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FORMAL SAFETY ASSESSMENT
FSA Group of Experts

Comments on FSA studies by Denmark

LNG carriers
Container vessels
Crude oil tankers
Cruise vessels
RoPax ships

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0. Introduction- General comments

This document can be considered as an unabridged version of doc. MSC 86/17/2, providing supporting details on the position of Greece on the 5 FSA studies submitted by Denmark.

At its 85th session, the Committee invited Member Governments and international organizations to submit, to MSC 86, comments on the FSA studies submitted for review and proposals regarding the terms of reference of the FSA Experts Group (MSC 85/17/2, section 2, MSC 85/26, section 17.9).

Specifically, this document comments on documents

- MSC 83/21/1
- MSC 83/INF.3
- MSC 83/21/2
- MSC 83/INF.8
- MEPC 58/17/2
- MEPC 58/17/INF.2
- MSC 85/17/1
- MSC 85/INF.2
- MSC 85/17/2 and
- MSC 85/INF.3

(all submitted by Denmark).

The above documents pertain to high-level FSA studies on LNG carriers, container vessels, crude oil tankers, cruise ships and RoPax ships. All studies were conducted as part of EU research project SAFEDOR.

MSC 83 has agreed to convene a FSA expert Group with the purpose of reviewing the FSA studies submitted to the IMO, and this group is expected to meet for the first time during MSC 86.

It is believed that he results of any set of FSA studies collectively involving a large subset of the world's commercial fleet must be of particular interest to the world shipping community. The FSA studies by Denmark certainly fall into this category, and the effort of the SAFEDOR project team and of Denmark to conduct these studies and bring them to the attention of the IMO is appreciated.

At the same time, and in view of the seriousness and far-reaching ramifications of some of the measures proposed in several of these studies, we are of the opinion that these studies should be able to withstand serious scrutiny and peer review by independent reviewers (see also doc. MSC 86/17/1 para. 6).

FSA should be one of the prime tools for IMO proactive safety regulation. But it was always stressed that the tool must be used in the proper way. This is all the more important for other issues too, such as the use of risk-based methods in Goal Based Standards.

How to use the FSA tool in the proper way is in our opinion the first and foremost issue of concern. This author and his colleagues have attempted on several occasions in the past to contribute to the improvement of the method itself, but more importantly, to its proper use. FSA is just a tool. Whether this tool is being used correctly or not rests with the users and can be critical.

Some general comments that concern all of the submitted FSA studies are first made.

As a general comment to the 5 submitted FSAs, a *sine qua non* requirement for any FSA study to be considered is that the adopted IMO FSA guidelines should be followed. These guidelines are described in MSC/Circ.1023-MEPC/Circ.392, and have been consolidated in the Annex of MSC 83/INF.2. But it is noted that there are a number of instances in the submitted FSA studies in which conformance with the guidelines is lacking.

For instance, timely and open access to all supporting documents is a central requirement of the IMO FSA guidelines (MSC 83/INF.2, Annex, section 9.2.1). Yet, even though the casualty databases that were used in these FSA studies are central to the analysis, one cannot access them so as to verify which accidents are included, or otherwise check the validity of the many claims made and of the ensuing risk analyses. At a minimum, these databases should be fully disclosed[1].

Another general issue with some of the submitted FSAs is that Step 2 does not follow Step 1 in the manner prescribed by the IMO FSA guidelines. These guidelines (MSC 83/INF.2, Annex, section 6.1.1) state that *"The purpose of the risk analysis in Step 2 is a detailed investigation of the causes and consequences of the more important scenarios identified in Step 1."* However, in many instances, the most important hazards identified in Step 1 (Hazard identification) are simply not examined in the rest of the FSA. This point is illustrated with some specific examples in the sections that follow.

A third issue common in many of these FSAs is confusing cause and effect. Collisions, groundings, fires and explosions are consequences, not causes. Yet, collisions, groundings, fires and explosions are typically referred to as 'initiating events', with no analysis as to what prior event really caused them. A collision or a grounding can be caused by other 'higher-level' (or 'root cause') events, such as a blackout, a steering gear failure, or other.

Doc. MSC 86/19/1 by Germany is cited, which recommends that the root causes of accidents should be investigated before RCOs are identified. In our opinion, the main question is, what RCOs are put in place to prevent such higher-level events from happening? If this is not done, the focus is on RCOs to mitigate the consequence rather than prevent the cause from happening. Such a confusion may also skew the risk analysis that follows, and in fact, it is not surprising that few of the analyzed RCOs deal with accident prevention and most deal with what can be done once the accident occurs (when it is usually too late).

The sections that follow comment on:

- FSA on LNG carriers (section 1)
- FSA on container vessels (section 2)
- FSA on crude oil tankers (section 3)
- FSA on cruise vessels (section 4)
- FSA on RoPax ships (section 5)

Some conclusions are in section 6.

