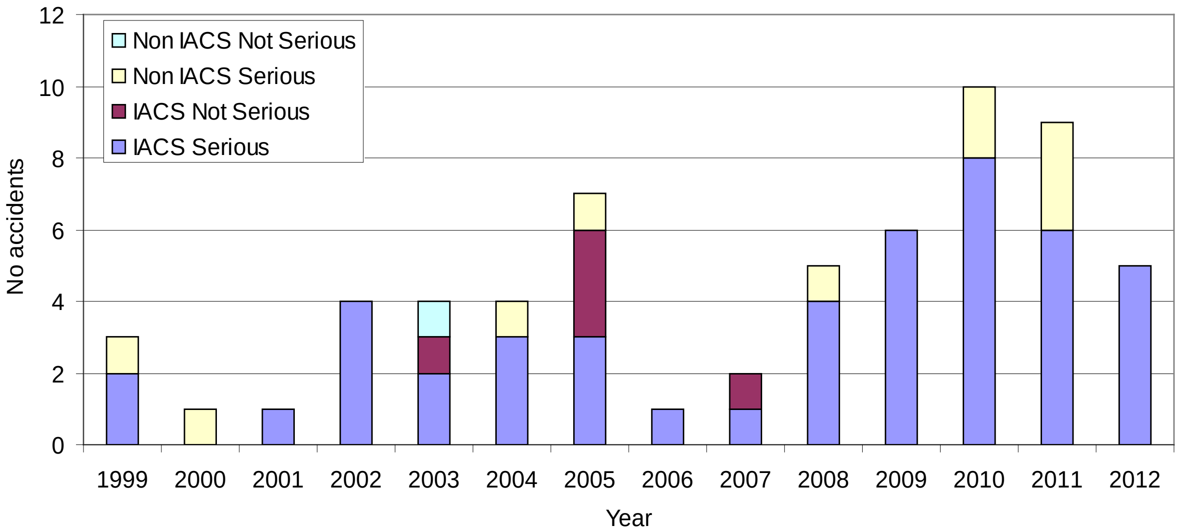


Fig. 8.31: Distribution of FX ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

Foundered

For foundering of RoPax, three casualty reports were provided by IHS Fairplay with all belonging to IACS class ships (2002, 2009 and 2012). Two of the ships were relatively small with passenger capacity of 200 or less. Two of the accidents with large ships occurred in harbour, one whilst under repair and the other at anchorage.

Hull / Machinery

In the SAFEDOR FSA for RoPax, a risk model for flooding was used considering all events where ships lost water tightness, e.g. due to leaving doors open (e.g. *Herald of Free Enterprise* type of accident, in year 1987) or structural failure (e.g. *Estonia* type of accident, in year 1994). In the IHS Fairplay database, casualty reports relating to this kind of risk may be assigned to both categories foundering (see previous section) and hull/machinery. IHS Fairplay contains 164 casualty reports of IACS class ships engaged in hull and machinery incidents. Only 21 of them are clearly related to hull damage and are distributed over time, as shown in Fig. 8.32. All were reported for the period 1997 to 2012.

A more detailed analysis of damage description given by IHS Fairplay showed that five of these accidents were damages of Ramp or internal Ramp with no potential of loss of water tightness, three were damages of bridge windows, one occurred in dock and five collect minor cracks or blocked doors (closed). Thus, seven casualty reports remained with potential of loss of water tightness and subsequent flooding ('06: 1, '07: 2, '09: 3; '10: 1); they refer to four door damages in heavy weather and en route, one hull damage in open sea, one heavy weather damage and one ramp/hold damage in heavy weather[6].

As earlier observed, the lack of recordings in earlier years of the reporting period and the increased data after year 2004 may be more attributed to the change of recording practice of the IHS database provider, rather than to genuine risk factors.

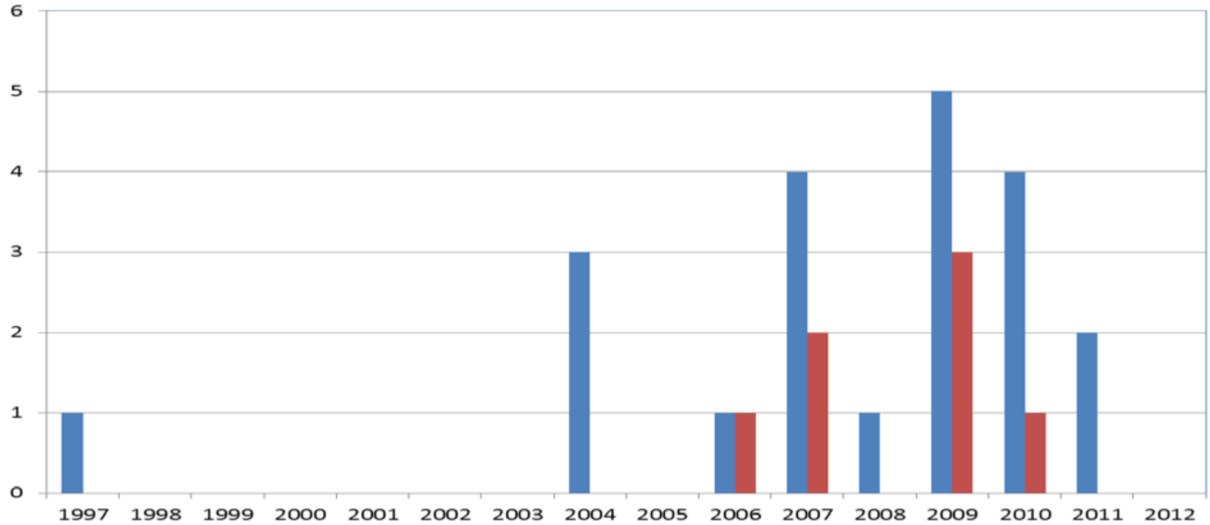


Fig. 8.32: Distribution of serious hull accidents between 1994 and 2012 for IACS class ships.

[6] In most cases, heavy weather was the initial cause of the casualty, but in none of the above cases flooding of the car deck took place (no WOD damage stability problem)

8.1.2.4 RoPax Rail

Collision

In total four accidents were reported for the period 1998 and 2012 (1998: two; 2009: one; 2012: one), of which one is categorised serious. All ships belong to category "IACS class".

Contact

For accident category contact ten accidents were reported, all serious and between 1997 and 2012 which were distributed over this period as shown in Fig. 8.33. All except that of 2003 are in the IHS Fairplay category "serious" and belong to category "IACS class".

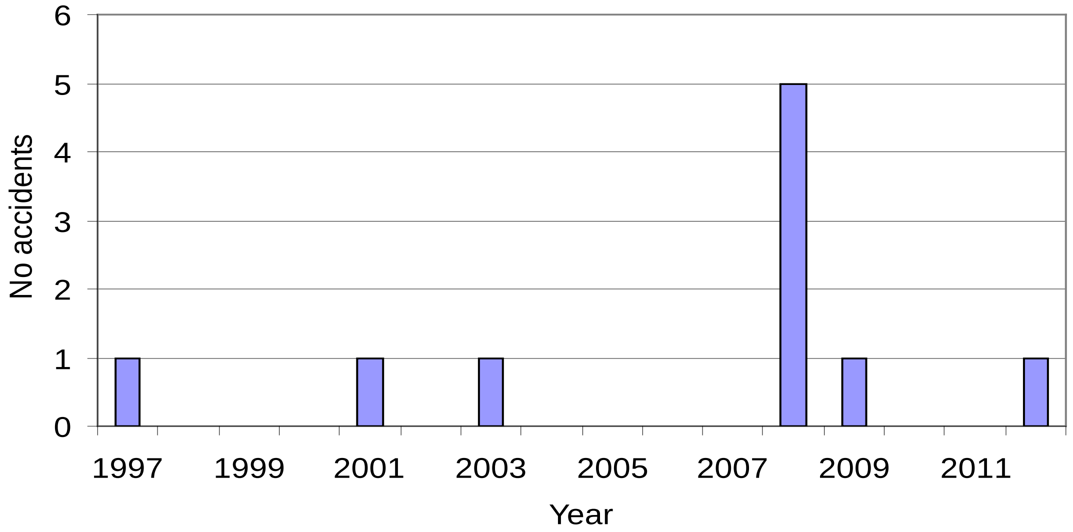


Fig. 8.33: Number of contact accidents ("serious" for RoPaxRail ships (all ships IACS class)

Grounding

Only one serious accident in 2005 is reported (IACS class).

Fire / Explosion

Between 1991 and 2012 four Fire/Explosion accidents were reported for IACS Class ships all of them classified serious.

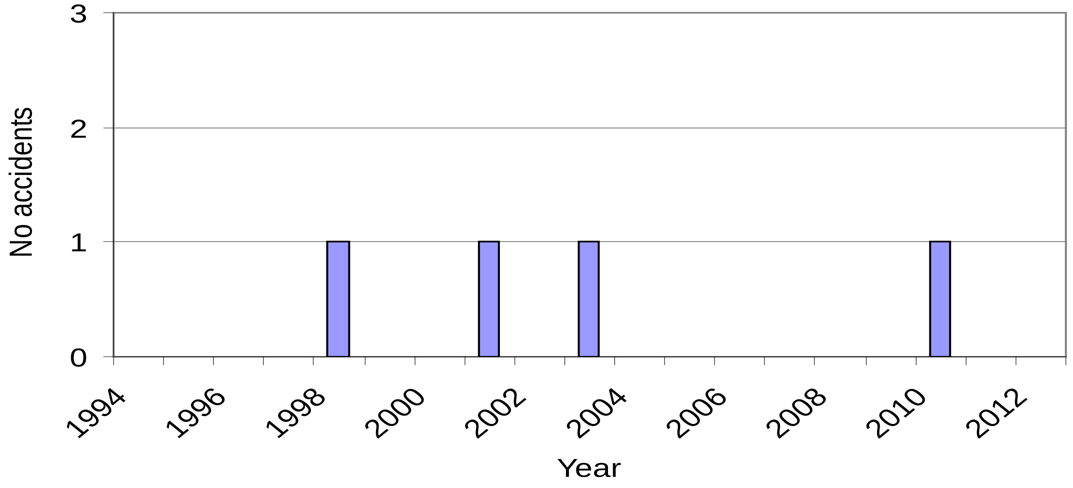


Fig. 8.34: Number of fire / explosion accidents per year for RoPaxRail ships

Foundered

No casualty reports provided by IHS-Fairplay.

Hull / Machinery

IHS Fairplay provides no hull damage related casualty reports for RoPaxRail ships.

8.2 Accident Frequencies

Two representative ship types were considered in the following *quantitative* risk analysis:

- Cruise considering cruise vessels and passenger ships;
- RoPax considering RoPax and RoPaxRail vessels.

With the basic data summarised in section 8.1 frequencies for the initial event of the different accident categories CN, CT, GR and FX were calculated and will be briefly summarised below (Fig. 8.35 and Fig. 8.36).

Cruise ship collisions were reported only after 1998 (as already mentioned in previous section) and the maximum frequency is observed for 2007. Grounding and contact accidents of cruise ships were reported over the whole period. For GR maximum annual accident frequency is calculated for 1995 and for CT in 2008, forming the highest observed frequencies among all accident categories. FX is also reported over the whole period under consideration.

The results for RoPax are similar to the development of accident frequencies for Cruise, with the CT accidents exhibit the highest frequencies with a remarkable peak in year 2008.

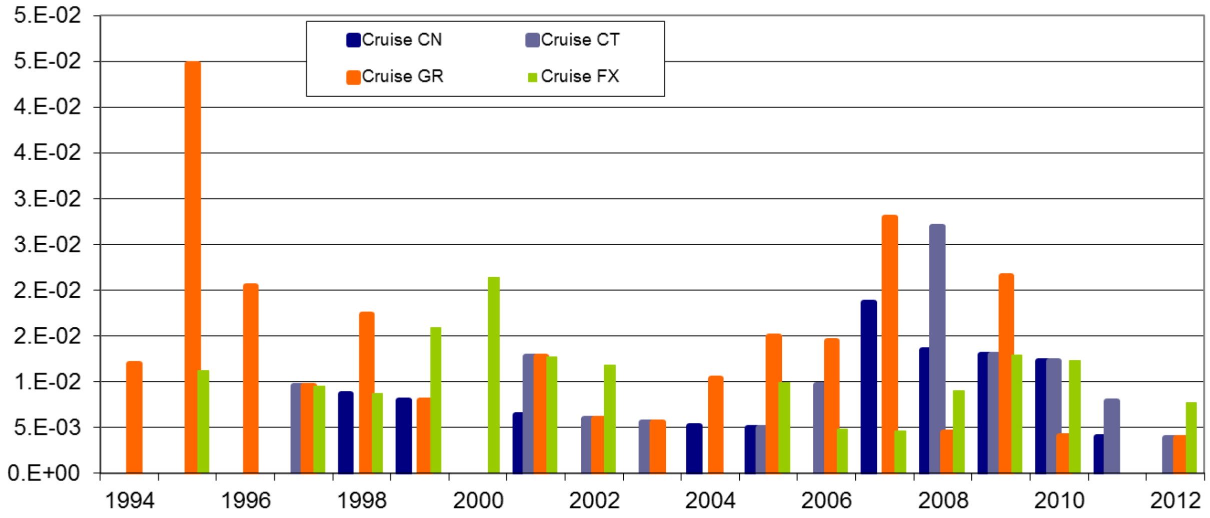


Fig. 8.35: Annual accident frequencies for ship type Cruise calculated for accident categories CN, CT, GR and FX considering only casualty reports complying with selection criteria.

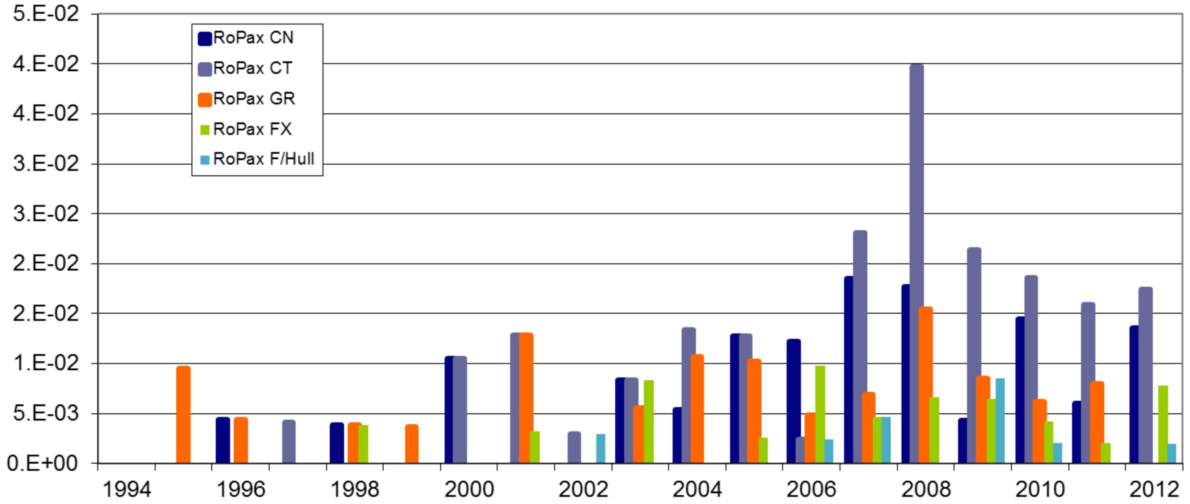


Fig. 8.36: Annual accident frequencies for ship type RoPax calculated for accident categories CN, CT, GR, FX and Foundering / Hull considering only casualty reports complying with selection criteria.

8.3 Risk Model

8.3.1 High-Level Event Sequence

Typically risk models are developed based on high-level event sequences covering the main events influencing the consequences and subsequently the risk. Such high-level event sequences cover the main parameters between incident or accident and consequence influencing the consequences, for instance the location of an incident or the success of consequence mitigating measures. For collision and grounding incidents the high-level event sequences could directly been taken from the GOALDS project (Fig. 8.37 and Fig. 8.38), whereas for the remaining accident categories of both ship types the high-level event sequences (Fig. 8.39 to Fig. 8.43) are developed on the basis of information provided by the FSA submitted to IMO (MSC 83/INF.2, MSC 83/INF.3). Both FSA are carried out in the EU research project SAFEDOR (2005 – 2009).

In the following the high-level event sequences for both ship types and all accident categories characterising the risk for both ship types under consideration.

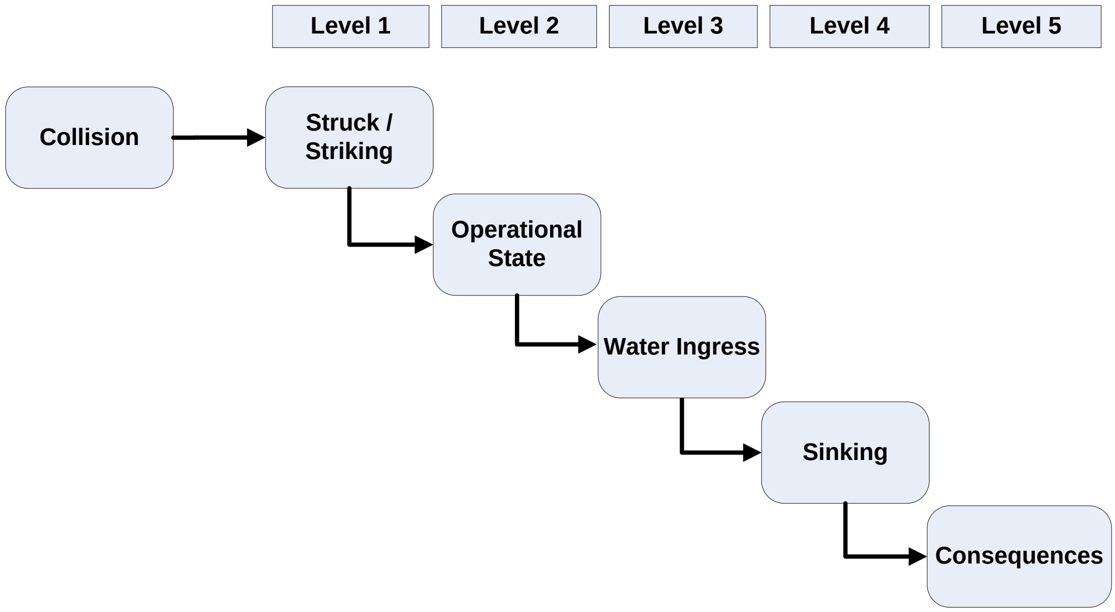


Fig. 8.37: High-level event sequence for collision of Cruise and RoPax (based on GOALDS)

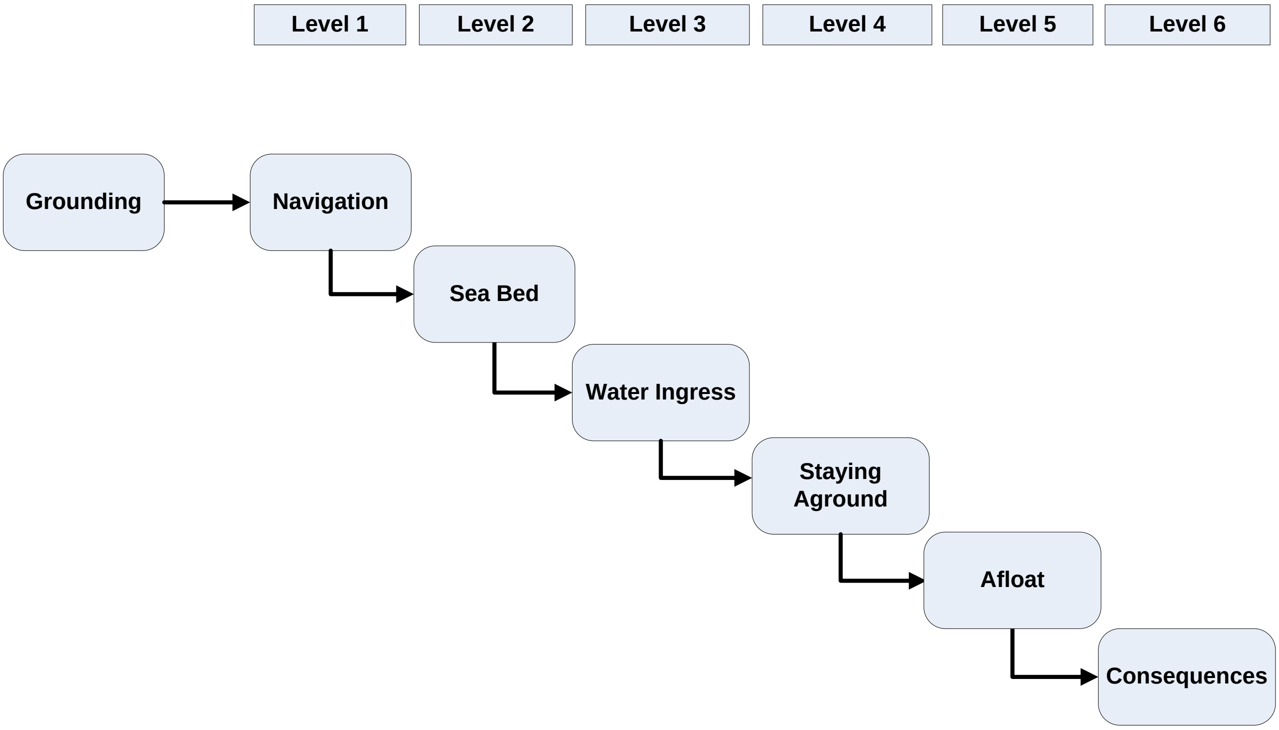


Fig. 8.38: High-level event sequence for grounding of Cruise and RoPax (based on GOALDS)

Both high-level event sequences for fire and explosion developed in SAFEDOR show slight differences as shown by the comparison in Fig. 8.39 (Cruise) and Fig. 8.40 (RoPax). In the event sequence for RoPax the origin of fire is considered along with extinguishing measures in the machinery, vehicle deck and accommodation area, whereas in the risk model for Cruise the focus is put on the escalation (spread of fire outside the compartment of origin).

