Developments to Further Enhance Safety of Passenger Ro-Ro Ships

Per Stefenson and Willem van Berlekom

SSPA Sweden
Göteborg

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PREFACE

This report was developed within the SURSHIP Programme (Survivability for ships, see www.surship.eu). The work was funded by VINNOVA (The Swedish Governmental Agency for Innovation Systems), VINNOVA registration number 2007-03541 and project number P32544-1. The SSPA project number was 4006 4317.

The aim of the project was to collect and analyse information, appropriate for the SURSHIP Action Group, from the VINNOVA-funded research projects "Research Study on the Sinking Sequence of MV Estonia" and "DESSO- Design for Survival Onboard".

24th of October, 2008

Claes Källström
Project Manager

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1 INTRODUCTION

This report is a reflection of the results from the “Research Study of Sinking Sequence of MV Estonia”[1] and the Desso[2] project with the focus on the course of events leading to accidents on Ro-Ro passenger ships. The main task of the Desso project was to develop a conceptual Ro-Pax ship using known technology and conclusions from previous accidents. Two of these accidents, the capsizing of Herald of Free Enterprise and Estonia initiated several changes to the safety rules for Ro-Ro passenger ferries. We have looked upon the existing rules at the time for the Estonia accident and which new rules that were developed in the aftermath, trying to find out if there are gaps in the present legislation regarding Ro-Ro passenger ship safety.

In this study the following main points are brought up with regard to recommendations of improving existing safety rules:

- A brief survey of rules introduced after the Herald of Free Enterprise and Estonia accidents
- Applicable rules for Estonia at time of accident
- Possible chain-breakers in the course of events in the Estonia accident
- Human factor contribution
- The ISM code
- Recommendations

A pattern appears that although in both these accidents the human factor had a decisive influence on the course events, which eventually led to the capsizing and sinking of the ferries, the focus in rulemaking has been on technical provisions, however with one important exception – the introduction of the ISM code. Secondly the technical and rulemaking focus has been on damaged stability, that is on the survivability of the vessel after a major water ingress and to a much lesser degree on how to avoid water ingress.

[1] “Research Study of Sinking Sequence of MV Estonia”, (SSPA Sweden AB, Safety at Sea, Chalmers Technical University and Maritime Research Institute Netherlands) funded by VINNOVA (The Swedish Governmental Agency for Innovation Systems) between March 2006 and May 2008. The VINNOVA Registration Number is 2005-02852 and the SSPA Project Number is 4006 4100.

[2] Desso, Design for survival onboard, (Consortium led by SSPA Sweden AB) funded by Vinnova, project nr 25042-1 and SSPA project nr 2003-3384.

2 OVERVIEW OF RULE DEVELOPMENT FROM 1987-

2.1 Amendments prior to the Estonia sinking September 28, 1994

The Herald of Free Enterprise accident initiated several changes in SOLAS as follows:

Amendments April 1988 – Reg 23-2 and 42,

In force Oct 22, 1988, Applicable to all ships

23-2: indicators for loading doors, including detectors of water infiltration; ro-ro spaces to be patrolled or monitored

42: Emergency lighting

Amendments October 1988 – Reg 8, 20-1 and 22

In force April 29 1990 for ships built after April 2 1990, however, some regulations shall be applied to all ships.

8: Ship's stability to count for passengers on one side, wind force etc in damaged condition,
Master must determine ship's stability after loading – applicable to all ships

20-1: Cargo loading doors to be locked shut before departure - applicable to all ships

22: Lightweight survey of stability every 5th year - applicable to all ships

Amendments April 1989 – Reg 15

In force Feb 1 1992 and applicable to ships built after that date.

15: The amendments are designed to reduce the number and size of openings in watertight bulkheads in passenger ships and to ensure that they are closed in the event of an emergency (fast-closing sliding doors).

Amendments April 1992 - Reg

Entry into force October 1, 1994

> New standards concerning the stability of existing ro-ro passenger ships after damage were included in the amendments to Chapter II-1. They were based on measures to improve the damage stability of new ro-ro passenger ships which came into force on 29 April 1990 but were slightly modified. The measures were phased in over an 11-year period beginning 1 October 1994.

<u>Amendments May 1994 – Chapter IX</u>

Entry into force July 1 1998 for passenger ships and tankers

This new Chapter to the Convention was designed to make mandatory the International Safety Management Code, which was adopted by IMO in November 1993 (Assembly resolution A.741(18)).