The reviews that follow are certainly not encyclopaedic and are submitted mainly as a basis for discussion within the FSA Group of Experts.

[1] See http://www.c4tx.org/ctx/job/cdb/dev/search.html for an example of an open database for tankers and bulk carriers (maintained by the Center for Tankship Excellence- CTX, USA).

1. FSA study on LNG carriers (MSC 83/21/1 and MSC 83/INF.3)

This FSA study recommends the following Risk Control Options (RCOs) for an LNG carrier:

- Risk based maintenance – Navigational systems
- Improved navigational safety – ECDIS
- Improved navigational safety -AIS integrated with radar
- Improved navigational safety – Track control system, and
- Improved navigational safety – Improved bridge design

The authors use the methodology that was already applied in other studies for various other ship types (e.g., NAV 51/10 for passenger ships, and MSC 81/24/5 for tankers, bulk carriers and product carriers), to prove that the above RCOs are cost effective for LNG carriers, which have similar recommendations.

Regarding conformance with FSA guidelines, there are at least two points in which such conformance seems to be lacking:

First, ECDIS was found to have a Gross Cost to Avert a Fatality (GCAF) of $ 3.1 million, even though the acceptance criterion is that RCOs should have a GCAF < $3 million. Granted, the GCAF is very close to $3 million, but the question is, how far can an RCO exceed it to still be recommended for adoption? If $3.1 million is acceptable, is $3.2 million acceptable? Is $3.4 million acceptable? Isn't the threshold just $3.0 million?

Second, no RCO interdependencies have been analysed, contrary to FSA guidelines, as specified in MSC 83/INF.2, Annex, section 7.2.3.3: *"Before adopting a combination of RCOs for which a quantitative assessment of the combined effects was not performed, a qualitative evaluation of RCO interdependencies should be performed."* No quantitative assessment of the combined effects of the RCOs was performed. But no qualitative evaluation of RCO interdependencies was performed either. At first glance, there should be interdependencies among the recommended RCOs, perhaps even strong ones, which would render the results of the analysis less relevant.

Substance-wise, the analysis is comprehensive. However, there are a large number of assumptions in the study that seem arbitrary and need better justification. For instance (list is certainly not exhaustive)[2]:

On page 37: "*A couple of previous studies have estimated the probability of water ingress given collision for two other ship types, i.e. P = 0.38 for passenger ships [49] and P = 0.35 for bulk carriers [50]. These probabilities are in general agreement, and it is assumed that they are also applicable to LNG carriers."* How can this assumption be justified, and which of the two numbers is used for LNG?

On page 40: "*The second part of the damage extent model determines whether the grounding damage is critical or not in terms of damage stability. First, the*

[2] Pages refer to doc. MSC 83/INF.3.

damage needs to crack the outer hull, and the probability for this is estimated to be 0.76 for passenger ships [49]. For the purpose of this study, the same value will be used for LNG carriers." Why LNG ships are assumed to be similar to passenger ships in that respect?

On page 42: "*In a recent study on passenger ships, it was estimated that between 70% and 75% of all fires were not escalating [56]. It can be assumed that this corresponds to the success rate of the fire fighting systems (both manual and automatic systems). For the purpose of this study on LNG carriers, it is assumed that the fire fighting systems have a similar success rate to that of HSC and passenger ships and the average will be used, i.e. 85% chance of controlling the fire and 15% chance of escalating fire. These values are inserted in the event tree."* How can such an assumption be made, given that firefighting systems and the potential of fire escalation of drastically different ship types (HSC/passenger vs. LNG) are not necessarily similar?

On page 120: "*For the purpose of this study the following assumptions were made:*

• *15% of fire/explosions in the engine room could be avoided*
• *20% of all drift groundings due to unavailability of the propulsion system could be avoided".* How were these numbers –15% and 20%- estimated? Is there any justification? How critical is this assumption?

On Page 126: *For the purpose of the study the following assumptions were made:*

• *10% of all loading/unloading incidents may be avoided by implementing this RCO."* Again, why 10%?

On page 133: "*For the purpose of this study, assuming that the effect of a 20% hull strength increment is equivalent to increase the double hull width of the vessel by 20%, the following has been considered: 1% probability reduction of critical damage in collision and contact scenarios and 2% probability reduction of critical damage in grounding scenarios."* Again, where do these numbers come from?

The study is full of many other similar assumptions, many based on expert opinion, but which are not justified, even though they could have a significant impact on the outcome of the study.

2. FSA study on container vessels (MSC 83/21/2 and MSC 83/INF.8)

A total of 33 risk control options (RCOs) are identified and documented. Most of them are related to collision and grounding which are associated with 68% and 14% of the total risk, respectively, according to the risk analysis. Two RCOs are found cost-effective and proposed as mandatory IMO requirements:

- AIS (Automatic Identification System) integrated with radar, and
- Track control system.

In addition, another RCO (introducing high bilge level alarms) is found to be cost-effective, but this is already required by MSC/Circ.608 for open-top containerships.