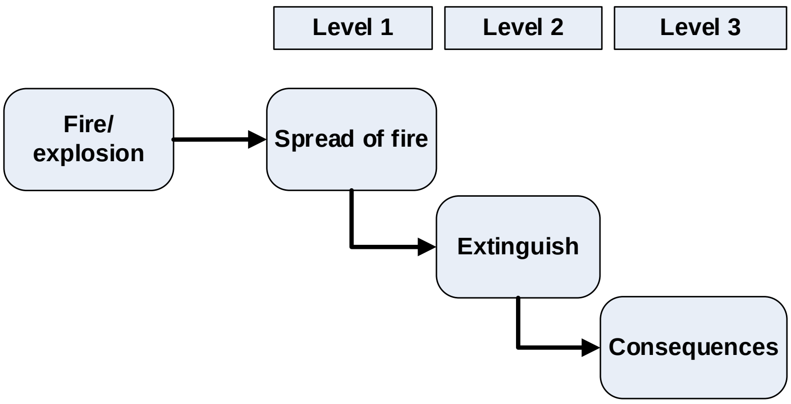


Fig. 8.39: High-level event sequence for fire / explosion on cruise ships (based on SAFEDOR FSA on Cruise)

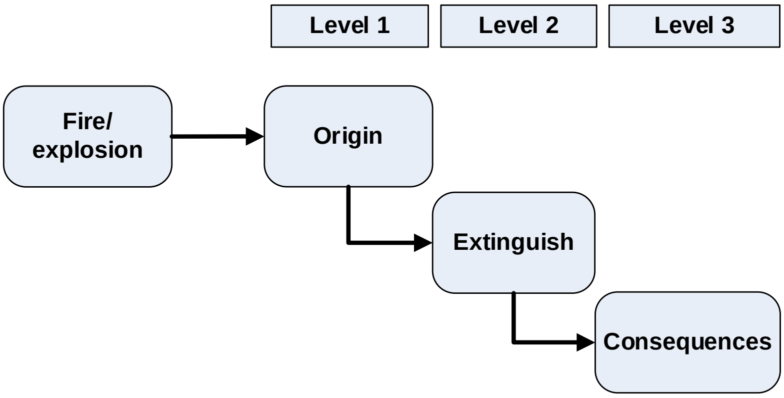


Fig. 8.40: High-level event sequence for fire / explosion on RoPax ships (based on SAFEDOR FSA on RoPax)

For Cruise a contact event sequence (Fig. 8.41) is developed comprising the kind of object contacted (e.g. wreck, platform, pier…) and further escalation via water ingress with potential of sinking. For RoPax this typically in FSA used accident category was replaced by the category *impact* (Fig. 8.42). Comparison of both event sequences showed that similar incidents were considered in this risk model.

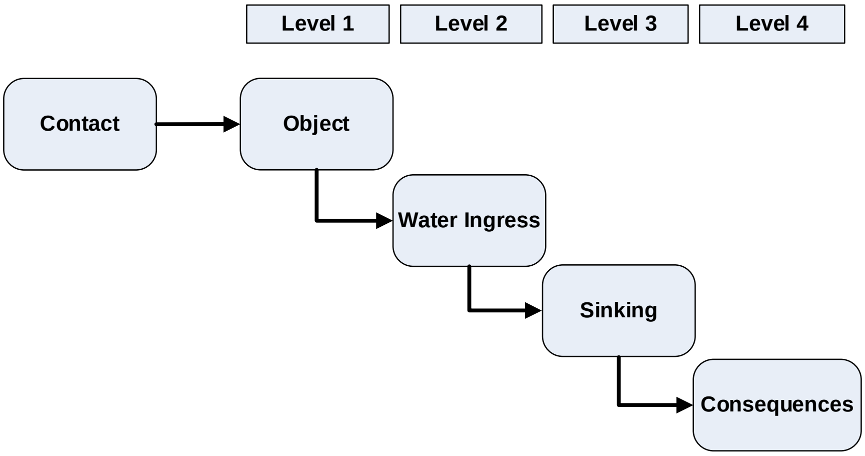


Fig. 8.41: High-level event sequence for contact of cruise ships (based on SAFEDOR FSA on Cruise)

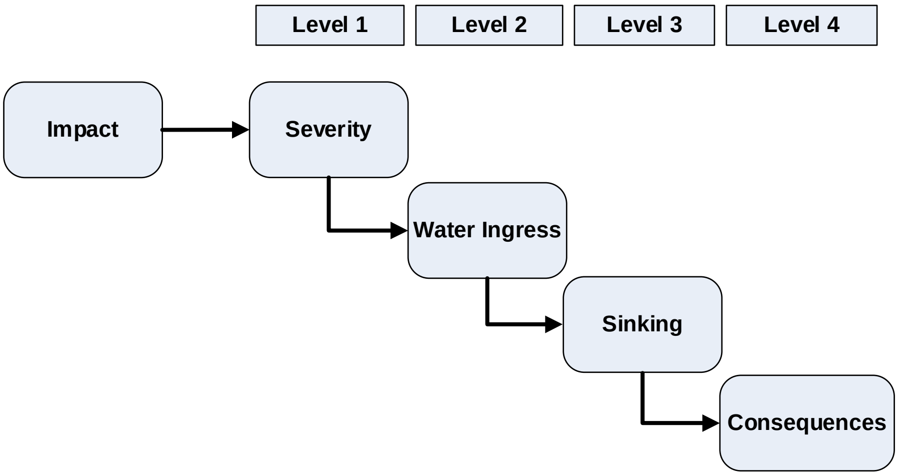


Fig. 8.42: High-level event sequence for contact / impact of RoPax ships (based on SAFEDOR FSA on RoPax)

Additionally, for RoPax an independent risk model relating to the flooding hazard was developed in the SAFEDOR FSA, which considers all risks relating to loss of water tightness *relating to non-accidental failures,* like doors left open or wave forces leading to non-accidental structural failure or opening of bow door (Herald of Free Enterprise and M/V Estonia type of accidents). Such casualties are typically assigned to the accident categories *foundering* and *hull/machinery* accidents in the IHS Fairplay casualty database. In particular for RoPax ships, *water ingress to car deck* has the potential of leading to rapid loss of stability and capsize, with high number of fatalities for persons on board. Since it contributes to the risk of RoPax ships, it is considered in the present study.

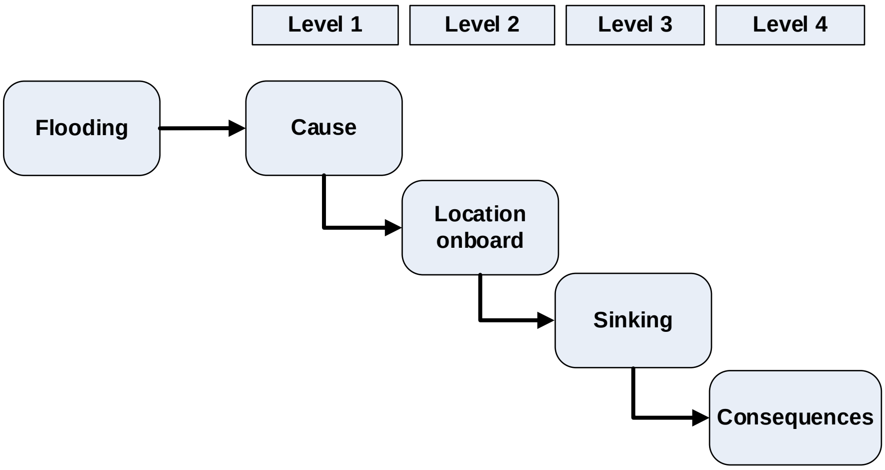


Fig. 8.43: High-level event sequence for flooding of RoPax ships (based on SAFEDOR FSA on RoPax)

8.3.2 Quantitative Risk Model

8.3.2.1 Cruise

Initial accident frequencies are determined considering the fleet at risk data and casualty reports for ships complying with the selection criteria summarised in section 8.1. Casualty reports for accident categories collision, contact and grounding are reviewed considering the database developed in GOALDS project. For the remaining accident categories, casualty reports as given by IHS Fairplay are used. All data are summarised in Table 8.2. In some cases the figures will deviate from the discussion in previous section because for quantification of risk model only the reviewed reports were considered.

Table 8.2: No of casualties and calculated accident frequencies for Cruise distinguishing the periods 1994 to 2012 and 2000 to 2012.

	Time Period 1994 - 2012		Time Period 2000 - 2012	
	No of casualties[7]	Frequencies[8]	No of casualties[7]	Frequencies[9]
Collision	19	5.78E-03	17	6.36E-03
Contact	23	6.99E-03	22	8.23E-03
Grounding	37	1.12E-02	26	9.73E-03
Fire/Explosion	25	7.60E-03	21	7.86E-03

The comparison of the accident frequencies for both periods shows that the collision and contact accident frequencies of cruise ships in the period from 2000 to 2012 were higher, whereas grounding accident frequency decreased by about 13%. For fire and explosion only small changes are observed (~2%). Compared to the GOALDS collision frequencies, numbers for both periods are lower due to the small number of accidents in 2011 and 2012 and further increasing fleet; on the contrary for grounding, the average accident frequency in the period 1994 to 2012 is slightly higher due to additional accidents identified.

As mentioned above, risk models of previous analyses are used for determining the current risk level for Cruise ships. In order to consider the development in the last years, initial accident frequencies for the period 2000 to 2012 are used.

Collision

Following considerations in project GOALDS (risk model B), the risk of collision is calculated considering two sinking scenarios, fast and slow, with the fatality rates of 80% respectively 5% of all persons on board. The dependent probabilities of the risk model are taken from GOALDS whereas the initial accident frequency is updated. The risk model is shown in Fig. 8.44. The probability of sinking is estimated on the basis of the attained subdivision index A equal to the required subdivision index R using SOLAS 2009 damage stability model and N_1 = 75% of persons on board. For a large cruise ship (L_{OA} = 320 m, POB = 6,500) the potential loss of life (PLL) is calculated to 8E-02 per ship year. This value is strongly dependent on the attained damage stability index A, for instance an increase of the damage stability by 4.6% (0.9 instead of 0.86) reduces the risk by 28% (5.7E-02). 77% of PLL for large cruise result from fast sinking/capsize scenarios in particular in restricted waters (37%) or terminal areas (33%) where the majority of collision occurs. Changes for the assumptions with respect to fatality rate and dependent probability of sinking would have a significant impact on total risk. For instance using a fatality rate of 40% for capsizes scenarios in terminal area the risk would be 16% lower (6.7E-02 instead of 8E-02).

The consequences for person on board are estimated using the GOALDS models with 5% fatalities for scenarios ending with "slow sinking" and 80% fatalities for scenarios ending with "fast sinking".

[7] serious cases, IACS ships at the time of incident
[8] Calculated considering IACS classed ships and the selection criteria specified: 3290 ship years
[9] Calculated considering IACS classed ships and the selection criteria specified: 2673 ship years

All results discussed so far are based on the GOALDS risk model dependent probabilities (only initial accident frequency was updated). The investigation of the casualty reports for this study showed that:

- Probability of ship being struck is 42% (calculated on 19 reports)
- Distribution of operational state is 87% terminal and 12.5% limited waters/en route (calculated on 9 reports for struck ships)
- Average probability of water ingress for struck ship is 67% (calculated on 5 reports for struck ship).

Due to the small number of casualty reports the changes are in the range of the 90% confidence interval, in particular those concerning operational state and probability of water ingress. In total the new figures listed above would cause an increase of collision risk by about 10%. However, due to the small number of reports the risk model is not updated in this part and the model shown in Fig. 8.45 is used.

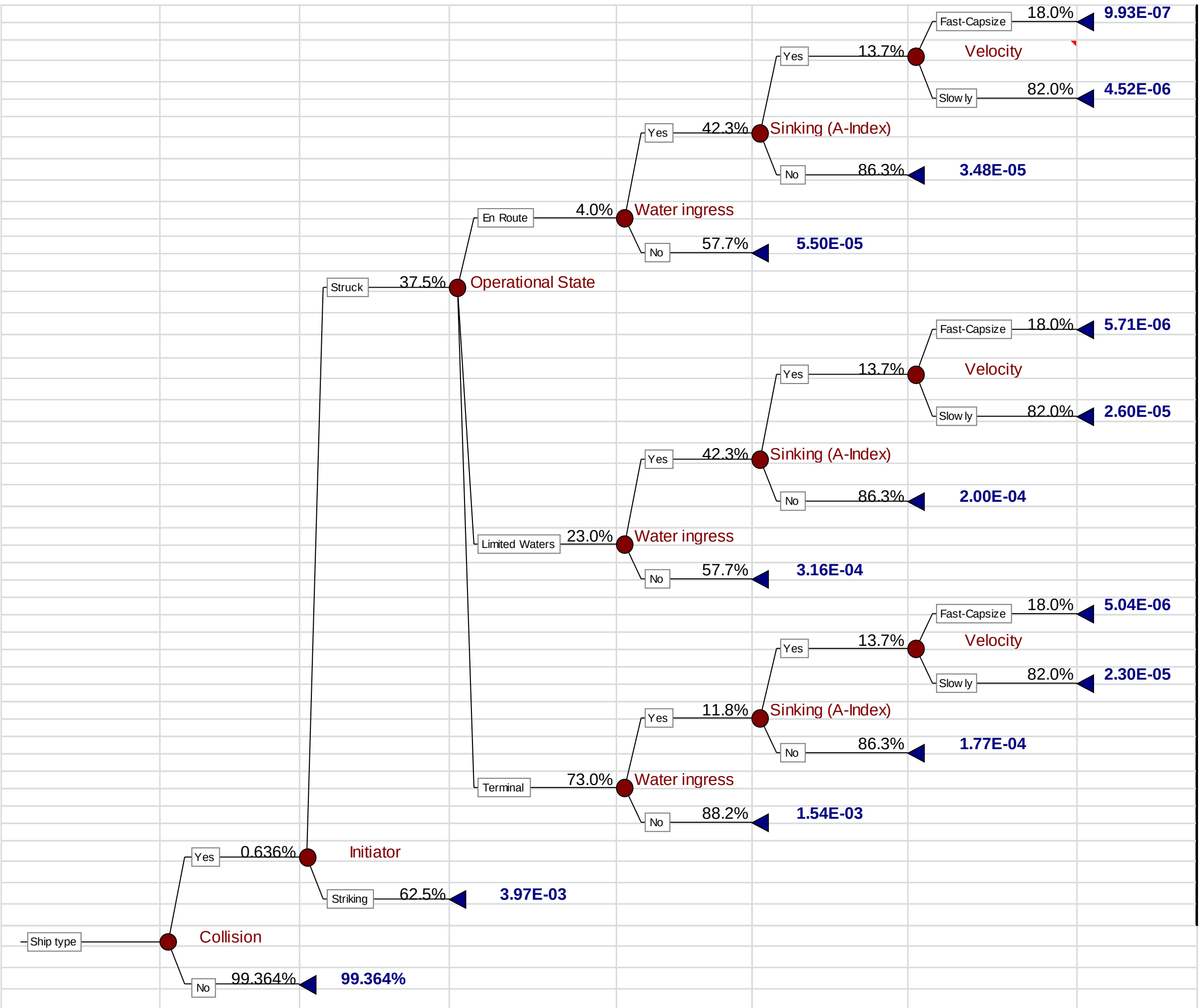


Fig. 8.44: CN risk model Cruise taken from GOALDS

Considering historical data for the consequences of collisions of cruise ships from the casualty database:

- There is no ship's total loss;

- Regarding the fatality rate, only one (1) accident was reported with 4 fatalities;
- Accident: Cruise ship (L_{oa}=146.5m, POB=2063) was the struck one (fatality rate: 0.2%).

Contact

Risk of contact is calculated using the risk model of the SAFEDOR FSA on Cruise with updated initial accident frequency. The risk model as developed in the SAFEDOR FSA is shown in Fig. 8.45. By using the scenarios as given in the FSA the risk for a cruise ship with 4,000 POB[10] is calculated to 9.4E-02, which is higher than the risk of collision, and results from the higher initial accident frequency (8.23E-03 compared to 1.2E-03), which again is caused by the limitation of the fleet at risk to ships > 20,000 GT, with only 2 contact accidents reported by LMIU. IHS Fairplay provides a significant higher number of 18 casualty reports for 2005 to 2012.

Besides the relatively high initial accident frequency, the high risk to persons on board due to CT is mainly a result of contact incidents in open sea (~80% of total risk). For these accident locations the sinking probability was empirically estimated in project SAFEDOR with 30%, which is for larger ships significantly higher than the SOLAS 2009 R-Index (~0.82, or 18% sinking probability) for collisions. Considering the SOLAS 2009 damage stability requirement (R-Index) it yields a PLL of 5.8E-02 per ship year, which is slightly lower than the collision risk. Considering that typical contact accidents with water ingress have significant similarities with grounding accidents the usage of the GOALDS models for estimating the attained index for grounding (refer to section grounding below) seems adequate leading to 4.8E-02 and 2.9E-02 respectively.

The authors of this report are of the opinion that the risk of contact should be lower than the risk for collision, because the majority of such accidents occurred in harbours, e.g. striking pier. These accidents are typically low energy accidents and in most cases the casualty reports contain no information on water ingress (no hull penetration or damage above water line). An investigation of the 23 CT casualty reports for 1994 to 2004 showed that less than 20% occurred in open sea, instead of 30% used in the SAFEDOR FSA. About 70% of the contact events occurred in port/harbour/dock. Based on this information the risk model was updated respectively. This update in combination with the reduced probability of sinking (SOLAS 2009 related estimation of sinking probability), a PLL of 4.1E-02 (R-Index) per ship year is calculated (considering A_{GR}: 3.4E-02 (Eq. 1) and 2.1E-02 (Eq. 2)). By applying the attained index for grounding the risk is about 50% (Eq. 2) respectively 33% (Eq. 1) of collision risk for a ship with 4,000 persons on board.

Whether the assumptions with respect to probability of sinking due to contact to iceberg or offshore structure are justified cannot be answered on basis of the sample (2,673 ship years) because return periods for these scenarios are about 90,000 ship years (offshore structure) and about 180,000 ship years for icebergs.

For this investigation CT risk is calculated using the model considering updated initial accident frequency, updated dependent probability for accident location and updated dependent probability for sinking in CT accidents with icebergs and offshore structures using Eq. (2) for damage stability in grounding accidents as shown in Fig. 8.46.

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[10] For better comparison to FSA on cruise the POB was used.