Perhaps the most significant deficiency of this FSA study, and one that we think makes it non-conformant with FSA guidelines, is the following:

There is a serious discrepancy between Step 1 (HAZID) and Step 2 (Risk Analysis). Among the various hazards in Step 1, it is stated that three have Risk Index (RI) = 9 and four have RI = 8 (MSC 83/INF.8, Annex, page 10). But these are not identified nor mentioned anywhere else in the FSA. The study goes on to consider as top hazards those with RI = 7.4 or below. The hazard with RI =7.4 is "bad working conditions during lashing (icy, wet floor)". However, this hazard is also eliminated from the rest of the FSA, on the ground that such accidents have their causes in loading/unloading operations in container terminals and are sometimes associated with port personnel rather than the ship's crew. Perhaps another reason for this omission is that accidents associated with lashing do not appear in the casualty databases used in Step 2.

Eliminating these hazards from the rest of the FSA (along with any possible RCOs to mitigate them) not only makes this FSA non-conformant with FSA guidelines, but, substance-wise, it shifts regulatory focus to RCOs that cannot do anything for the hazards that the study itself recognizes as most important. A major cause for this seems to be the lack of coverage of these hazards in the used database. However, in such cases, other means of risk analysis, than just analysis of the historical database, should be followed in the FSA, such as first principles, modelling, etc.

In addition, like in the LNG FSA, no RCO interdependencies have been analysed, contrary to FSA guidelines, as specified in MSC 83/INF.2, Annex, section 7.2.3.3.

Another conformance matter is that there are no details on the Delphi method used by experts (as provided in the LNG FSA study), and no estimate of experts' degree of agreement, as specified in FSA guidelines (MSC 83/INF.2, Annex, section 3.3 and Appendix 9)).

Substance-wise, the study uses two reference ships (page 7, Table 2, of doc. MSC 83/INF.8), a 1,706-TEU feeder and a 4,444-TEU larger (mainline) vessel. The range of sizes of vessels under study should be broader, to cover smaller and larger vessels. Feeders can be <500 TEU and mainline vessels over 10,000 TEU.

But even if these two ship sizes are used, no differentiation in accident frequencies as a function of ship size is taken into account. If different sizes are used, one might ask the question, which are more risk-prone, feeders or larger vessels? Instead (see page 10, Table 3), the two size categories are lumped together as an “average” vessel of 2,150 TEU (which is somewhere in between the two reference sizes, but not their arithmetic average (3,075 TEU), as Table 3 claims) and then the analysis is carried out for this average vessel. This may mean that the recommended RCOs may be acceptable for this average (but fictitious) vessel but not for both reference vessels, and that there might be RCOs that are rejected for the average vessel but good for one of the reference vessels. Different RCOs might be good, depending on vessel size.

As in the LNG FSA, a large number of assumptions that are not clearly justified but which could have a big impact are made. Here is a sample (page 18):

Table 8: Collision – ship damage probability for struck vessel and striking vessel

Operational state	Ship damage	Assumed probability
Manoeuvring at low speed, near the terminal $P_{low\ speed|collision} = 0.40$	Minor damage only	$P_{minor\ damage} = 1.0$ struck $P_{minor\ damage} = 1.0$ striking
	Critical hull damage water ingress	Does not occur at low speed collisions
Passage at reduced speed in port approach areas or entrance channels $P_{reduced\ speed|collision} = 0.40$	Minor damage only	$P_{minor\ damage} = 0.5$ struck $P_{minor\ damage} = 0.8$ striking
	Critical hull damage water ingress	$P_{critical\ damage} = 0.5$ struck $P_{critical\ damage} = 0.2$ striking
En route, at full speed at sea $P_{full\ speed|collision} = 0.20$	Minor damage only	$P_{minor\ damage} = 0.2$ struck $P_{minor\ damage} = 0.5$ striking
	Critical hull damage water ingress	$P_{critical\ damage} = 0.8$ struck $P_{critical\ damage} = 0.5$ striking

It is not clear where all these probabilities come from. Probably expert opinion? If yes, on what basis?

3. FSA study on crude oil tankers (MEPC 58/17/2 and MEPC 58/17/INF.2)

This study may have very serious regulatory ramifications, as it recommends for mandatory adoption a set of 7 RCOs, perhaps the most important of which is increased side tank widths and increased double bottom heights for crude oil tanker newbuildings.

The 7 RCOs are:

- Hot Works Procedures Training.
- Active Steering Gear Redundancy;
- Electronic Chart Display Information System;
- Navigational Sonar;
- Ship Design Modifications – Enhanced Cargo Tank Subdivision;
- Ship Design Modifications – Increased Double Bottom Height (not economically viable for VLCC);
- Ship Design Modifications – Increased Side Tanks Width.

Perhaps the most important issue of non-conformance of this FSA study with FSA guidelines concerns the use of CATS (for 'Cost to Avert a Tonne of Spilled Oil') as an environmental risk evaluation criterion. The use of such a criterion is only a proposal by project SAFEDOR and is nowhere described in the IMO FSA guidelines, let alone adopted by the IMO. A fortiori, the same is true for the threshold of 60,000 USD/tonne of spilled oil used extensively in the FSA study for the environmental evaluation of many RCOs. Yet, the CATS criterion is portrayed as already been adopted within the IMO official FSA guidelines[3]. The same is true for the 60,000 USD/tonne threshold. But it is well known that the subject of environmental risk evaluation criteria is the subject of discussion of an MEPC correspondence group (coordinated by Greece) since 2006, and that no consensus on this particular subject has yet been reached (see MEPC 58/17, MEPC 58/23 section 17, and most recently, MEPC 59/17).

In addition, and as with the containership FSA, there is a serious discrepancy between Step 1 (HAZID) and the rest of the FSA. In Table 4 of MEPC 58/17/2 (Annex), most (4 out of 7) of the top-ranked hazards from step 1 are attributed to communication problems. Yet, section 10 of said Annex states that *"due to a large diversity of causes, communications problems were not further addressed at the current state."*

This FSA confuses causes and consequences. Collisions, groundings and fires and explosions are consequences, not causes. Yet, this FSA treats them as causes, not looking at the root even that may have led to a collision, or to a

[3] See, for instance, statement in MEPC 58/INF.2, Annex, section 13.2,*"There are several indices used by IMO that express cost effectiveness in relation to safety of life and the environment; for the purposes of this study the Gross Cost of Averting a Fatality (GCAF) (Equation 1), **Gross Cost of Averting one Tonne of Oil Spilled (CATS)** [43] (Equation 2) and Net Cost of Averting a Fatality (NCAF) (Equation 3) are used."* (emphasis ours).

grounding. Perhaps as a result, machinery failures are not included in the risk model, allegedly because they are not among the causes that can lead to ‘Loss of Watertight Integrity’ (LOWI) (section 3.3.1 and Fig. 13 of Annex to MEPC 58/INF.2). But a machinery failure may be the first event that eventually leads to a grounding or collision, and eventually to LOWI and a spill.

Examples:

Amoco Cadiz (1978): Steering gear failure led to loss of manoeuvering capability which ultimately led to drift grounding and to one of the worst spills in Europe. Outcome would not be different if ship were double hull.

Braer (1993): Main engine failure led to drift grounding and a massive spill. Ship lost power due to improperly secured pipes rolling around deck, destroying the fuel oil tank vents and allowing sea water into fuel. The Captain was told the pipes had come lose, at least a day earlier, but apparently failed to appreciate the importance of the problem, and in any event failed to react to the issue.

Nassia (1994): This accident in the Bosporus which killed 42 included the sequence: collision, fire, and grounding. Was the *Nassia* a collision, or a fire, or a grounding? The correct answer is “all of the above”. And the correct answer for cause is “none of the above”. The cause was a blackout on the bulk carrier *BC Shipbroker*. Without electrical power, the *Shipbroker* had no steering, and turned into the *Nassia*.

According to the analysis (section 4.2 of Annex to MEPC 58/INF.2), tank explosions are the most important type of hazard. But the issue of what to do about them is not addressed. Tank explosions are also assumed independent of hull type (Table 7 of Annex to MEPC 58/INF.2). In fact, one can make the argument that double hulls are easier to clean and hence less prone to tank cleaning-related explosions, but they may be more prone to explosions due to cargo leaking into a ballast tank.

Examples:

Nai Giovanna (1974): This 133,853 dwt double hulled OBO, trading in oil, was en route from Los Angeles to the Persian Gulf in ballast, when she sank about 1200 miles WSW of San Francisco after being ripped by fire and violent explosions in her empty tanks. 32 survivors, 8 fatalities.

Berge Istra (1975): This VLCC-sized OBO had a structure that is very similar to a double hull tanker. The double bottom is for all purposes the same. Ship was loaded with iron ore. The rapid sinking of the ship indicates that a gas explosion in the double bottom of the ship ripped the ship structure open, and water flooded the double deck and the engine room. 30 of 32 killed.

Note that the last two examples were OBOs, not pure crude oil tankers. One was trading in oil, the other was not. The fact that the Danish FSA did not look at OBOs (as in our opinion it should) is immaterial, as OBOs are similar to double hull tankers in many respects and these examples show what can happen if oil leaks into the double hull or bottom.

A related issue is that this FSA study does not examine inerting the ballast tanks as a possible RCO. In fact, the way the screening of RCOs is performed is not clear. Some other RCOs that might be worth to examine, such as twin screws and passive vacuum have also been excluded, unknown why.

Also, the estimated risk reduction of RCOs was performed using the Delphi method, however the level of agreement among the experts involved is not shown (MSC 83/INF.2, Annex, section 3.3 and Appendix 9).