The consequences for person on board are estimated using the model developed in SAFEDOR FSA:

- 40% - 80% and 100% fatalities for contact to icebergs or offshore structures and fast sinking
- 20% fatalities for contact to bridge and fast sinking
- 7.5% fatalities for contacts to harbour structures and fast sinking
- Zero fatalities for scenarios with slow sinking and remaining scenarios

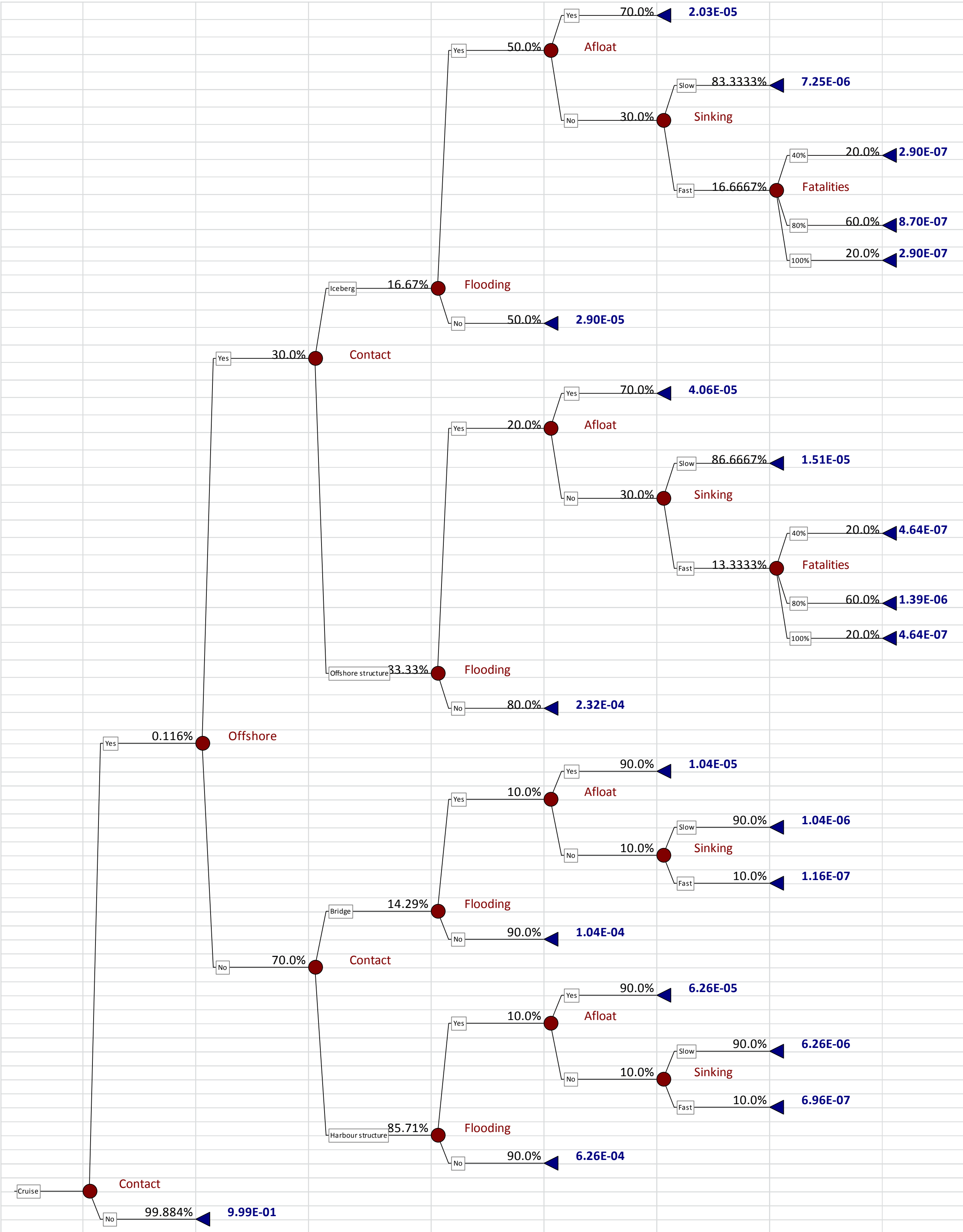

Fig. 8.45: CT risk model Cruise (SAFEDOR FSA)

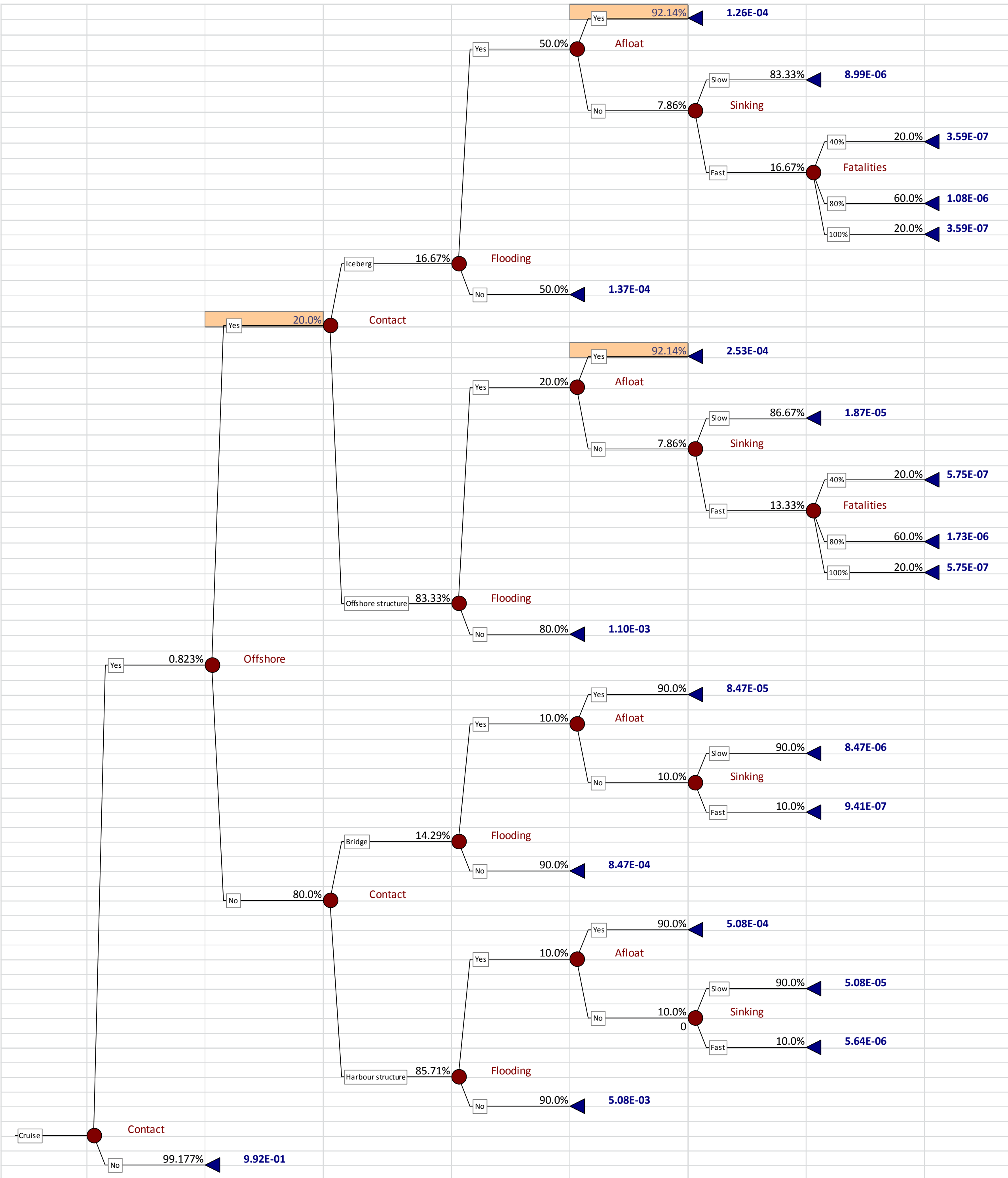

Fig. 8.46: CT risk model Cruise (SAFEDOR FSA updated; dependent probabilities for medium cruise ship with 4,000 POB)

Historical data from casualty database regarding consequences:

- No ship's total loss because of contact event. Note that the case of "Costa Concordia" is registered as "grounding" event in the casualty database (see Annex A; ship came in contact with submerged rock, while moving).

- Regarding the fatality rate, only in one accident there were 3 fatalities.
- Accident: Cruise ship (L_{oa}= 243.2 m, Number of Passengers = 1,744, not available the exact number of Persons on board) had a contact with a fixed installation (struck pier in harbour); fatality rate in the range of 0.2%.

Grounding

Risk of grounding is calculated considering two sinking scenarios, fast and slow, with fatality rates of 80% respectively 5% of all person on board. Attained index is estimated using the following empirical proposal of GOALDS project in lack of a better model[11]:

$$A_{GR} = A_{CN} + 0.1 \cdot (1 - A_{CN}) \quad (1)$$

$$A_{GR} = \begin{cases} A_{CN} + 0.1 \cdot \text{for } A_{GR} \leq 1 \\ 1 \text{ else} \end{cases} . \quad (2)$$

Risk model is shown in Fig. 8.47. Probability of sinking is estimated using SOLAS 2009 damage stability model in combination with the GOALDS proposal for Attained index mentioned above. For a large cruise ship (6,500 POB) PLL is calculated to 2.4E-01 per ship year (Eq. 1) and 7.5E-02 (Eq. 2). Again, these figures demonstrate the influence of the assumptions made with respect to probability of sinking.

The consequences for person on board are estimated using the GOALDS models with 5% fatalities for scenarios ending with “slow sinking” and 80% fatalities for scenarios ending with “fast sinking”.

For the investigation summarised in this report Eq. 2 was used.

[11] Note that in Task 3 of this project, the probabilistic assessment of risk due to raking (side, contact and grounding) damages will be investigated giving a feedback to the relevant part of Task 1 for an update of the Grounding and Contact risk models.

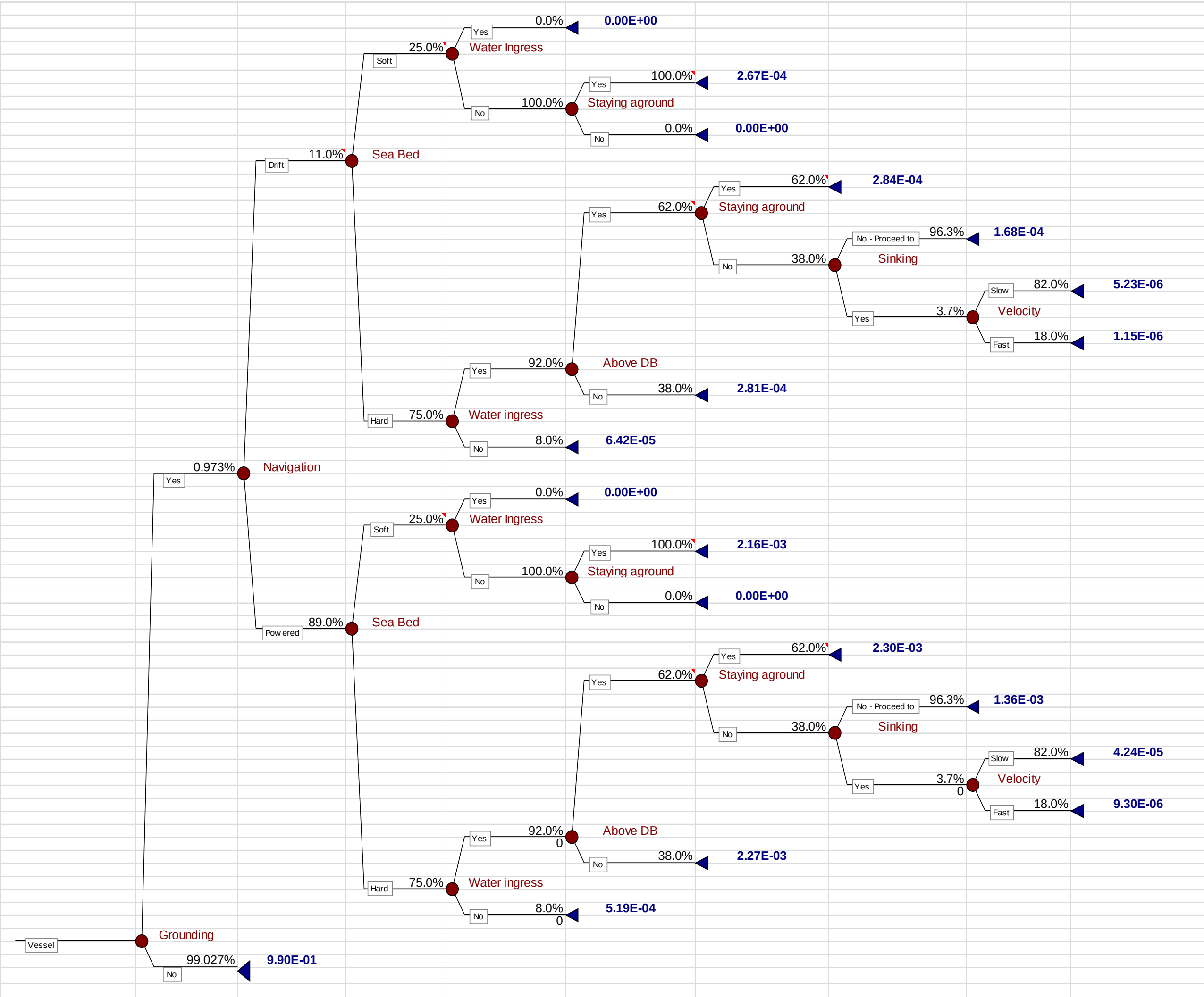

Fig. 8.47: GR risk model Cruise (developed in GOALDS)

Historical data from database regarding consequences:

- In the NTUA-SDL Casualty database used in Task 3, a grounding event is defined as an accident for which the vessel is going aground, or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.), including hitting a submerged rock, whereas contact events are assigned to accidents when the ship had an impact on a fixed installation or object, which extends *over the surface level (like a pier or higher extending rock)*, or impact on a floating object (barge, container etc.). Thus, the *Costa Concordia* accident is herein classified as powered grounding.
- According to the statistics, two accidents with ship's total loss because of powered grounding were here identified (cruise ships Sea Diamond and Costa Concordia, both hitting submerged rocks). The side damage was extending above the double bottom's bilge area and was below WL in both cases. Both ships sunk slowly.
- Sea Diamond (L_{oa}= 142.95 m, Persons on board at the time of accident =1,546) = 2 fatalities (0.13%).

- Costa Concordia (L_{oa}= 289.59 m, Persons on board at the time of accident = 4,229) = 32 fatalities (0.8%)

Fire & Explosion

Risk of contact is calculated using the risk model of the SAFEDOR FSA on Cruise with updated initial accident frequency. The risk model as developed for the FSA on Cruise is shown in Fig. 8.48. Using the scenarios as given in the FSA the risk in terms of PLL for a large cruise ship (6,500 POB) is calculated to 2.3E-02 per ship year.

The consequences for person on board are estimated using the model developed in SAFEDOR FSA:

- 2 fatalities for fire in more than one compartment with medium to large person density and rapid extinguishing
- 2 fatalities for fire in more than one compartment with low to medium person density and slow extinguishing
- 5 fatalities for fire in more than one compartment with high person density and slow extinguishing
- 5 fatalities for fire outside compartments and fire could be contained in fire zone with low to medium person density
- 2.5% fatalities for fire outside compartments and fire could be contained in fire zone with high person density
- 0.5% fatalities for fire outside compartments and fire could not be contained in fire zone but restrained
- 7.5% fatalities for fire ending with total loss of vessel.

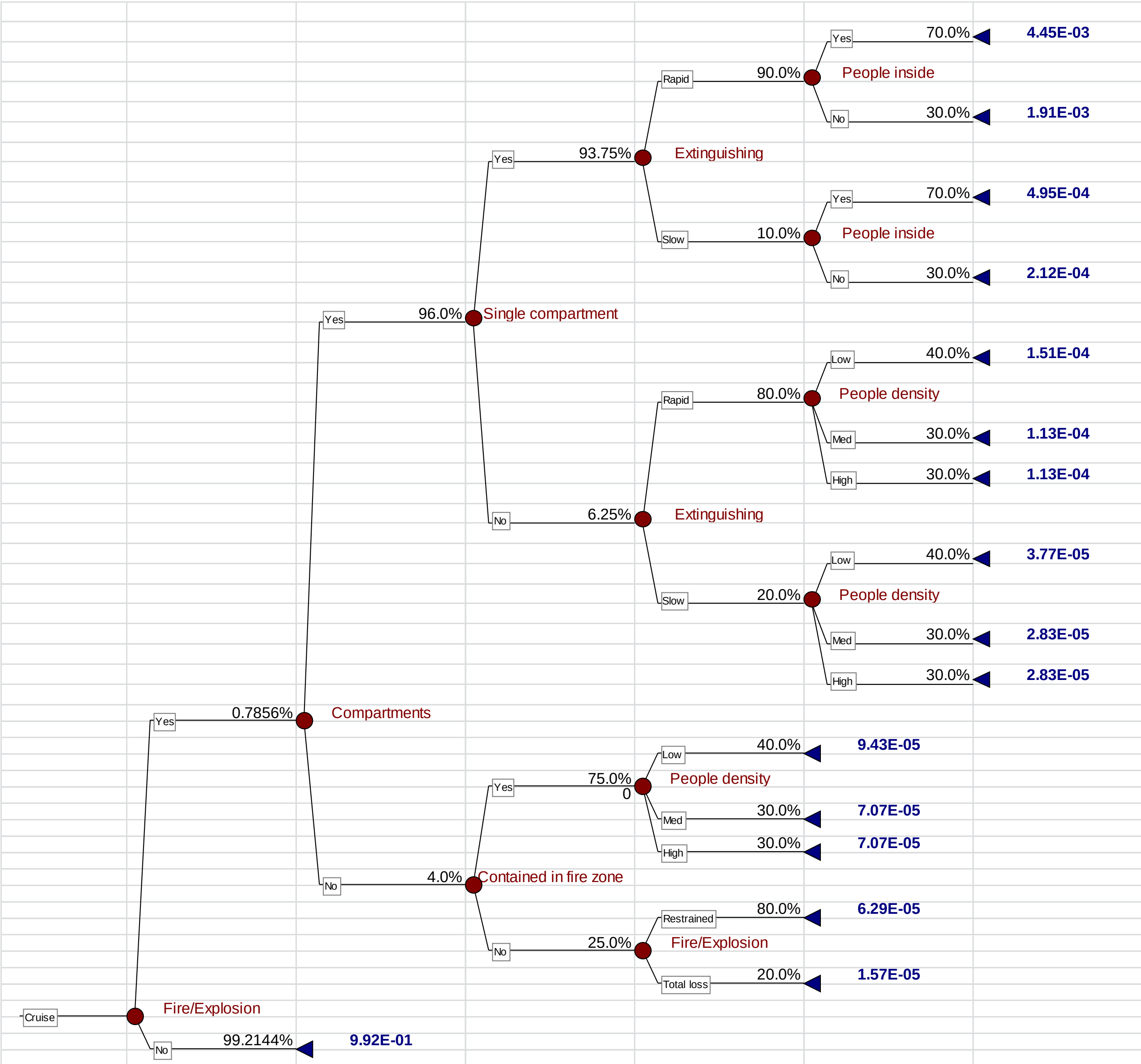

Fig. 8.48: FX risk model Cruise taken from SAFEDOR FSA

8.3.3 RoPax & RoPaxRail

Initial accident frequencies are determined considering the fleet at risk data and casualty reports for ships complying with the selection criteria summarised in section 8.1. Basic data regarding number of casualties and initial accident frequencies for RoPax are summarised in Table 8.3.

Table 8.3: Number of casualties considered for ship type RoPax as well as calculated initial accident frequencies for different accident categories and periods 1994 to 2012 and 2000 to 2012

	Time Period 1994 - 2012		Time Period 2000 - 2012	
	No of casualties[12]	Frequencies[13]	No of casualties[12]	Frequencies[14]
Collision	55	8.16E-03	53	9.95E-03
Contact	87	1.29E-02	86	1.61E-02
Grounding	42	6.23E-03	37	6.94E-03
Impact	= CT			
Flooding	= FD + HD			
Fire/Explosion	25	3.71E-03	24	4.50E-03
Foundering	3	4.45E-04	3	5.63E-04
HD	7	1.04E-03	7	1.32E-03

The comparison of the accident frequencies for the both periods shows that for all accident categories the accident frequencies for the period from 2000 to 2012 are higher than for the period from 1994 to 2012. Possible reasons like increase of traffic or improvements in data collection are already discussed in GOALDS project (GOALDS, 2011).