Moreover, RCO interdependencies have not been examined (as required in MSC 83/INF.2, Annex, section 7.2.3.3).

Recommending RCOs such as increasing the width of side tanks and the height of bottom tanks needs reliable penetration data in case of a collision and grounding. Such data is not shown in the study, but only some modelling studies are cited. In fact, the process used for evaluating the increase in double bottom height is not fully described. But, as near as one can tell, it was assumed that, if the inner bottom is penetrated, and the ship is not completely lost, the spill will have the volume of an average tank. If this is the case, it is inconsistent with IMO's guidelines for calculating spillage from grounding damage.

As regards penetration, Devanney (2008)[4] shows an analysis of penetration data from collisions in the CTX casualty database for which such data exists. His Table 1 is reproduced below.

[4] Devanney, J. (2008), "Formal Safety Assessment in Wonderland," Center for Tankship Excellence (CTX) working paper (available at www.c4tx.org).

Table 1: Depth of Penetration in CTX Collisions

Struck Ship	D.O.P. m	Angle	Impact	Own Spd	Other Spd	Dead	Volume m3
eleni v	22		MS	14		0	5320
stolt dagali	21	80	AP			19	Y
nagasaki spirit	15		MP			51	14100
british vigilance	15	135	AP	14.5	12	0	0
esso greensboro	+14	90	MP	15	15	44	7000
tekton	11		M			0	600
burmah agate	11	35	AS	1	12	32	40500
maersk navigator	+10		MP			0	29400
arctic	9	90	A			4	?
tullahoma	8	90	AP		15	1	?
keytrader	6.1	50	FS			16	2790
jambur	+6		FS			?	3800
baltic carrier	6	50	AS			0	2900
venpet	+5	150	AS	15	13.5	2	34800
esso brussels	4.6	60	MS	A	15.5	16	5000
alva cape	3.6	90	FS	4	3	33	2066
high endurance	3	20	AP			0	0
genmar kestrel	+3		AS			0	1400
kaminesan	2	10	BP			0	0
esso chittagong	1	15	FP	1	7	?	Y
eagle milwaukee	I				6	0	0
bergitta	I		TP	12	18	0	0

According to the above reference, in the last 50 years there has been exactly one tanker collision with known depth of penetration in which the design changes suggested by the Danish FSA (wider side tanks) might have made a difference in the amount of oil spilled. That was the *Genmar Kestrel/Trijata* side-swipe which spilled about 1,200 tons of oil (2004).

In the cost-benefit assessment, it is not clear in what way many of the costs (particularly those referring to the extra capital and operational costs due to larger tanks) and many of the benefits are computed. All this analysis should be made available for scrutiny.

Also, no finite element analysis is reported for the new design and no effect of the change on seakeeping (most notably roll) is assessed.

In our opinion, review of this FSA study should be postponed until the CATS issue is resolved by MEPC. But other deficiencies including those listed above should also be addressed.

4. FSA study on cruise ships (MSC 85/17/1 and MSC 85/INF.2)

According to this FSA study, it is demonstrated that the safety level of cruise ships lies within the ALARP region. It also states to show that accidents are dominated by collision and grounding scenarios with low frequencies but potentially high fatality numbers. It also identifies some Risk Control Options (RCOs) as cost-effective for a specific cruise ship design.

The study claims that the following RCOs are providing considerable risk reduction in a cost-effective manner:

- Implementation of procedures for Bridge Resource Management and
- Increase in the required subdivision index for damage stability.

In addition, the study confirms (see also NAV 51/10) the following risk control options to be cost effective for Cruise ships:

- Improved bridge design (above SOLAS),
- ECDIS - Electronic Chart Display and Information System, and
- Increased Simulator Training for Navigators.

In the Annex of MSC 85/17/1, section 2 (page 2), the authors of the study make some analogies with the aviation industry to make the point that accident statistics can be very deceiving if based on small samples. In fact, the calculation of airline accident risk is typically based on a *per flight fatality risk* (estimated at around 1 in 8 million for first world international airlines[5]), whereas for maritime transport, most FSA studies use the UK Health and Safety Executive *indicative* figures of maximum tolerable *annual fatality risk* of 1/10,000 for passengers and 1/1,000 for crew members.

As an aside, it is noted that expressing fatality risk on an annual basis implicitly assumes an annual number of trips undertaken by both crew and passengers. We are of the opinion that risk would be better modelled on a per trip basis (if one does not travel by ship, risk is zero), and for cruise ships in which the potential number of fatalities can be high, that maximum tolerable fatality risk levels should be revised downwards.

As in other FSA studies, collisions, contacts, groundings and fires/explosions are assumed to be primary causes of accidents, although that term is not extensively used. Again, these are consequences, not causes. And again the result is that emphasis are placed on RCOs that try to mitigate the consequences of an accident, once that occurs. Document NAV 51/10 (FSA for large passenger ships) is extensively referenced, and that study indeed has some preventive measures, such as ECDIS and other. However, the emphasis of this FSA is mainly on consequence mitigation measures, such as buoyancy enhancements, damage stability enhancements, etc.

[5] Barnett, A. (2006) “Global Passenger-mortality Risk Decreased Substantially in Accidents From 2000 to 2005,” Flight Safety Digest, 14-19.

A puzzling feature in the risk analysis (Annex II of MSC 85/INF.2) seems to be the use of fatality data of ferries and ro-pax vessels to formulate worst-case scenarios for cruise vessels. In fact, Table 7-2 of Annex II of MSC 85/INF.2 (page 20) contains only accidents of ferries and RoPax vessels, including the *Herald of Free Enterprise*, the *Estonia*, and the *Al Salam Boccaccio 98*. But some of the very accident scenarios that have occurred on these ferries and RoPaxes, including water ingress via the bow door if the latter is left open (*Herald of Free Enterprise*) or is detached (*Estonia*) simply cannot occur on a cruise ship.

So we do not really see the relevance of much of this table, nor can we subscribe to the statement *"One could argue that Estonia and Al Salam Boccaccio 98 are the two most relevant accidents to investigate when trying to learn how a worst case scenario possibly could occur."* Note that the *Al Salam Boccaccio 98*, whose capsizing took 10 minutes, was a RoPax in which two extra passenger decks were added in a conversion and was very different in design from a cruise ship.

Much of the probability and consequence data that populates the various event trees used extensively in the analysis seems arbitrary or difficult to justify. For instance, Fig. 7-1 of Annex II of MSC 85/INF.2 (page 22) represents a very elaborate event tree for the event of a cruise ship collision. This figure is reproduced below for illustration purposes.