As mentioned above, risk models of previous analyses are used for determining current risk level for RoPax. In order to consider the last year's development, the initial accident frequencies for the period from 2000 to 2012 are used for calculating the risk.

Collision

Risk of collision is calculated using the GOALDS risk model considering two sinking scenarios, fast and slow, with fatality rates of 80% respectively 5% of all person on board. The risk model is shown in Fig. 8.49. Probability of sinking is estimated using SOLAS 2009 damage stability model. For a ship of 200 m length and 1,100 persons on board PLL is calculated to 1.2E-01 per ship year (based on the utilisation assumptions of the SAFEDOR FSA). Compared to SAFEDOR FSA this risk is about five times higher (2.3E-02) which is mainly caused by the consideration of sinking for collision in terminal area (in SAFEDOR FSA sinking at berth is excluded) and the initial accident frequency which is about five times lower (1.26E-03 for serious casualty outside berth).

The consequences to person on boards were estimated using the GOALDS model:

- 5% fatalities for scenarios with slow sinking

12 serious cases, IACS ships at the time of incident

13 Calculated considering IACS classed ships and the selection criteria specified: 6738 ship years

14 Calculated considering IACS classed ships and the selection criteria specified: 5328 ship years

• 80% fatalities for scenarios with fast sinking.

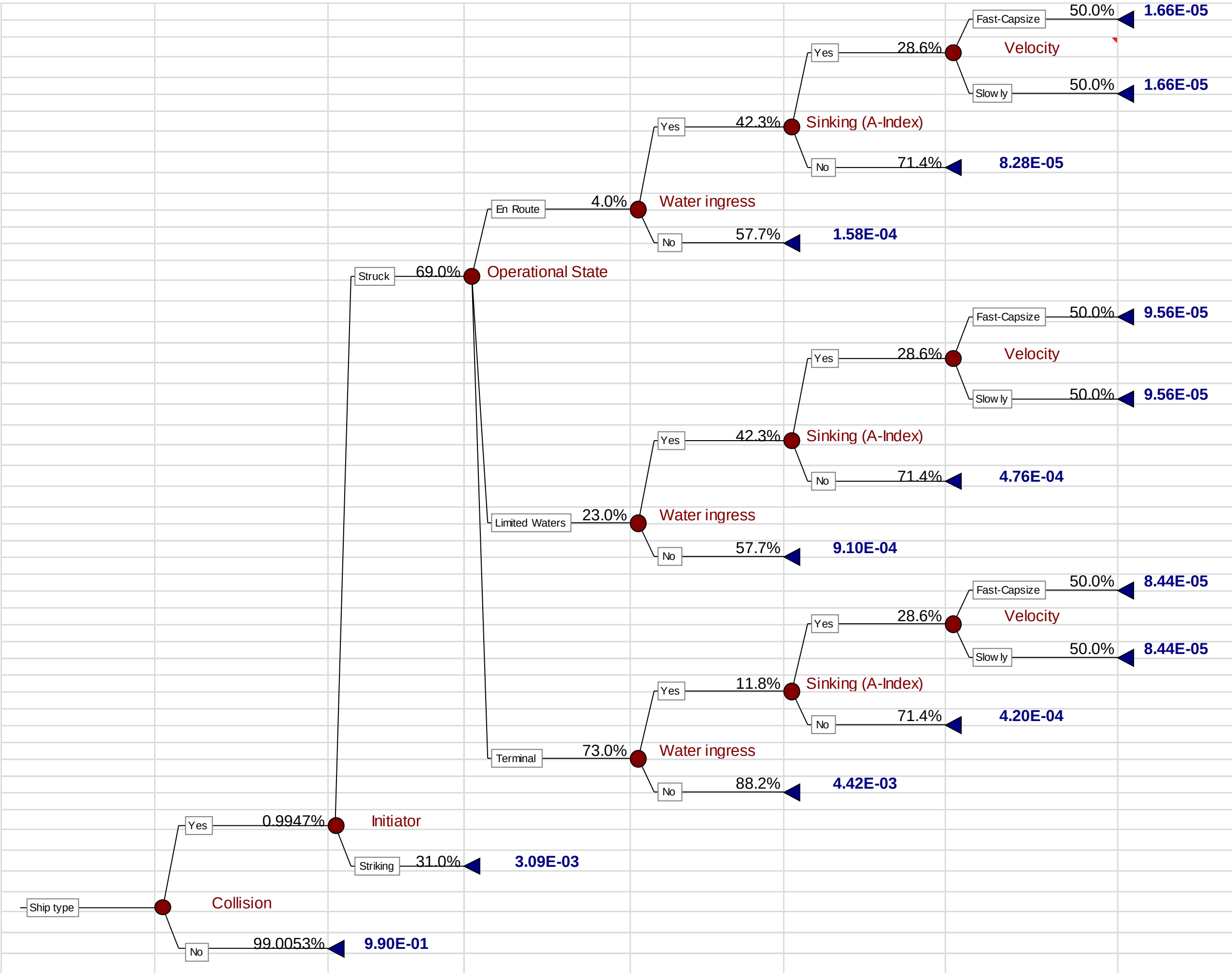

Fig. 8.49: CN risk model RoPax (developed in GOALDS)

Contact

As mentioned above in the SAFEDOR FSA on RoPax the accident category contact was not considered. Instead of this a risk model for ***impact*** was developed, which considers similar casualties typically assigned to contact (see also Table 10 of FSA, MSC 85/INF.3). Therefore this *impact* model is populated with the data assigned to IHS Fairplay accident category contact.

The risk model as developed in the SAFEDOR FSA is shown in Fig. 8.50. At the beginning of the event tree it is distinguished between minor and serious damage without specifying both categories. For this investigation *only serious casualties* are considered (IHS Fairplay classification) and therefore in the model the probability for *serious accident is set to 100%, automatically increasing the* risk. However, it is known, also, that assignment to severity categories differ between LMIU (FSA on RoPax) and IHS Fairplay and the effect on the risk calculated by the model has to be carefully analysed.

In total 75 casualty reports were available for 1994 to 2012. Investigating the textual description of the casualties showed that more than 90% occurred in port/harbour/dock. Most of contacts are to pier or quay (60%). In seven cases it is clearly stated or it can be concluded that water ingress occurred. All of these were caused by contact to breakwaters or submerged objects. The rate of water ingress when having contact to breakwater is about 60% and ~50% for contact to wreck/submerged objects. Using this information the probability of water ingress is estimated to 10% of all contact incidents (7 of 75 casualties). Some of the reports provide information on damage extent, for instance tear/crack/gash between 1 m and 3.5 m length with water ingress, from which it can be concluded that the effect on ship safety is smaller than for typical grounding or collision damages.

The effect of SOLAS 2009 required index in the SAFEDOR risk model was investigated (using SOLAS required index to estimate the probability of sinking) showing that the risk would increase in comparison to the SAFEDOR FSA. Furthermore, SOLAS 2009 damage stability requirement is based on collision accidents, therefore this model is regarded to be not applicable in this context and it was not further considered.

For this investigation the dependent probabilities of the SAFEDOR FSA are used except for flooding and the initial accident frequency updated as shown in Fig. 8.50.

In SAFEDOR FSA the consequences for persons on board are estimated as follows:

- 0.2% for slow sinking scenarios
- 23% for fast sinking scenarios

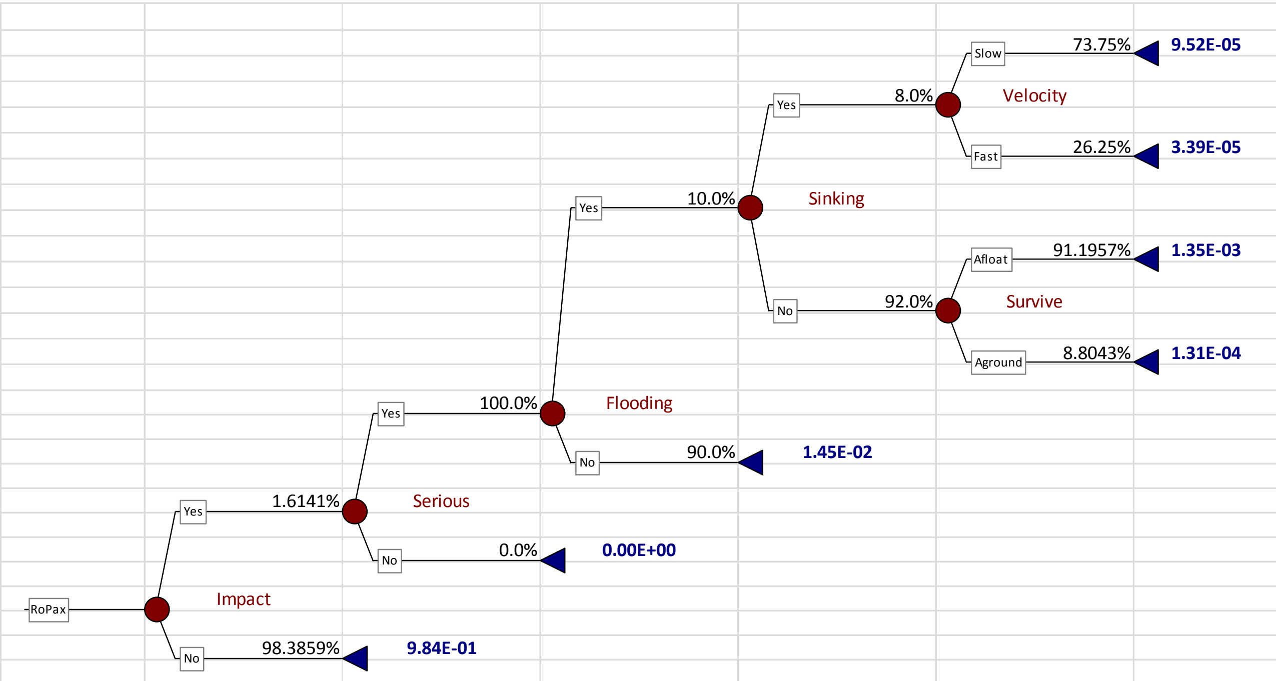

Fig. 8.50: CT / Impact risk model RoPax

Grounding

Risk of grounding is calculated considering two sinking scenarios, fast and slow, with fatality rates of 80% respectively 5% of all person on board. Attained index is estimated using the empirical proposals of GOALDS project (Eq. 1 and Eq. 2 in section Grounding for Cruise).

The risk model is shown in Fig. 8.51. Probability of sinking is estimated using SOLAS 2009 damage stability model in combination with the GOALDS proposal for the Attained index as mentioned above. For a ship of 200 m length and 1,000 passengers and 100 crew on board the PLL is calculated to 9E-02 per ship year (Eq. 1; with Eq. 2 6.1E-02), which is about four (Eq. 2 three) times higher than in the SAFEDOR FSA on RoPax (2.3E-02). This difference is caused by the observed higher accident frequency (factor 2 for serious events) plus a higher probability of flooding for damages above the double bottom, partly compensated by a lower probability of fast sinking.

For this investigation the GOALDS models with Eq. 2 and update initial accident frequency was used.

The consequences to person on boards were estimated using the GOALDS model:

- 5% fatalities for scenarios with slow sinking
- 80% fatalities for scenarios with fast sinking.

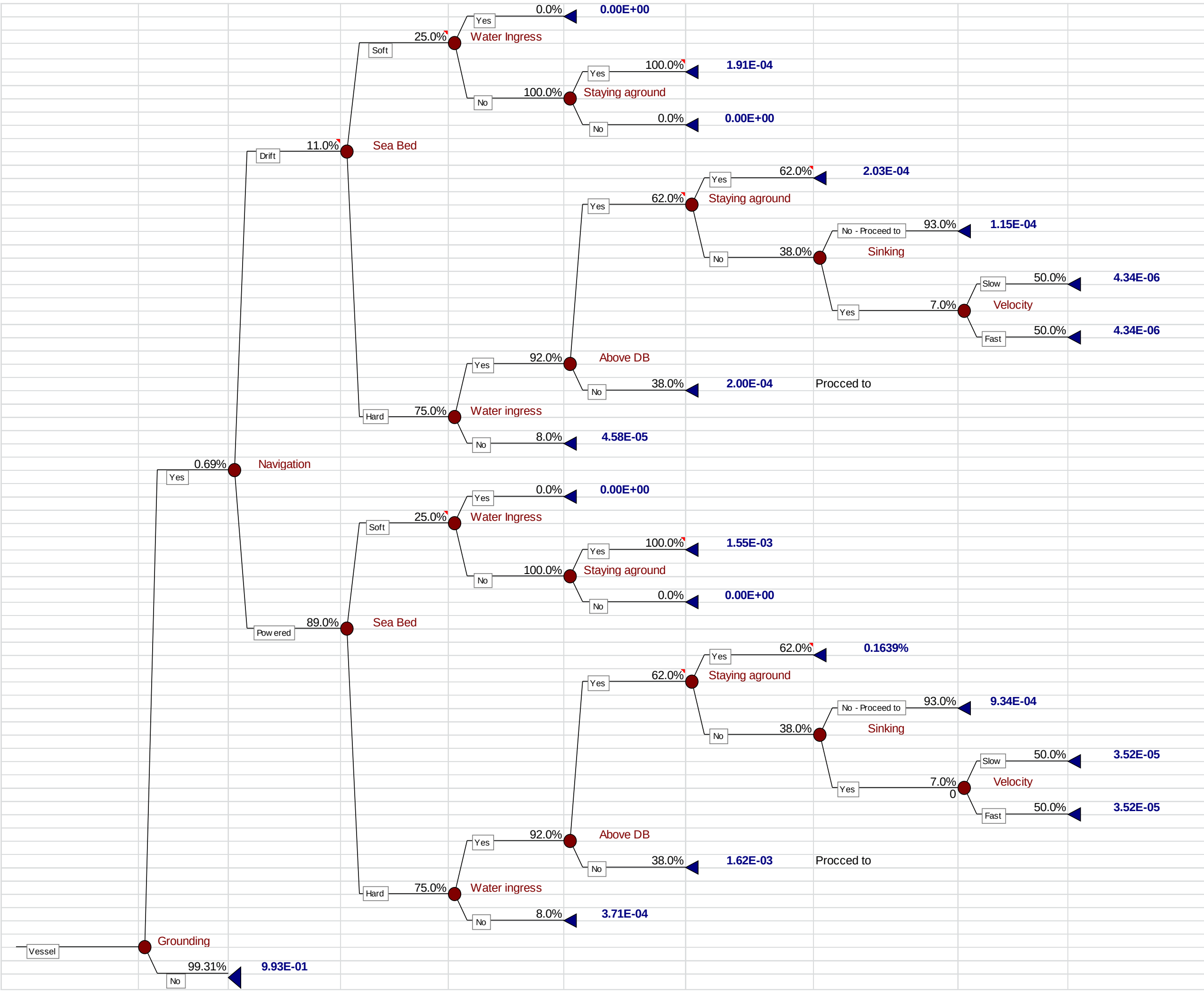

Fig. 8.51: GR risk model RoPax (based on GOALDS)

Fire & Explosion

Risk of fire and explosion is calculated using the risk model of the SAFEDOR FSA on RoPax with updated initial accident frequency. The risk model as developed for the FSA is shown in

Fig. 8.52. For a medium size RoPax vessel and updated initial accident frequency the risk in terms of PLL is calculated to 6.5E-02 per ship year. In SAFEDOR FSA the consequences for persons on board are estimated as follows:

- 0.7% for fire in machinery – escalation – unsuccessful evacuation
- 75% for fire in machinery – escalation – fire uncontrolled
- 8% for fire on vehicle deck - escalation – unsuccessful evacuation
- 8% for fire in accommodation - escalation – unsuccessful evacuation

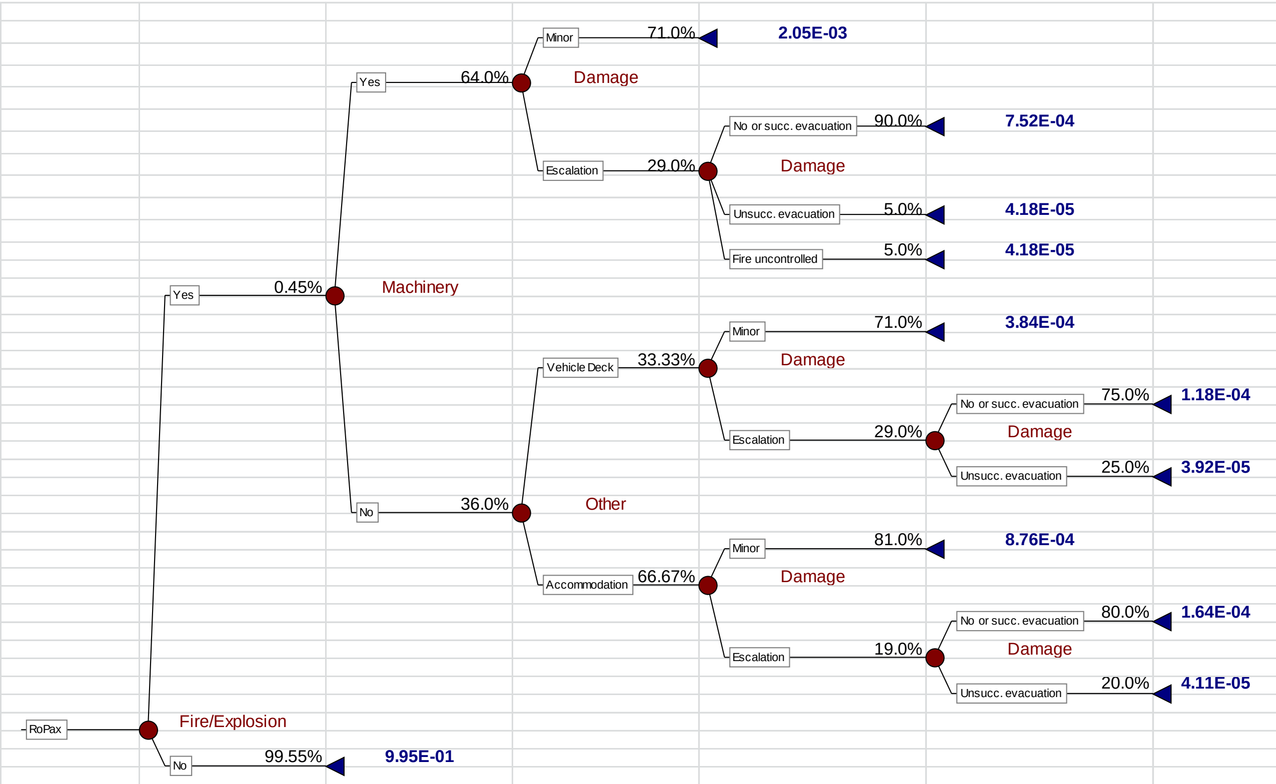

Fig. 8.52: FX risk model RoPax (From SAFEDOR FSA on RoPax)

Flooding

From the data provided in the SAFEDOR FSA on RoPax it can be concluded that this risk model covers both foundering and hull damages. With this risk model and only updating initial accident frequency (Fig. 8.53) the PLL is calculated to 2.6E-01 per ship year for a RoPax with 2,240 person on board and occupancy values as given in the SAFEDOR FSA. *This PLL is about two times higher than in SAFEDOR FSA (1.1E-01), which is caused by two times higher number of persons on board*. In SAFEDOR FSA the consequences for persons on board are estimated 12% for scenarios “slow sinking” and 66% for scenarios “fast sinking”. No fatalities are considered for all other scenarios.

In general, it is not clearly explained if the risk model of the SAFEDOR FSA on RoPax already considers the impact of the so-called Stockholm Agreement on ship design, as well as the amendments to SOLAS and IACS Unified Requirements to bow doors and other external doors following the Estonia accident, which all have contributed to reduced probability for water entering the Ro-Ro deck as well as increased probability for survival in case water enters the Ro-Ro deck. In this respect the dependent probabilities used in the SAFEDOR FSA risk model are regarded as too high (in 60% of cases in which wave caused bow door damages and in 20% of open doors the ship sinks). Reducing these dependent probabilities to more realistic, but still conservative values, of 10% for both scenarios reduces the risk by about 34%. Further, consideration of SOLAS 2009 damage stability criterion in the scenario wave damage of hull lead to further decrease in the risk of flooding by about 20% to 25% for medium and large RoPax, whereas for small vessels the effect is negligible.

The risk model used for this investigation is shown in Fig. 8.54. The consequences in terms of assumed fatalities are unchanged:

- 12% fatalities for scenarios ending with slow sinking
- 66% fatalities for scenarios ending with fast sinking, and
- No fatalities for all other scenarios.

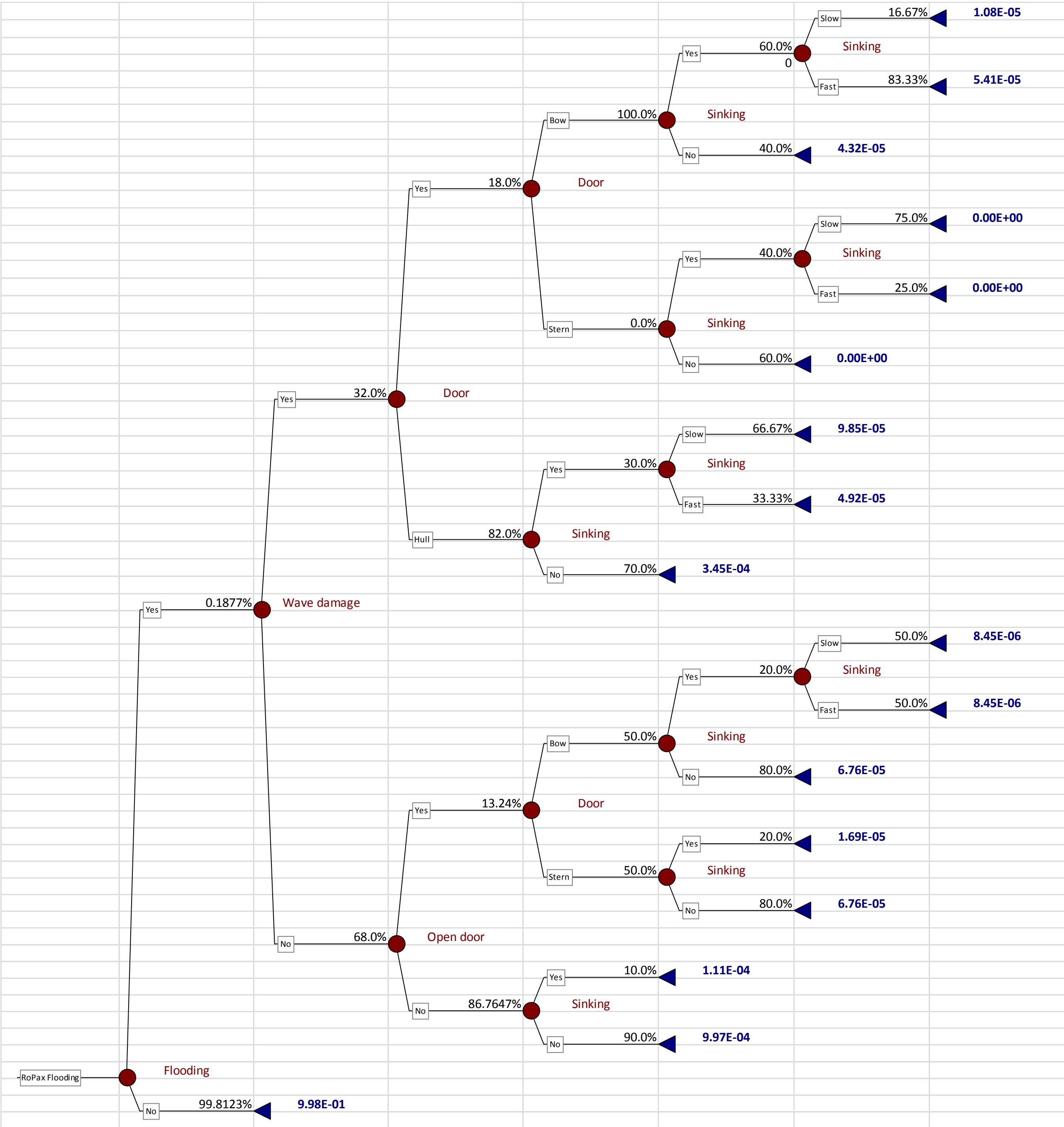

Fig. 8.53: Flooding risk model RoPax from SAFEDOR FSA on RoPax

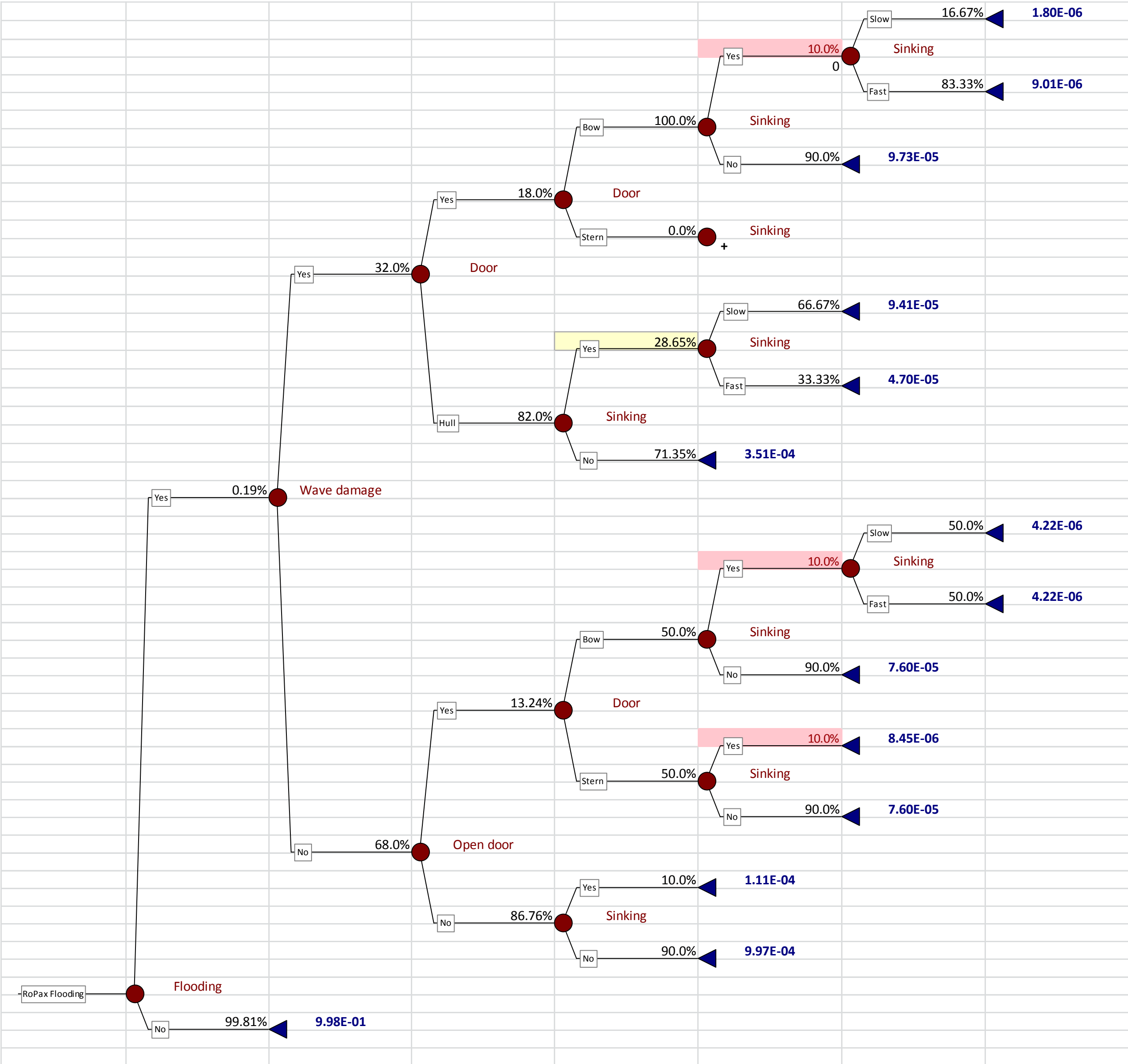

Fig. 8.54: Flooding risk model RoPax with updated probabilities and initial accident frequency

8.3.4 Risk

The risk for Cruise and RoPax ships is calculated for three representative ship sizes of each ship type under consideration. The characteristic data for the reference ships are summarised in Table 8.4 considering length, gross tonnage, R-Index (SOLAS 2009) as well as nominal person on board. For risk calculation occupancy rates are considered as specified using information from project partners, CLIA as well as GOALDS project. Furthermore, the R-Index is used which typically is lower than the attained index for ships built (conservative because slightly higher risk is calculated).

In following subsequent sections the calculated risk is expressed in terms suggested in FSA Guidelines, PLL per ship year and FN diagram, but also in terms of billion passenger hours and billion passenger kilometres as used in other industries. In order to show the contribution of different accident categories to total risk the risk values for the different accident categories are also provided. All risks are calculated using initial accident frequency for the period from 2000 to 2012.

Table 8.4: Characteristic data for ships used to calculate risk due to ship operation using the risk models explained in section 8.3.2

	Length (OA)	GT	R	Passengers	Crew
Cruise					
Small	142	11000	0.6991	300	100
Medium	269	92000	0.8214	3000	1000
Large	320	160000	0.8597	5135	1595
RoPax					
Small	103.7	10000	0.7151	450	50
Medium (Med)	185	43000	0.80	2108	132
Large (Baltic)	251	60000	0.83	3000	280

For evaluating the risk FN diagram with updated risk areas (intolerable – ALARP – negligible) are used. The procedure followed to derive the FN criteria is as explained in the IMO FSA Guidelines (IMO, 2013), and in MSC 72/16 (2000). The basis for this approach is a benchmark against the airline industry. The airline industry is chosen because of the good statistical data and the generally excellent safety record.

The revenue for the airline industry from passenger transport for the IATA members can be found in the IATA annual reports. The reports normally contain both total revenue and the total numbers of fatalities. The revenue from air-freight, which needs to be subtracted from the total revenue to arrive at the revenue for passenger transport, is not always stated explicitly in the reports, and has for some years been estimated to be 12% of the total revenue, based on statements in some of the annual reports. Based on the IATA Annual Reports for the period 2007 to 2013 the number of fatalities per $billion revenue from passenger transport are determined (Fig. 8.55).

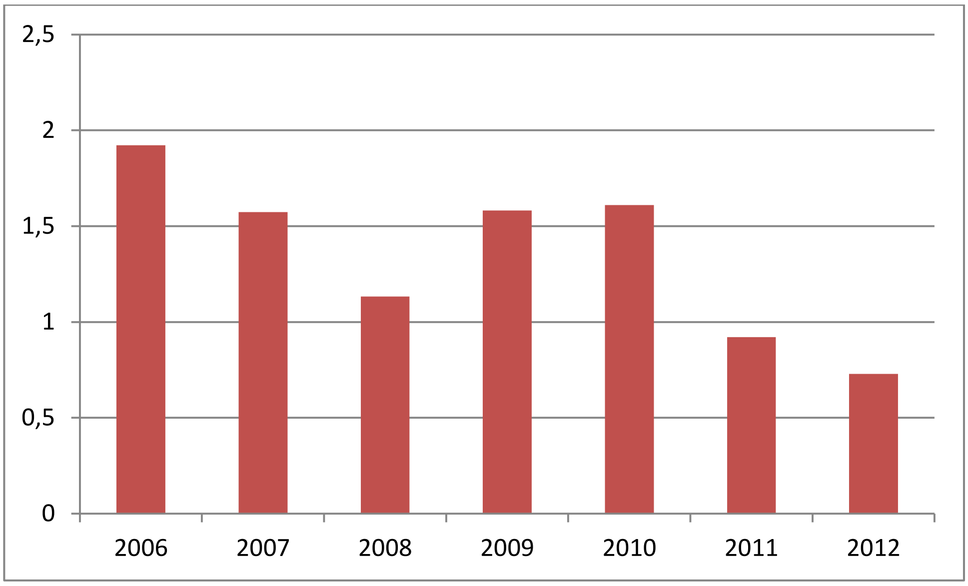

Fig. 8.55: Fatalities per $billion in revenue for the international airline industry (IATA Members)

The figure from the last annual report available was 0.73 fatalities per $billion (all numbers from IATA (2013)). The indication is a rather steady decline from the 5.7 fatalities per $billion referred to in MSC 72/16 (2000), which was based on the annual report IATA (2000). Since there seems to be this steady decline, the 2012 data is used for the benchmark.

For the passenger ships, there is no organisation following up the trends like IATA does for airlines. The source of information is therefore annual reports from RoPax and Cruise operators. For the cruise liners the revenue per berth is about $0.1 million, but varies considerably. The on-board sale is about 15% of this, which may indicate a transport value of $0,085 million per berth. However, more importantly, it is difficult to argue that the purpose of Cruise is transport. It is therefore more justifiable to use data for Ro-Pax operators to establish the benchmark. This is the same approach as used to establish the FN diagram in IMO (2013). In MSC 72/16 (2000) there is an FN diagram established for RoPax, which have been used as a benchmark for all passenger ships. Alternatively it may be stated that the Cruise ships should have safety criteria equivalent to the criteria that apply to RoPax.

By studying annual reports from RoPax operators in the Baltic, North Sea, the English Channel and the Mediterranean it is established that the revenue per passenger-year is about $0.05 million. In this number the contributions from tax-free sales on-board have been removed from the revenue.

An FN Curve based on the information above is therefore suggested for N = 1,000 passengers on board. This could be used as a general benchmark for passenger ships, see Fig. 8.56. The criteria are about half an order of magnitude stricter than the criteria derived in MSC 72/16 (2000), and reflect the general improvement in transport safety.

It should be emphasised that these curves should only be used as benchmarks, and not as absolute criteria. For example, if ships with very large numbers of passengers turned out to be associated with risks in the intolerable area according to this curve, this is an indication that it is likely to be easy to identify cost effective risk control options, and such risk control options should be implemented according to the criterion for Value for Preventing Fatalities (VPF).

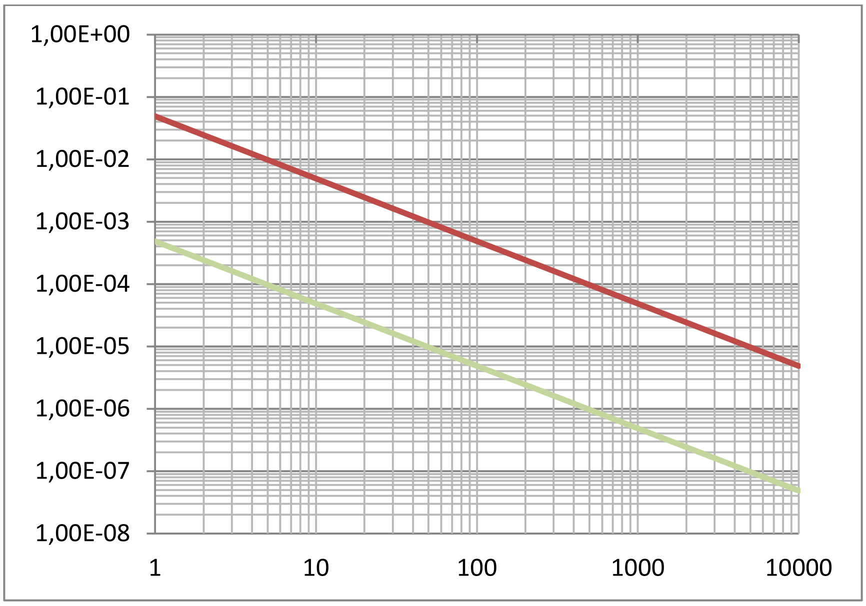

Fig. 8.56: FN criteria for passenger ships: Intolerable limit (red), Negligible/Broadly acceptable (green)

8.3.4.1 Cruise

Using the risk models for the different accident categories the risk to person on board is calculated in terms of potential loss of life (PLL). Risk in terms of PLL is calculated using the number of person on board (POB) as given in Table 8.4 and considering an average occupancy of 90%[15]. The average occupancy is determined on basis of annual reports of two large cruise operators as well as on information provided by CLIA for Antarctic journeys, where it was assumed that the occupancy level is slightly lower than for other locations.

The results for the different accident categories as well as the total risk are summarised in Table 8.5 for the three reference ship size categories. The main risk contributors are collision and grounding (always about 80% of total risk, increasing with ship size). Following the results the contribution of contact accidents is relatively high, in particular for small ships. This risk is nearly exclusively driven by the scenarios contact to iceberg and offshore structure leading to sinking of vessel.

The contribution of grounding decreases from about 50% to 36% with increasing ship size. With respect to this accident category it is not clear if the effect of ECDIS is considered appropriately. In NAV 51/10 the effect of ECDIS is quantified to 66% risk reduction (without track control). ECDIS is already required for ships passenger ships ≥ 500 GT constructed on or after 1. July 2012. Therefore, the effect of ECDIS on grounding accident frequency cannot be considered by historical data. However, even if some of the passenger ships are equipped with ECDIS before this date, a further reduction of grounding risk of about 50% can be expected (Small: 1.1E-02 ; Medium: 4.1E-02; Large: 3.3E-02).

This will also have an effect on the shape of the FN curve discussed below because grounding and collision mainly specify the FN curve for higher fatality rates.

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[15] Occupancy factor is applied to both, passenger and crew

Table 8.5: Risk for Cruise ships in terms of PLL based on average accident frequency 2000 to 2012

	Time Period 2000 - 2012				
	No of casualties	**Frequencies**	**PLL**		
		Ship year $^{-1}$	Ship year $^{-1}$		
Size category			Small	Medium	Large
Max POB[16]			400	4,000	6,730
Av. Passengers			270	2700	4622
Collision	17	6.36E-03	9.6E-03	5.7E-02	7.3E-02
Contact	22	8.23E-03	1.0E-02	2.0E-02	1.8E-02
Grounding	26	9.73E-03	2.1E-02	8.3E-02	6.5E-02
Fire / Explosion	21	7.86E-03	2.7E-03	1.3E-02	2.1E-02
Total	--	3.22E-02	4.3E-02	1.7E-01	1.8E-01

The FN diagrams for the three reference ship types are shown in Fig. 8.57, Fig. 8.58 and Fig. 8.59. The risk areas in these figures (negligible, ALARP and intolerable risk) are determined using updated r-value (fatalities per billion $ turnover), an average turnover of 50,000 $ per passenger year and the average number of passengers. So the risk is calculated considering all persons on board (360, 3,600 and 6,057) whereas the thresholds relate to the societal benefit in terms of turnover (passengers: 270, 2,700 and 4,622).

As shown by these figures all ship size categories are in the ALARP area, only for small cruise ships some parts of the FN curve are in the region of intolerable risk. However, the above mentioned consideration of ECDIS would reduce the risk of grounding and move the FN curve into the ALARP area (Fig. 8.60).

It should be mentioned that these results depend also on the model used for estimating the attained index for grounding and contact damages. The effect of this model can be seen when comparing Fig. 8.58 and Fig. 8.60 that show FN curves for Medium cruise ship considering Eq. 1 (Fig. 8.58) and Eq. 2 (Fig. 8.61).

The shape of the FN curve relates to the assumptions used when developing the risk models. The consequence in terms of fatalities assigned to a scenario in the risk model is always a value representative for the consequences of all similar scenarios. The group of similar scenarios will lead to different numbers of fatality. In order to keep the risk model manageable similar scenarios are merged and a representative number of fatalities assigned. For GOALDS focusing on damage stability the risk model consider two representative fatality

[16] POB: person on board considers passengers and crew; maximum POB nominal passenger capacity plus crew (see also Table 8.4)

rates (5% and 80%). Due to the fact that CN and GR are the major risk contributors the shape of FN curve is dominated by these accident categories. It should be noted that for the evaluation of risk control options by cost benefit assessment the risk in terms of PLL is used which is independent of the granularity of the consequences.