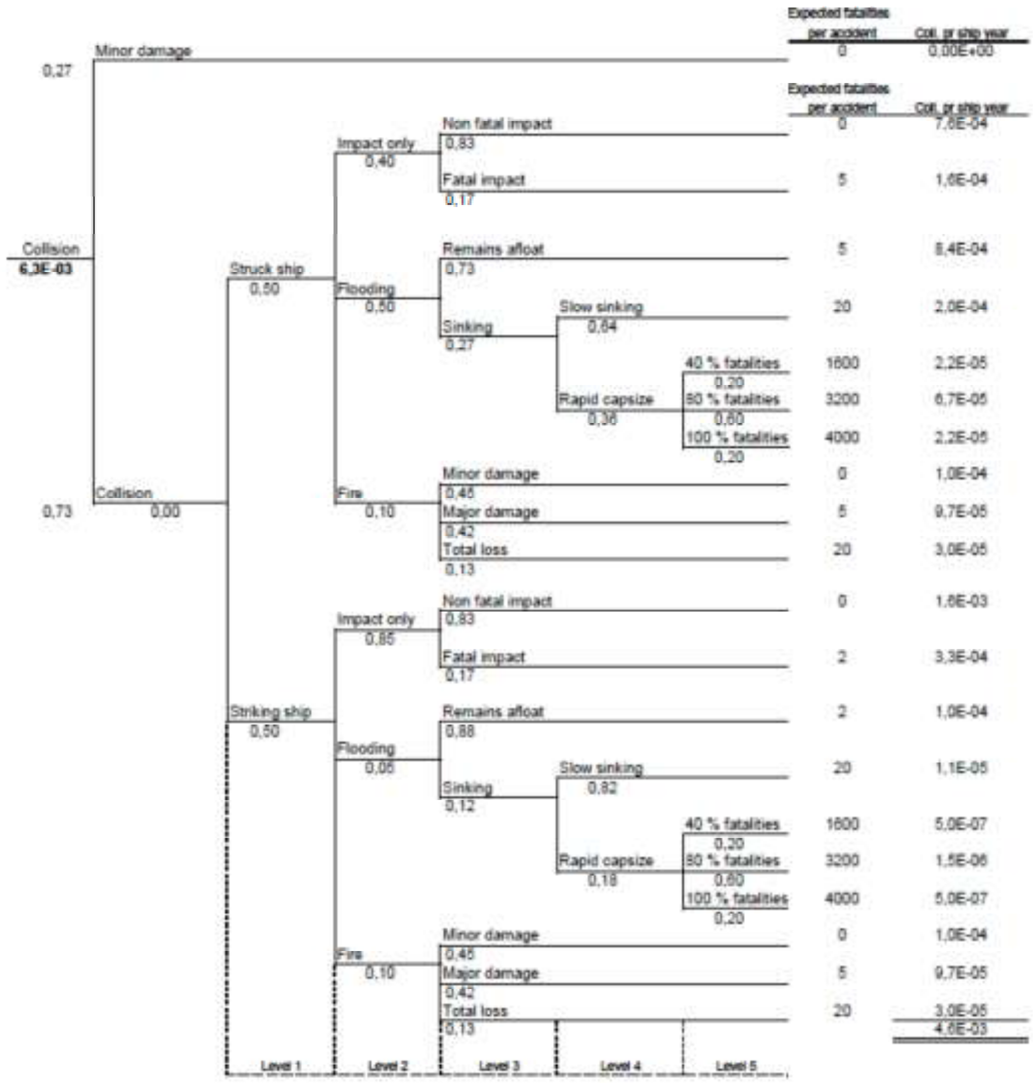

Figure 7-1: Collision event tree

At Level 1, given a collision, the study assumes that the cruise ship is the striking ship with probability 50% or the struck ship with probability 50%. It is not clear whether the 50-50 chance is documented by accident statistics or seems like a reasonable assumption. It is conceivable that cruise ships may be more prone to get struck by another ship than strike another ship, due to differences in navigation equipment, manoeuvering ability, etc. But if the probabilities are not 50-50, the results of the analysis may be different.

At Level 2, if the cruise ship is the striking ship, the FSA study states that this will result to impact only with probability 85%, to flooding with probability of 5% and to fire with probability of 10%. If it results to fire, it will result to minor damage with 0 fatalities (with a probability of 45%), to major damage with 5 fatalities (with a probability of 42%), and to total loss with 20 fatalities (with a probability of 13%). It is not clear how all of these numbers were estimated, although it is understood that some were based on expert opinion. Certainly the scenario of a cruise ship striking a tanker may result in a much higher number of fatalities due to fire (see also next paragraph).

At Level 5, the number of fatalities if the vessel capsizes rapidly (1,600 fatalities with probability 20%, 3,200 fatalities with probability 60% and 4,000 fatalities with probability 20%) is based on the fatality numbers in the same Table 7-2 referenced earlier, even though that table (as already mentioned) refers to ferries and RoPax ships and only one of the accidents reported there is a collision[6]. Also it is not clear where the probabilities come from.

There are many more such numbers in the whole analysis, not just for collisions, but for all other accident scenarios, that are very hard to follow. All are very important, even critical, in determining the overall risk level. Yet, many of these numbers seem arbitrary and need better justification. Plus, no sensitivity analysis has been performed on these numbers. It is understood that many of these numbers are based on expert opinion, yet no estimate of experts' degree of agreement is provided, as specified in FSA guidelines (MSC 83/INF.2, Annex, section 3.3 and Appendix 9).

Similar considerations pertain to the calculation of the risk reduction of selected RCOs, such as buoyancy enhancements, increase of GM, etc. For instance, an elaborate set of calculations (most of which are not immediately available for scrutiny and involve a large number of assumptions, some of which may be hidden) concludes that if freeboard is increased by 0.5 meters, this will save 2.1 lives per ship's ship lifetime for the collision scenario. But this number is critical in determining the cost-effectiveness of proposed RCOs. In fact, after a set of cost-benefit calculations, which include estimates of additional income due to more deck space (among others), this increase of GM is found to produce specific financial benefits, and results in a GCAF of $1,120,000 and an NCAF of minus $5,260,000 over the ship's lifetime, rendering this RCO cost-effective.

There are a multitude of such numbers and calculations in the study, all of which are very difficult to follow, let alone justify. This is contrary to the IMO FSA guidelines (MSC 83/INF.2, Annex, section 9.2.1), in that timely and open access to all supporting documents is a central requirement of any FSA study.

[6] Interestingly enough, this is the Doña Paz ferry collision with a tanker, which then resulted in a fire and more than 4,000 fatalities, way more than those assumed in the collision-fire scenario of Fig. 7-1.

5. FSA on RoPax Ships (MSC 85/17/2, and MSC 85/INF.3)

According to the FSA study on RoPax it is demonstrated that the safety level of RoPax ships lies within the ALARP region. It also shows that accidents are dominated by collision and grounding-related flooding. The study claims that the following RCOs are providing considerable risk reduction in a cost-effective manner:

- improved damage stability and survivability after flooding,
- all measures aimed at improving navigational safety not requiring additional manning levels,
- improved fire prevention and protection and
- improved evacuation arrangements.

According to step 1 (HAZID), the top-ranked hazards are: failure of evacuation equipment during an emergency; human error and/or lack of training during an evacuation; collision between a car and the vessel or between two cars during loading and fire in accommodation while in open sea or navigating in coastal waters. As in other FSAs, collisions, groundings, impacts and other accident hazards are treated as causes and not as consequences of other, root-cause events (such as for instance, a steering gear failure that leads to a collision). This may skew the ensuing analysis including what may be appropriate RCOs.

A positive feature of this FSA is that there seems to be no apparent gap between step 1 and the rest of the FSA, which is a deficiency of some of the other FSA studies. But the RCOs that are brought up for assessment are very generic, for instance, "improved navigation safety," "improved evacuation arrangements," "improved fire prevention and protection," etc. This seems to be the result of the 'high level' nature of this FSA.