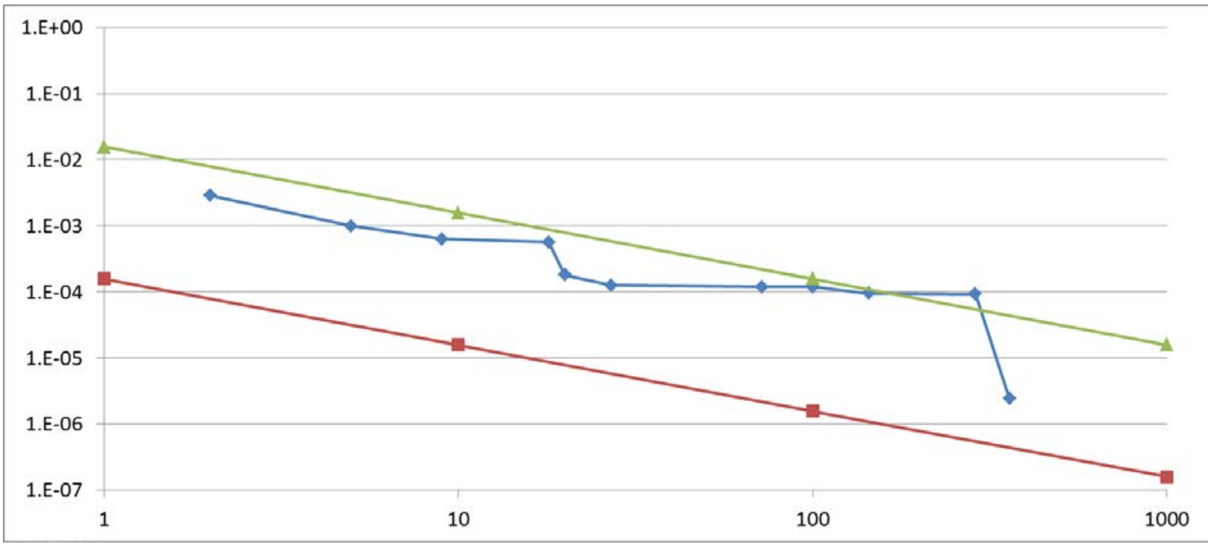


Fig. 8.57: FN diagram for “Small” Cruise (POB=400)

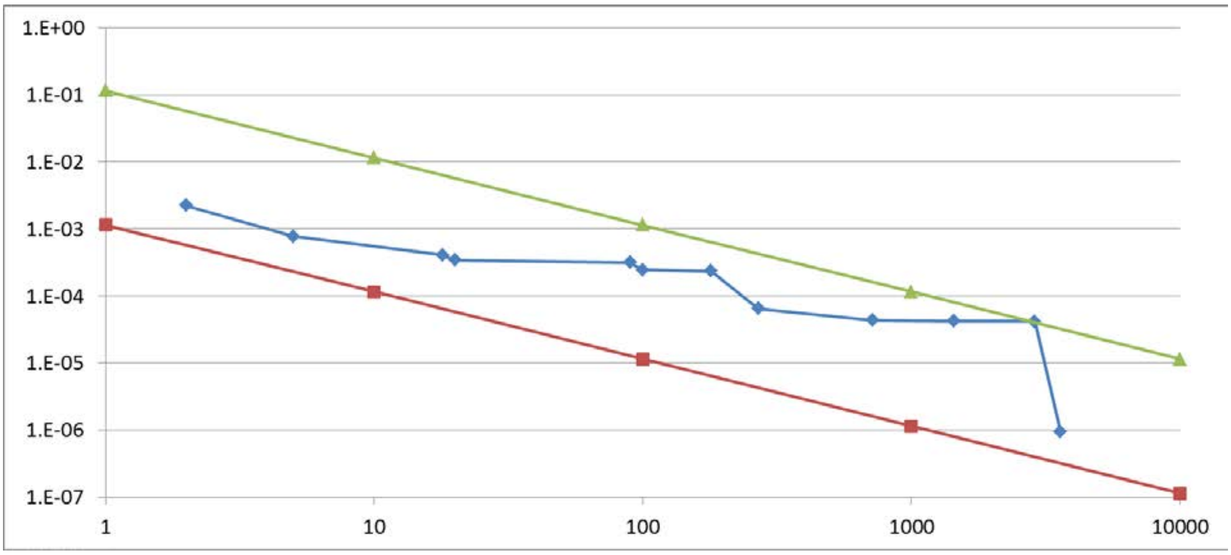


Fig. 8.58: FN diagram for “Medium” Cruise (POB=4,000)

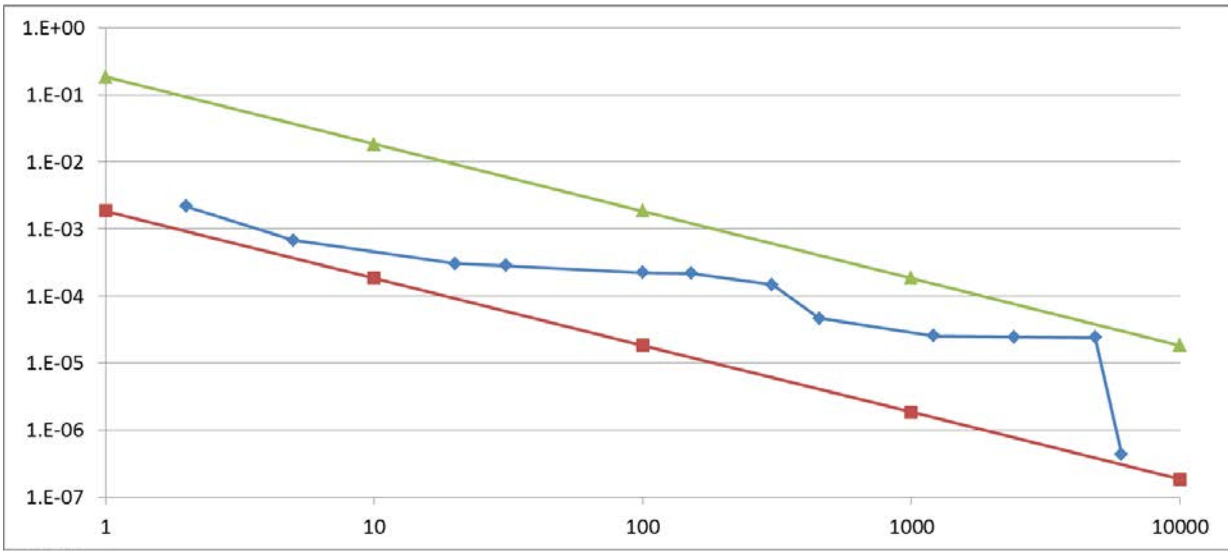


Fig. 8.59: FN diagram for “Large” Cruise (POB=6,730)

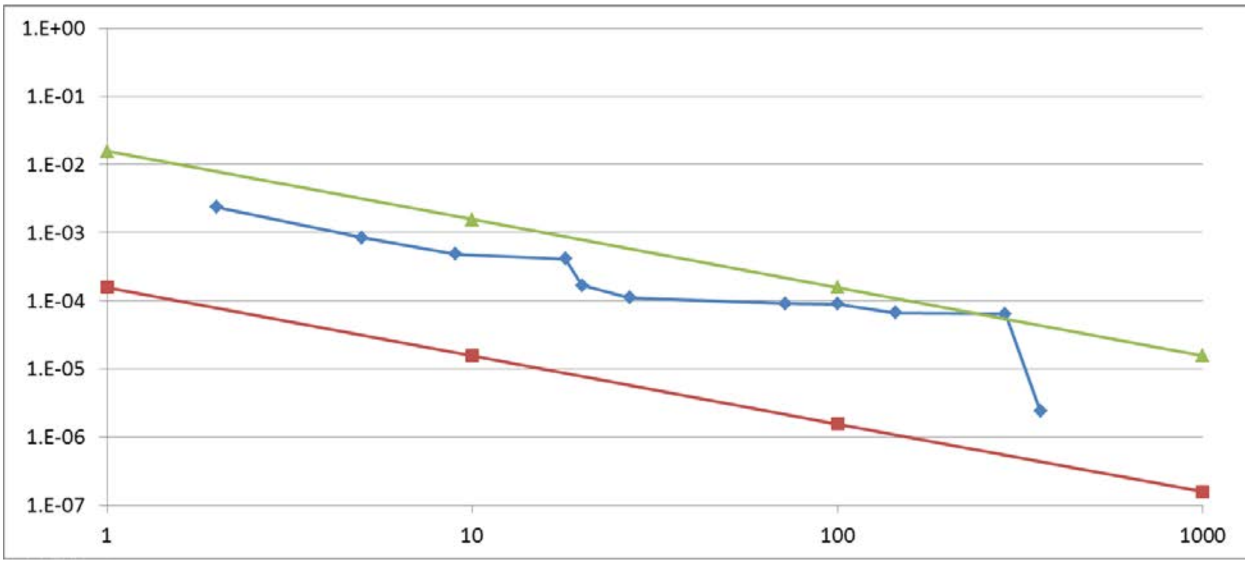


Fig. 8.60: FN diagram for “Small” Cruise (POB=400) considering the effect of ECDIS

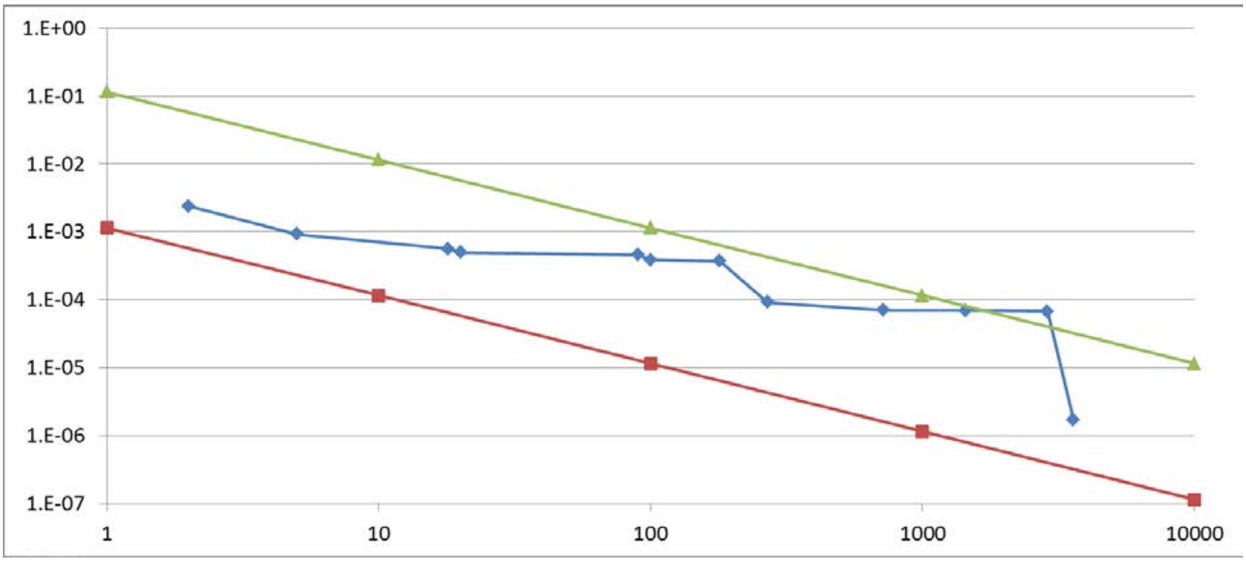


Fig. 8.61: FN diagram for "Medium" Cruise (POB=4000) considering the effect of Eq. 1 of damage stability index for grounding

The individual risk (IR) for a person on board of a cruise vessel is calculated for different units, e.g. per hour, per journey (7 or 14 days) and results are summarised in Table 8.6, Table 8.7 and Table 8.8. As mentioned above the occupancy/utilisation rate is assumed to be 90%. For calculating the individual risk of a person per hour on board of a cruise ship the PLL per ship year is divided by the number of operating hours per year based on the assumption that a cruise vessel typically operates 360 days per year and is at sea for 12 hours per day. Furthermore, more relevant for the cruise segment; the risk for two typical journeys (7 days and 14 days) is calculated. These data provide the information to calculating the individual risk for person with different exposure time. In order to make the results comparable to other transport means risk in terms of fatalities per billion passenger hours and billion passenger kilometres is calculated.

Table 8.6: Journey dependent individual risk for "Small" Cruise

SMALL							
Max POB	300		7 days	14 days			
Crew	100	No Days operation	360	360	Speed	15	kn
		Hrs. at sea per day	12	12		27.8	km/h
Occupancy ø	90%	No of days/journey	7	14			
POB ø	360	Hrs per trip	84	168	Annual Pax km	3.2E+07	
		Hrs per year	4320	4320			
	PLL	Individual Risk					
	Fat per ship year					per 10^9 passenger hrs	per 10^9 passenger km
CN	9.56E-03	per person hr	6.1E-09	6.1E-09		6.1E+00	2.2E-01
		per journey	5.2E-07	1.0E-06			
CT	1.00E-02	per person hr	6.4E-09	6.4E-09		6.4E+00	2.3E-01
		per journey	5.4E-07	1.1E-06			
GR	2.12E-02	per person hr	1.4E-08	1.4E-08		1.4E+01	4.9E-01
		per journey	1.1E-06	2.3E-06			
FX	2.74E-03	per person hr	1.8E-09	1.8E-09		1.8E+00	6.3E-02
		per journey	1.5E-07	3.0E-07			
Total	4.35E-02	per person hr	2.8E-08	2.8E-08		2.8E+01	1.0E+00
		per journey	2.3E-06	4.7E-06			

Table 8.7: Journey dependent individual risk for "Medium" Cruise

Medium							
Max POB	3000		7 days	14 days			
Crew	1000	No Days operation	360	360	Speed	15	kn
		Hrs. at sea per day	12	12		27.8	km/h
Occupancy ø	90%	No of days/journey	7	14			
POB ø	3600	Hrs per trip	84	168	Annual Pax km	3.2E+08	
		Hrs per year	4320	4320			
	PLL	Individual Risk					
	Fat per ship year					per 10^9 passenger hrs	per 10^9 passenger km
CN	5.68E-02	per person hr	3.7E-09	3.7E-09		3.7E+00	1.3E-01
		per journey	3.1E-07	6.1E-07			
CT	1.97E-02	per person hr	1.3E-09	1.3E-09		1.3E+00	4.6E-02
		per journey	1.1E-07	2.1E-07			
GR	8.28E-02	per person hr	5.3E-09	5.3E-09		5.3E+00	1.9E-01
		per journey	4.5E-07	8.9E-07			
FX	1.33E-02	per person hr	8.5E-10	8.5E-10		8.5E-01	3.1E-02
		per journey	7.2E-08	1.4E-07			
Total	1.73E-01	per person hr	1.1E-08	1.1E-08		1.1E+01	4.0E-01
		per journey	9.3E-07	1.9E-06			

Table 8.8: Journey dependent individual risk for "Large" Cruise

Large								
Max POB	5135		7 days	14 days				
Crew	1595	No Days operation	360	360	Speed	15	kn
		Hrs. at sea per day	12	12		27.8	km/h
Occupancy ø	90%	No of days/journey	7	14			
POB ø	6057	Hrs per trip	84	168	Annual Pax km	5.5E+08	
		Hrs per year	4320	4320			
	PLL	Individual Risk					
	Fat per ship year					per 10^9 passenger hrs	per 10^9 passenger km
CN	7.31E-02	per person hr	2.8E-09	2.8E-09		2.8E+00	1.0E-01
		per journey	2.3E-07	4.7E-07			
CT	1.78E-02	per person hr	6.8E-10	6.8E-10		6.8E-01	2.5E-02
		per journey	5.7E-08	1.1E-07			
GR	6.50E-02	per person hr	2.5E-09	2.5E-09		2.5E+00	8.9E-02
		per journey	2.1E-07	4.2E-07			
FX	2.14E-02	per person hr	8.2E-10	8.2E-10		8.2E-01	2.9E-02
		per journey	6.9E-08	1.4E-07			
Total	1.77E-01	per person hr	6.8E-09	6.8E-09		6.8E+00	2.4E-01
		per journey	5.7E-07	1.1E-06			

8.3.4.2 RoPax

Using the risk models for the different accident categories the risk to persons on board of RoPax ships is calculated in terms of potential loss of life (PLL). Occupancy rates have been updated to 100% utilisation for 12.5% of the year, 75% utilisation for 25% of the year and 50% utilisation for the rest of the year[17]). The results are summarised in Table 8.9 below.

As shown by these PLL values the main risk contributor is collision (~40%). Flooding contributes to about 20% of total risk which is lower than the results of SAFEDOR FSA, where a contribution of 50% was calculated.

The FN diagrams for the three representative ship sizes are shown in Fig. 8.62, Fig. 8.63 and Fig. 8.64. Like for cruise ships the thresholds for the risk regions negligible – ALARP – intolerable are calculated considering the annual average of passengers (282; 1318; 1875) and the turnover per passenger (50,000 $ per passenger and year) whereas the risk is calculated considering all persons on board (passenger and crew considering occupancy rates).

Table 8.9: Risk for RoPax ships in terms of PLL based on average accident frequency 2000 to 2012

	Time Period 2000 - 2012				
	No of casualties	**Frequencies**	**PLL**		
		Ship year $^{-1}$	Ship year $^{-1}$		
			Small	Medium	Large
Max. POB			500	2,240	3,280
Av. Number passenger			282	1318	1875
Collision	53	9.95E-03	5.5E-02	1.7E-01	2.1E-01
Contact/Impact	86	1.61E-02	2.7E-03	1.2E-02	1.7E-02
Grounding	37	6.94E-03	3.0E-02	7.0E-02	7.2E-02
Fire/Explosion	24	4.50E-03	1.3E-02	5.5E-02	8.2E-02
Flooding	10	1.88E-03	2.2E-02	7.8E-02	1.1E-01
Total	--	3.49E-02	1.2E-01	3.9E-01	4.9E-01

As shown the societal risk for RoPax vessel is partly in the region of intolerable risk, which is also an effect by the updated thresholds for fatalities per billion $, which is, as mentioned above, about eight times lower than the value determined in 1999. Also the effect of Stockholm agreement was considered only with respect to the probability of sinking after door damage, and not for other accident categories. For comparison the FN diagram for medium

[17] These utilisation rates were provided by the project partners

RoPax vessel using the same threshold as applied in SAFEDOR is shown in Fig. 8.65 and here the societal risk is in the ALARP region[18].