Also as a result, the study makes little attempt to calculate the specific risk reduction ΔR associated with an RCO, but instead estimates ΔRmax, the <u>maximum</u> risk reduction potential of the RCO, performs a parametric analysis on ΔR (and sometimes also on the cost ΔC of the RCO) so as to calculate a range of GCAF values, and carries out a broad set of sensitivity analyses afterwards. It is suspected that this may not be the way prescribed in the IMO FSA guidelines.

An example is shown in the table that follows, representing the impact of RCO4 (improved evacuation arrangements) on the risk model (MSC 85/17/1, Annex II, page 18).

Table 15: Impact of RCO4 on Risk Model (ΔFatality rate=75%)

Accident Category	ET scenario	ET branch probability		Change ΔFR
		basis	new	
fire	Machinery/unsuccessful evacuation/fatality rate	0.7	**0.2**	75%
	Machinery/fire uncontrolled/fatality rate	75	**18.75**	75%
	Vehicle deck/unsuccessful evacuation/fatality rate	8	**2**	75%
	Accommodation/unsuccessful evacuation/fatality rate	8	**2**	75%
collision	Slow sinking/fatality rate	12	**3**	75%
grounding	Slow sinking / fatality rate	3	**0.75**	75%
impact	Slow sinking / fatality rate	0.2	**0.05**	75%
flooding	Slow sinking / fatality rate	12	**3**	75%

In all the above accident categories, the change in fatality rate (ΔFR) is constant and equal to 75%. Afterwards a sensitivity analysis is performed, with ΔFR ranging from 0 to 100%. The questions what is really the value of ΔFR associated with this RCO, and how such a risk reduction can be obtained, seem to be outside the scope of this FSA.

The cost-benefit assessment is in the same spirit and does not seem very informative either. Take for instance RCO2a, measures improving damage stability, whose results are shown in Figure 10 of Annex II (page 33), which is reproduced below:

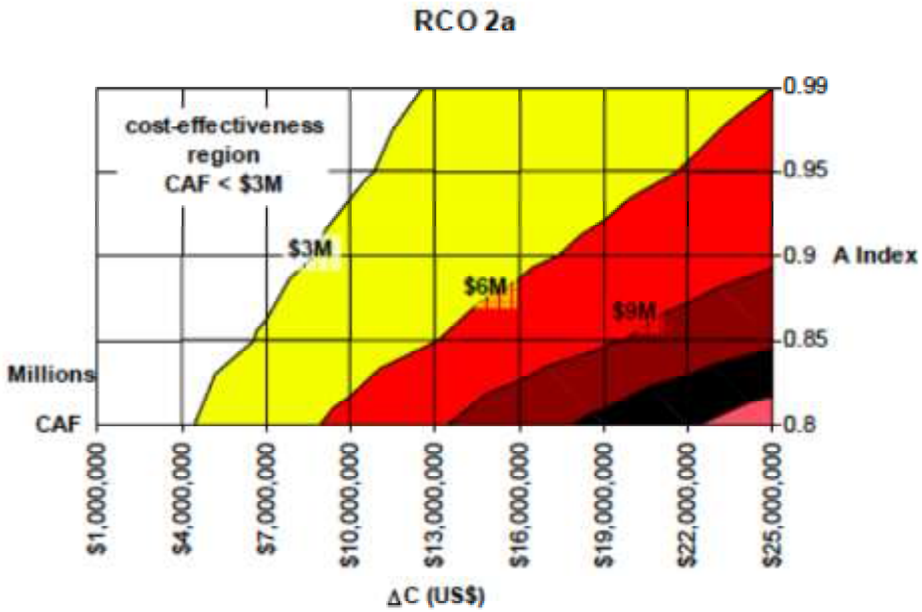

Figure 10: GCAF Sensitivity to Attained Index A and Cost Implications RCO2a: Measures Improving Damage Stability ("stay afloat")

One can see that this is a double parametric figure, with both the A index and the cost ΔC being allowed to vary for this RCO, with the GCAF figures calculated for each combination. The central questions, what is the attained value of the A index and what is the resulting cost, seem to be outside the scope of this FSA.

The study contains several such examples, which do not translate into very useful conclusions. The fact that different categories of RoPax vessels are lumped together as an "average" ship of 25,000 GRT having a maximum capacity of 1,000 passengers and 1,900 lane metres does not help much either. Also a price of 120 EUR per tonne is being used for the cost of fuel, but this is rather low given the latest market volatility and the fact that most RoPax vessels use cleaner fuel than other vessels and, in many cases, they do use low sulphur fuel oil that is more expensive.

6. Conclusions

The effort by Denmark to bring forward these FSA studies is appreciated, and we look forward to discussing them within the FSA Group of Experts. At the same time, we believe that if the FSA method is to have the role it deserves, concerns such as those shown herein (and these are only a sample) should be addressed. In particular, casualty databases used for these studies should be made public and contain information properly organized so as to reveal the real causes of the accidents.