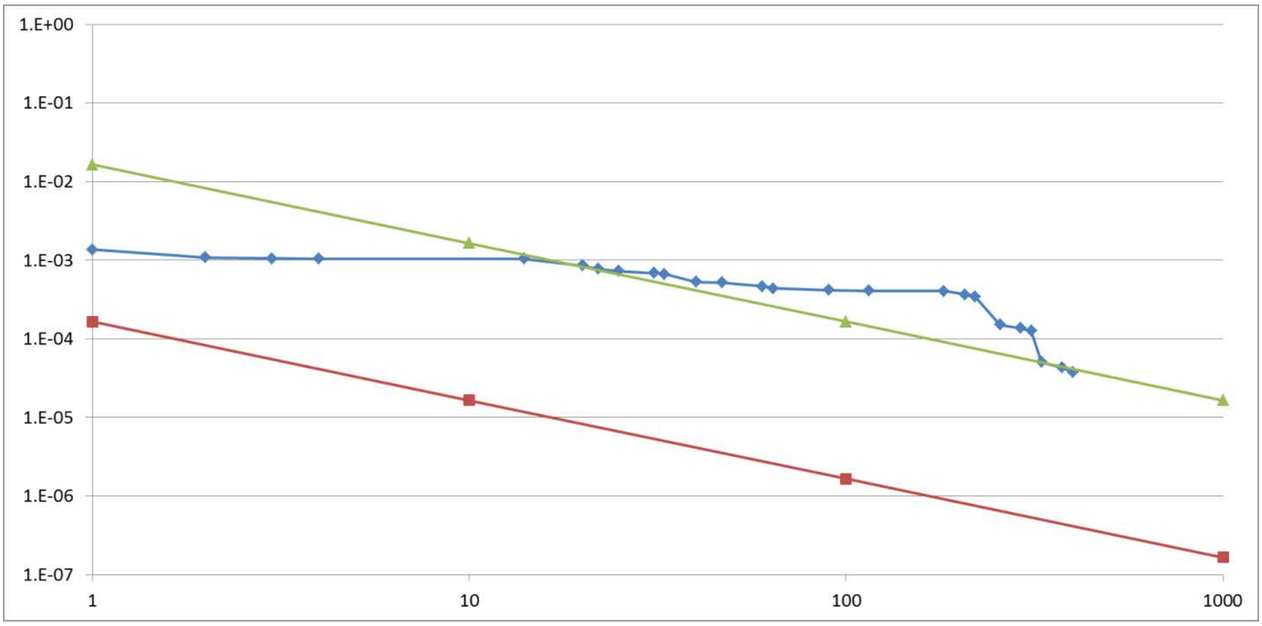


Fig. 8.62: FN diagram for "Small" RoPax considering seasonal passenger numbers

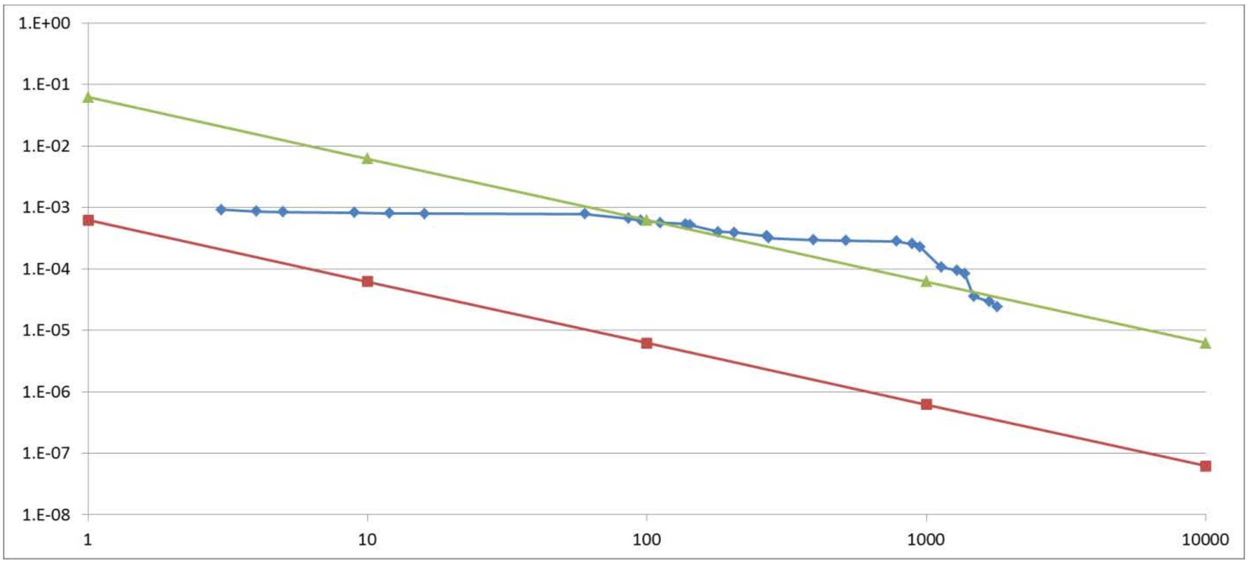


Fig. 8.63: FN diagram for "Medium" RoPax considering seasonal passenger numbers

[18] This comparison shows also the importance of regular update of both the r-value as well as the economic value of the activity

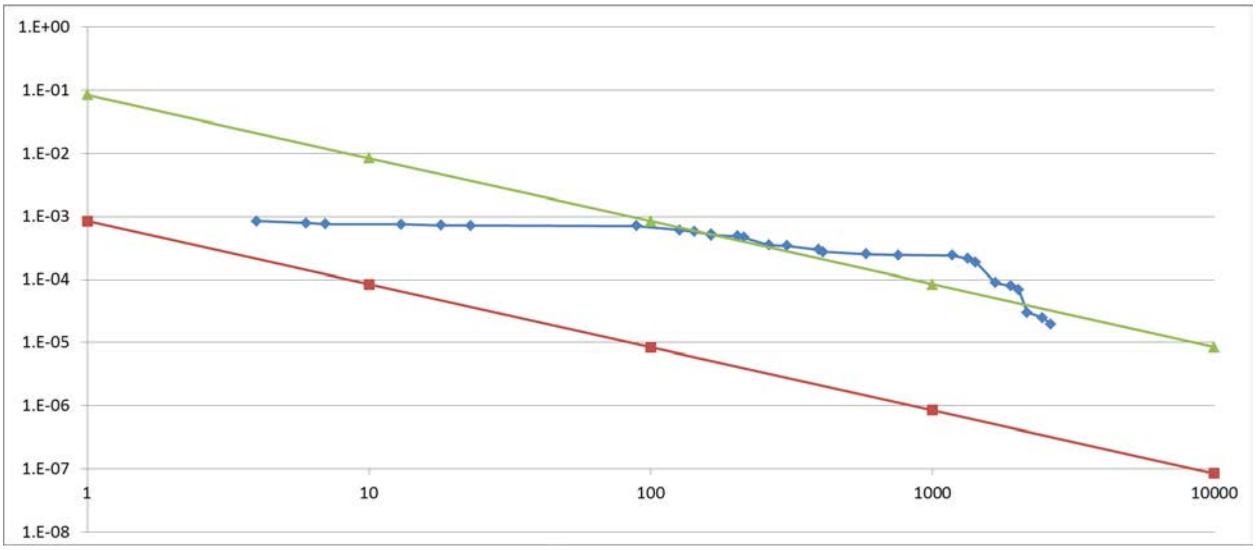


Fig. 8.64: FN diagram for "Large" RoPax considering seasonal passenger numbers

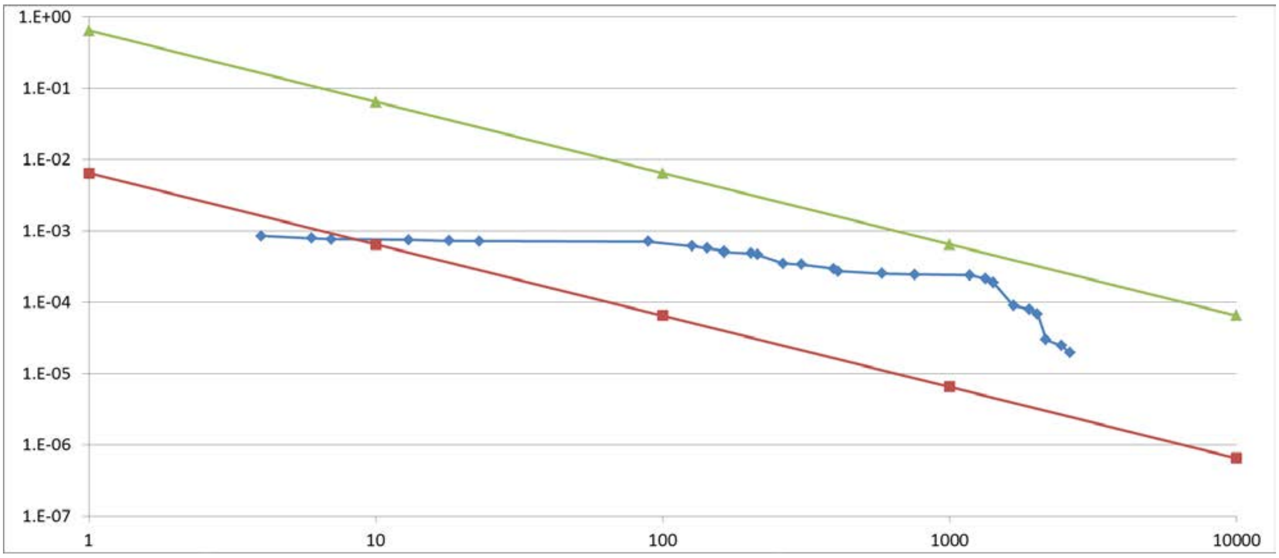


Fig. 8.65: FN diagram for "Medium" RoPax considering seasonal passenger numbers and old threshold values for fatalities

Individual risk values are calculated for passengers on RoPax of different size and two representative journeys, one between Dover and Calais and the other between Kiel and Oslo (for small RoPax only Dover – Calais) and are summarised in Table 8.10, Table 8.12 and Table 8.14. For one of the trips the risk in terms of fatalities per billion passenger hours and fatalities per billion passenger kilometres is calculated from PLL and characteristic operational data and summarised in Table 8.11, Table 8.13 and Table 8.15.

Table 8.10: Journey dependent individual risk for “Small” RoPax

SMALL				
Pax	450		Kiel - Oslo	Calais-Dover
Crew	50	No Days operation per year		360
Total	500	At sea per trip (hrs)		1.5
Load	%-year	No of trips per day		10
100%	12.5%	Hrs per day		15
75%	25.0%	Hrs per year		5400
50%	62.5%			
POB	332			
	PLL	IR		
	per ship year			
CN	5.54E-02	per hr		3.1E-08
		per journey		4.6E-08
CT	2.70E-03	per hr		1.5E-09
		per journey		2.3E-09
GR	2.97E-02	per hr		1.7E-08
		per journey		2.5E-08
FX	1.26E-02	per hr		7.1E-09
		per journey		1.1E-08
FL	2.19E-02	per hr		1.2E-08
		per journey		1.8E-08
Total	1.22E-01	per hr		6.8E-08
		per journey		1.0E-07

Table 8.11: Individual risk in terms of fatalities per 10^9 person hours and 10^9 person kilometres for "Small" RoPax (Calais-Dover)

SMALL				
Pax	450			
Crew	50	Speed	18	kn
Total	500		33.3	km/h
		Annual Pax km	8.0E+07	
POB	332			
	PLL			
	Fat per ship year	per person hr	per 10^9 passenger hrs	per 10^9 passenger km
CN	5.54E-02	2.3E-08	2.3E+01	7.0E-01
CT	2.70E-03	1.1E-09	1.1E+00	3.4E-02
GR	2.97E-02	1.2E-08	1.2E+01	3.7E-01
FX	1.26E-02	5.3E-09	5.3E+00	1.6E-01
FL	2.19E-02	9.2E-09	9.2E+00	2.8E-01
Total	1.22E-01	5.1E-08	5.1E+01	1.5E+00

Table 8.12: Journey dependent individual risk for “Medium” RoPax

Medium (Med)				
Pax	2108		Kiel - Oslo	Calais-Dover
Crew	132	No Days operation per year	360	360
Total	2240	At sea per trip (hrs)	20	1.5
Load	%-year	No of trips per day	1	10
100%	12.5%	Hrs per day	20	15
75%	25.0%	Hrs per year	7200	5400
50%	62.5%			
POB	1450			
	PLL	IR		
	per ship year			
CN	1.70E-01	per hr	1.6E-08	2.2E-08
		per journey	3.3E-07	3.3E-08
CT	1.16E-02	per hr	1.1E-09	1.5E-09
		per journey	2.2E-08	2.2E-09
GR	7.00E-02	per hr	6.7E-09	8.9E-09
		per journey	1.3E-07	1.3E-08
FX	5.52E-02	per hr	5.3E-09	7.1E-09
		per journey	1.1E-07	1.1E-08
FL	7.75E-02	per hr	7.4E-09	9.9E-09
		per journey	1.5E-07	1.5E-08
Total	3.84E-01	per hr	3.7E-08	4.9E-08
		per journey	7.4E-07	7.4E-08

Table 8.13: Individual risk in terms of fatalities per 10^9 person hours and 10^9 person kilometres for "Medium" RoPax (Kiel-Oslo)

Medium (Med)				
Pax	2108			
Crew	132	Speed	18	kn
Total	2240		33.3	km/h
		Annual Pax km	3.5E+08	
POB	1450			
	PLL			
	Fat per ship year	per person hr	per 10^9 passenger hrs	per 10^9 passenger km
CN	1.70E-01	1.6E-08	1.6E+01	4.9E-01
CT	1.16E-02	1.1E-09	1.1E+00	3.3E-02
GR	7.00E-02	6.7E-09	6.7E+00	2.0E-01
FX	5.52E-02	5.3E-09	5.3E+00	1.6E-01
FL	7.75E-02	7.4E-09	7.4E+00	2.2E-01
Total	3.84E-01	3.7E-08	3.7E+01	1.1E+00

Table 8.14: Journey dependent individual risk for “Large” RoPax

Large (Baltic)				
Pax	3000		Kiel - Oslo	Calais-Dover
Crew	280	No Days operation per year	360	360
Total	3280	At sea per trip (hrs)	20	1.5
Load	%-year	No of trips per day	1	10
100%	12.5%	Hrs per day	20	15
75%	25.0%	Hrs per year	7200	5400
50%	62.5%			
POB	2155			
	PLL	IR		
	per ship year			
CN	2.14E-01	per hr	1.4E-08	1.8E-08
		per journey	2.8E-07	2.8E-08
CT	1.73E-02	per hr	1.1E-09	1.5E-09
		per journey	2.2E-08	2.2E-09
GR	7.24E-02	per hr	4.7E-09	6.2E-09
		per journey	9.3E-08	9.3E-09
FX	8.21E-02	per hr	5.3E-09	7.1E-09
		per journey	1.1E-07	1.1E-08
FL	1.05E-01	per hr	6.8E-09	9.1E-09
		per journey	1.4E-07	1.4E-08
Total	4.91E-01	per hr	3.2E-08	4.2E-08
		per journey	6.3E-07	6.3E-08

Table 8.15: Individual risk in terms of fatalities per 10^9 person hours and 10^9 person kilometres for "Large" RoPax (Kiel-Oslo)

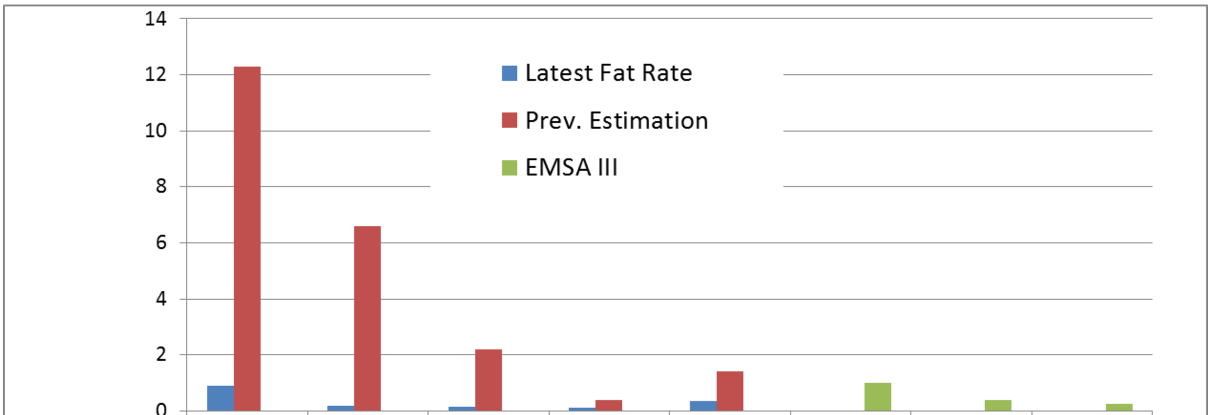
Large (Baltic)				
Pax	3000			
Crew	280	Speed	18	kn
Total	3280		33.3	km/h
		Annual Pax km	5.2E+08	
POB	2170			
	PLL			
	Fat per ship year	per person hr	per 10^9 passenger hrs	per 10^9 passenger km
CN	2.14E-01	1.4E-08	1.4E+01	4.1E-01
CT	1.73E-02	1.1E-09	1.1E+00	3.3E-02
GR	7.24E-02	4.7E-09	4.7E+00	1.4E-01
FX	8.21E-02	5.3E-09	5.3E+00	1.6E-01
FL	1.05E-01	6.8E-09	6.8E+00	2.0E-01
Total	4.91E-01	3.2E-08	3.2E+01	9.5E-01

9 CONCLUSIONS

Based on the risk models provided by the SAFEDOR FSA on cruise ships and its update in the GOALDS project, the risk for cruise ships is calculated considering updated initial accident frequencies (based on historical data for the period from 2000 to 2012) and the effect of SOLAS 2009 with respect to damage stability. Additionally, risk models are updated based on information provided by most recent casualty reports of IHS Fairplay database.

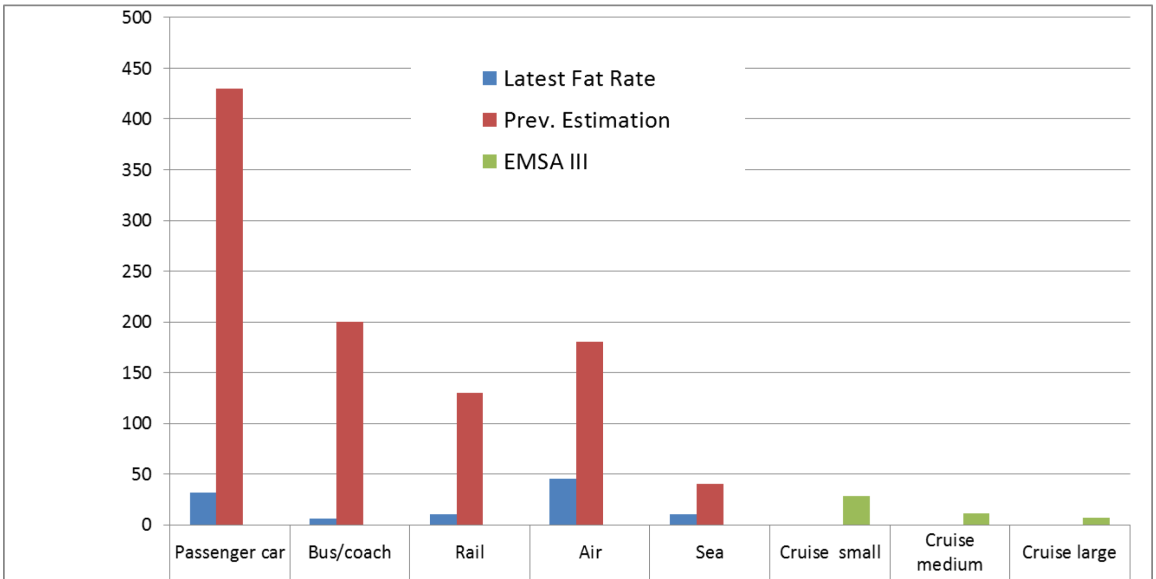
The evaluation of the risk analysis by means of FN diagram show that all reference ship size categories of cruise ships are in the ALARP risk area. The comparison of these results with characteristic data for other transport modes taken from part 2 (Appendix B) of this report showed no particularities. For instance, in Fig. 9.1, the comparison in terms of fatalities per billion passenger kilometres is shown considering other transport modes: passenger car, bus/coach, rail and air and for these the latest fatality rate from EU (“Latest Fat Rate”) and the previous estimate (“Prev. Estimation”) based on EU data up to 2001 combined with a trend adjustment to 2007 are presented. It is worth to mention that “Latest Fat Rate” can be regarded as a lower bound because of effects like under-reporting and “Prev. Estimation” as an upper bound respectively. However, it is also mentioned that these data for other modes were determined considering different basic population, e.g. historical data for “sea” ” includes personal and major accidents, whereas the predictions include only major accidents, or assumptions used for estimation, e.g. the predictions are sensitive to the assumed consequences (fatality rates) in the sinking scenarios which have not been calibrated against historical data. Furthermore, “sea” combines data on cruise, RoPax and small passenger ships in EU waters only. However, even considering these limitations it is concluded that the risk for Cruise is in the expected range (compared to “sea”) and in similar range compared to other modes.

Respective results regarding the comparison to other modes of transport in terms of billion passenger hours are shown in Fig. 9.2. Additionally, comparing Fig. 9.1 and Fig. 9.2 for air demonstrate the effect of “risk dimension”. Due to the high speed of air transport the number of passenger kilometres cast a much positive light on the risk level than the dimension of passenger hours.



	Passenger car	Bus/coach	Rail	Air	Sea	Cruise small	Cruise medium	Cruise large
Latest Fat Rate	0.9	0.2	0.16	0.1	0.34			
Prev. Estimation	12.3	6.6	2.2	0.4	1.4			
EMSA III						1.01	0.40	0.24

Fig. 9.1: Comparison between different transport modes in terms of fatalities per billion passenger km



	Passenger car	Bus/coach	Rail	Air	Sea	Cruise small	Cruise medium	Cruise large
Latest Fat Rate	32	6	10	45	10			
Prev. Estimation	430	200	130	180	40			
EMSA III						27.95	11.09	6.78

Fig. 9.2: Comparison between different transport modes in terms of fatalities per billion passenger hours

Evaluating the results for RoPax ships by means of societal risk with the updated threshold values for intolerable risk, it showed that the FN curve partly lies in the area of intolerable risk (Fig. 8.62, Fig. 8.63 and Fig. 8.64). One reason for this significant change in the FN evaluation, compared to the SAFEDOR FSA, is the use of *updated boundaries for the risk areas*. As explained in section 8.3.4 of this report and in Appendix A of part 2 the relation between risk and turnover in the reference air industry has been significantly changed within the last 15 years leading to lower boundaries for the risk acceptance areas. This conclusion is also supported by the comparison between the PLL results of this analysis and that of the SAFEDOR FSA (Table 9.1) showing a similar risk level.

The results for RoPax ships in terms of PLL show that the main risk contributor is collision with about 40% of total risk. This accident category and grounding will be further investigated in subsequent Tasks of this project and there may be a feedback to the present assessment, especially with respect to the grounding accidents (task 3) and even the contact accidents.

However, as mentioned above, the risk evaluation on the basis of the FN diagram should be used as a benchmark indicating that additional risk control options should be analysed, rather than as a strict assessment criterion. This conclusion is also supported by a similar comparison to other modes of transport like above for Cruise shown in Fig. 9.3 and Fig. 9.4:

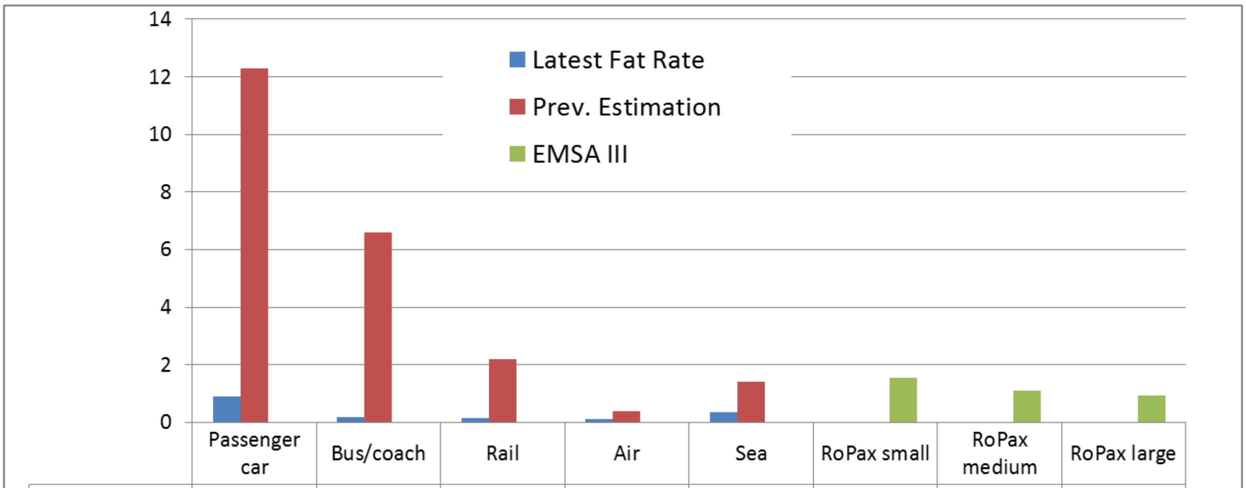
- Risk of transport by sea for RoPax in terms of fatalities per 10^9 passenger kilometres
    - o is slightly above values for “Prev. Estimation” for sea transport, but significantly higher than “Latest Fat Rate” results for all means of transport
    - o is significantly lower than “Prev. Estimation” for passenger car and bus/coach

- is lower than “Prev. Estimation” for rail
- is higher than “Prev. Estimation” for air transport

- risk of transport by sea for RoPax in terms of fatalities per 10^9 passenger hours
  - is roughly the same as “Prev. Estimation” for sea transport
  - is about four to six times higher than “Latest Fat Rate” values for sea transport
  - is significantly lower than “Prev. Estimation” for all other means of transport
  - is about the same compared to “Latest Fat Rate” values for passenger car and air transport but higher than for bus/coach.

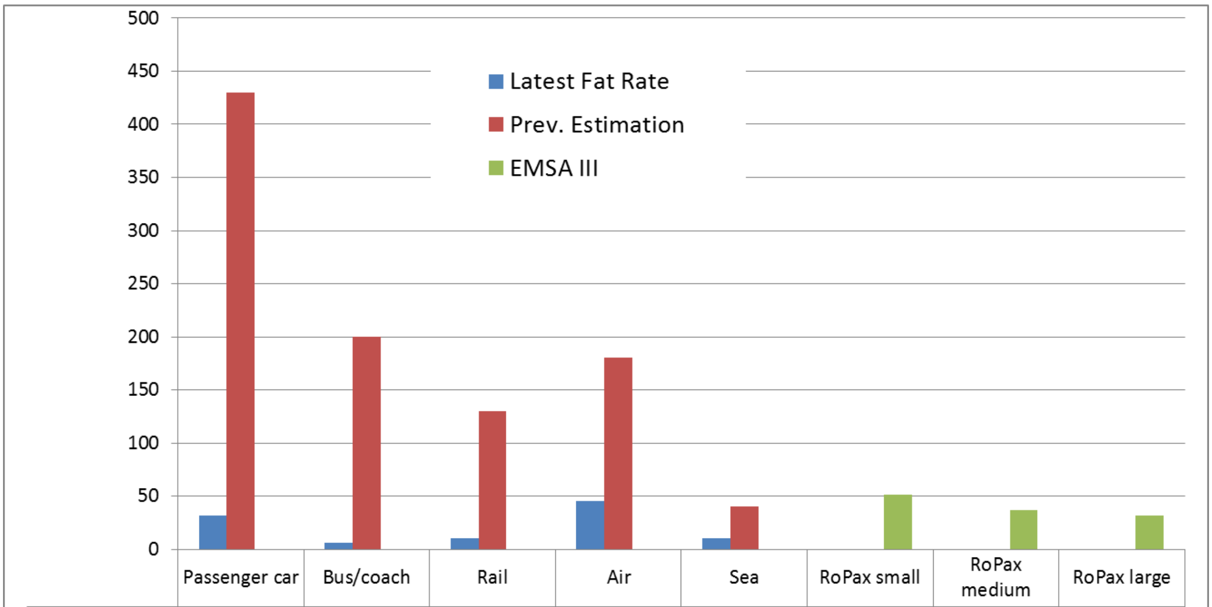
Table 9.1: Comparison of risk results in terms of PLL from this investigation and SAFEDOR FSA for RoPax

	This investigation					SAFEDOR FSA
	No Acc.	Accident freq.	Ship size			
			small	medium	large	
Max POB			500	2,240	3,280	1,100
Collision	53	9.95E-03	5.5E-02	1.7E-01	2.1E-01	2.34E-02
Contact / Impact	86	1.61E-02	2.7E-03	1.2E-02	1.7E-02	1.39E-03
Grounding	37	6.94E-03	3.0E-02	7.0E-02	7.2E-02	2.57E-02
Fire / Explosion	24	4.50E-03	1.3E-02	5.5E-02	8.2E-02	5.95E-02
Flooding	10	1.88E-03	2.2E-02	7.8E-01	1.1E-01	1.12E-01
Total	--	3.49E-02	1.23E-01	3.85E-01	4.91E-01	2.22E-01



	Passenger car	Bus/coach	Rail	Air	Sea	RoPax small	RoPax medium	RoPax large
Latest Fat Rate	0.9	0.2	0.16	0.1	0.34			
Prev. Estimation	12.3	6.6	2.2	0.4	1.4			
EMSA III						1.54	1.10	0.95

Fig. 9.3: Comparison between different transport modes in terms of fatalities per billion passenger km



	Passenger car	Bus/coach	Rail	Air	Sea	RoPax small	RoPax medium	RoPax large
Latest Fat Rate	32	6	10	45	10			
Prev. Estimation	430	200	130	180	40			
EMSA III						51.20	36.79	31.64

Fig. 9.4: Comparison between different transport modes and RoPax in terms of fatalities per billion passenger hours

This comparison between the risk for cruise and RoPax vessel and other transport modes shows that the evaluation greatly depends on the metric used. An evaluation of the risk in terms of *fatalities per billion kilometres* is beneficial for all transport means with a *high velocity*, with inferior performance of sea transport. When evaluating the risk in terms of passenger hours, however, then comparative data are more uniform among all modes of transport. Following the Formal Safety Assessment guidelines it is recommended to evaluate the risk of ships in terms of *fatalities per ship year*. As shown by the FN diagrams the risk for RoPax vessel is partly in the area of intolerable risk, when considering the updated threshold values, whereas the risk for cruise ships is in tolerable risk area.

10 REFERENCES

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ANNEX A

For the purpose of the present study, the casualty database used in the GOALDS project was updated in order to include additional casualty records (Task 1). It was also further developed in terms of structure to accommodate information relevant to Task 3 of this project.

Briefly, the update of the casualty database, with respect to Task 1 work, is focusing on the followings:

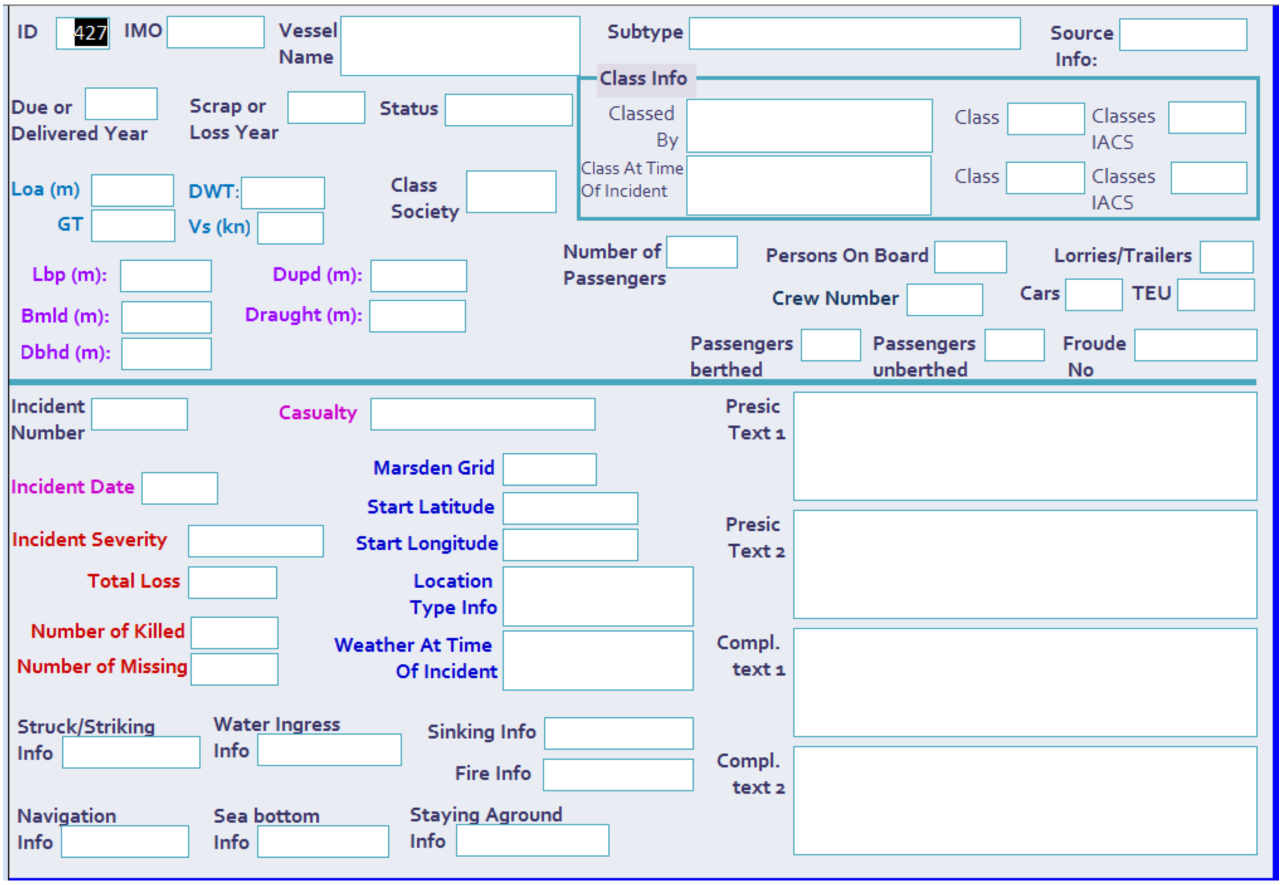
- Regarding collision and grounding events, new records were imported to the database in order to extend the time period from 2009 up to 2012.
- Contact events were inserted to the database concerning the period 1990-2012 since in GOALDS project the particular records had been excluded from the relevant work analysis.
- All records were reviewed and populated accordingly.
- Initial casualty information is coming from IHS database. This information was enhanced from other sources especially in cases where accident investigating reports were available.

The calculation of the frequencies of initiating event is based on the reviewed data and follows the filtering described in section 8.1.

For the purpose of the project study, the following have been considered:

- *Collision event:* striking or being struck by another ship (regardless of whether under way, anchored or moored).
- *Grounding event:* being aground, or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.) including reefs or hitting submerged rocks.
- *Contact:* impact with fixed installation or object which extends over the surface level, or impact with a floating object.
- Captured accidents were assigned to one of the predefined main incident categories according to the last “accidental event”.

Screen Shot of SDL Casualty Database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IMO
Vessel Name
Subtype
Source Info:
Class Info
Classed By
Class
Classes IACS
Class At Time Of Incident
Class
Classes IACS
Due or Delivered Year
Scrap or Loss Year
Status
Loa (m)
DWT:
Class Society
GT
Vs (kn)
Number of Passengers
Persons On Board
Lorries/Trailers
Lbp (m):
Dupd (m):
Crew Number
Cars
TEU
Bmld (m):
Draught (m):
Dbhd (m):
Passengers berthed
Passengers unberthed
Froude No
Incident Number
Casualty
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Marsden Grid
Incident Date
Start Latitude
Incident Severity
Start Longitude
Presic Text 2
Total Loss
Location Type Info
Number of Killed
Weather At Time Of Incident
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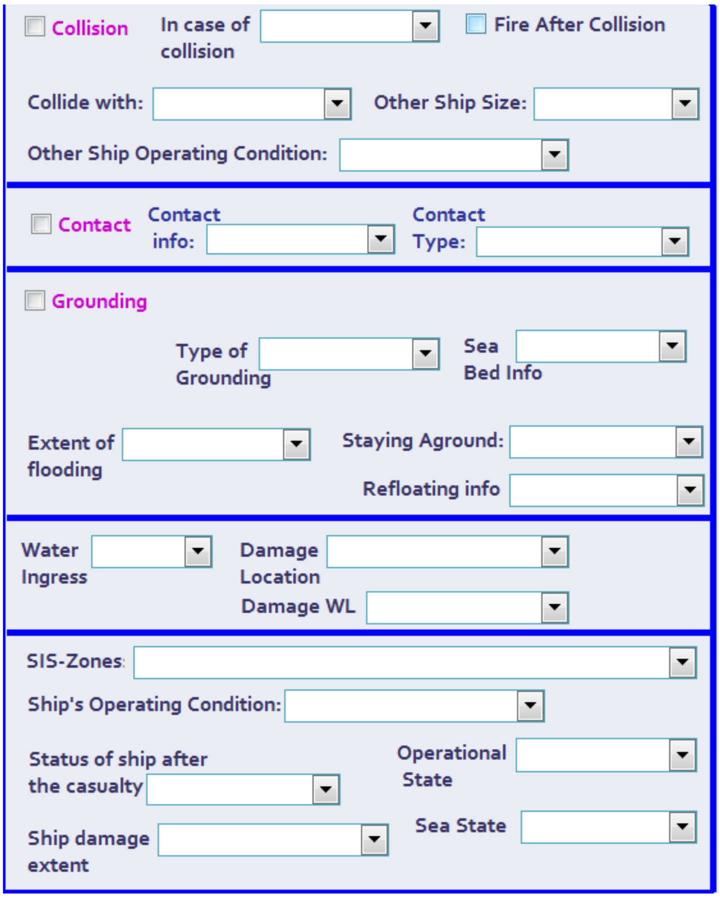
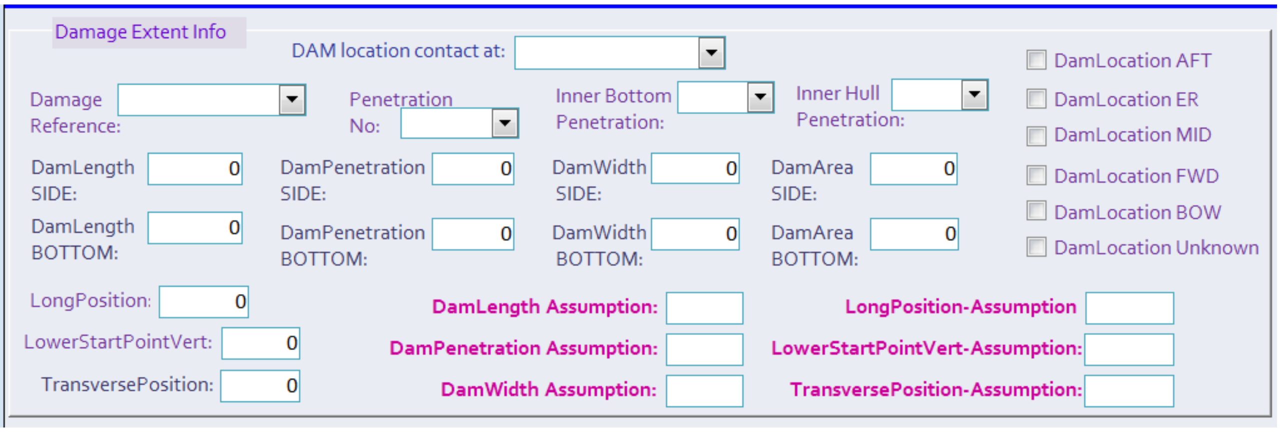
Struck/Striking Info
Water Ingress Info
Sinking Info
Fire Info
Compl. text 2
Navigation Info
Sea bottom Info
Staying Aground Info


Collision
In case of collision
Fire After Collision
Collide with:
Other Ship Size:
Other Ship Operating Condition:
Contact
Contact info:
Contact Type:
Grounding
Type of Grounding
Sea Bed Info
Extent of flooding
Staying Aground:
Refloating info
Water Ingress
Damage Location
Damage WL
SIS-Zones
Ship's Operating Condition:
Status of ship after the casualty
Operational State
Ship damage extent
Sea State


Damage Extent Info
DAM location contact at:
Damage Reference:
Penetration No:
Inner Bottom Penetration:
Inner Hull Penetration:
DamLocation AFT
DamLocation ER
DamLocation MID
DamLocation FWD
DamLocation BOW
DamLocation Unknown
DamLength SIDE: 0
DamPenetration SIDE: 0
DamWidth SIDE: 0
DamArea SIDE: 0
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DamPenetration BOTTOM: 0
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DamArea BOTTOM: 0
LongPosition: 0
LowerStartPointVert: 0
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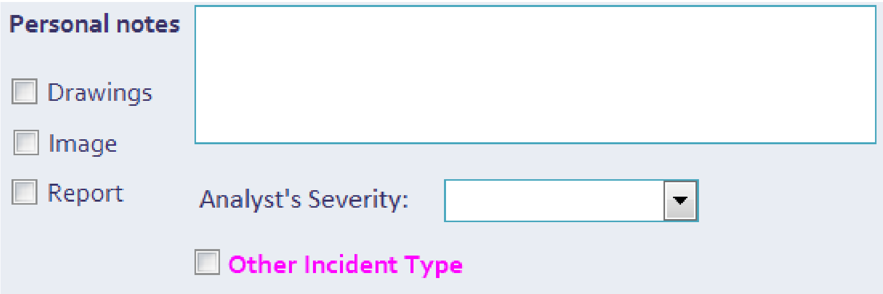
DamWidth Assumption:
LongPosition-Assumption
LowerStartPointVert-Assumption:
TransversePosition-Assumption:


Personal notes
Drawings
Image
Report
Analyst's Severity:
Other Incident Type

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