The Code establishes safety management objectives which are:
- to provide for safe practices in ship operation and a safe working environment;
- to establish safeguards against all identified risks;
- to continuously improve safety management skills of personnel, including preparing for emergencies.

The Code requires a safety management system (SMS) to be established by "the Company", which is defined as the shipowner or any person, such as the manager or bareboat charterer, who has assumed responsibility for operating the ship.

The company is then required to establish and implement a policy for achieving these objectives. This includes providing the necessary resources and shore-based support. Every company is expected "to designate a person or persons ashore having direct access to the highest level of management".

The procedures required by the ISM Code should be documented and compiled in a Safety Management Manual, a copy of which should be kept on board.

Note: The implementation of the ISM code on passenger ships was brought forward within EU to 1 July 1996.

2.2 Amendments after the Estonia sinking September 28, 1994

The amendments listed below, refer to those of relevance for ro-ro passengers ships.

<u>Amendments November 1995 – Chapters II-1, II-2, III, IV, V and VI</u>

Entry into force July 1 1997
Chapter II-1

Regulation

8-1:	The SOLAS 90 damage stability standard, which had applied to all ro-ro passenger ships built since 1990, was extended to existing ships in accordance with an agreed phase-in programme. Ships that only meet 85% of the standard had to comply fully by 1 October 1998 and those meeting 97.5% or above, by 1 October 2005. (The SOLAS 90 standard refers to the damage stability standard in the 1988 (October) amendments to SOLAS adopted 28 October1988 and entering into force on 29 April 1990.)
8-2:	Special requirements for ro-ro passenger ships carrying 400 passengers or more. This is intended to phase out ships built to a one-compartment standard and ensure that they can survive without capsizing with two main compartments flooded following damage.
10:	Watertight door acting as vehicle loading/unloading ramp must not be subject to damage if the bow visor is damaged or detached.
15:	Remote – controlled doors must be shut before the voyage starts and remain shut during the crossing
20-1/2/3	Strengthening of the watertightness requirements for the car deck

Chapter II-2,

Reg. 28-1	Escape routes should ensure the rapid and orderly movement of passengers to assembly points.

Chapter III,

Reg 6.5	Ro-ro passengers ships shall be fitted with a public address system
Reg 24-1	Improved requirements for life saving appliances.
Reg 24-2	Requirement for all passenger ships to have full information on the details of passengers on board
Reg 24-3	Requirement on helicopter pick-up area

Chapter V

Reg 13 Requirement to have an established working language.

Reg 23 Operational limits

Entry into force July 1 1998

Chapter V, Regulation 23 Navigation bridge visibility

Stockholm agreement February 1996

18 States including 11 EU countries signed a Northern European regional arrangement laying down specific stability requirements for ro-ro passenger ships (beyond SOLAS). The Stockholm agreement has been adopted as an EU directive.

2.3 Applicable rules for Estonia 1994

According to the building contract (ref. JAIC[3]) Estonia (Viking Sally) was built to fulfil SOLAS 74 (although the contract date was before the entry of force of SOLAS 74).

According to the “Research Study of Sinking Sequence of MV Estonia”[4] the main reason for the eventual loss was the lack of compliance with the IMO regulations on forward collision bulkhead (Chapter II-1, regulation 10).

[3] Joint Accident Investigation Committee report on the Estonia Accident

[4] “Research Study of Sinking Sequence of MV Estonia”, (SSPA Sweden AB, Safety at Sea, Chalmers Technical University and Maritime Research Institute Netherlands) funded by VINNOVA (The Swedish Governmental Agency for Innovation Systems) between March 2006 and May 2008. The VINNOVA Registration Number is 2005-02852 and the SSPA Project Number is 4006 4100.

3 ACCIDENT CHAIN OF EVENTS

According to the DESSO project, **foundering and fire** are the two most common reasons for total loss of ships. These types of accidents are also the kind of accidents that craves the largest number of lives. The DESSO project have analyzed a number of accidents involving passenger ships and tried to find “chain breakers” that could have avoided the accidents. Regarding loss of lives in foundering accidents, it is stated that capsizing or large listing angles are the major problem for the passengers and crews possibilities to evacuate. If there is water ingression to the ship, **sinking without heeling** will save a lot of lives.

It is obvious that the best way of avoiding capsizing is to keep the water out of the ship and the class regulations should give clear instructions of how to build the ship strong enough to withstand any weather conditions on the decided route. Furthermore additional safety barriers should avoid water ingression if the first barrier fails. This should have been the purpose of the collision bulkhead that was “missing” on Estonia.

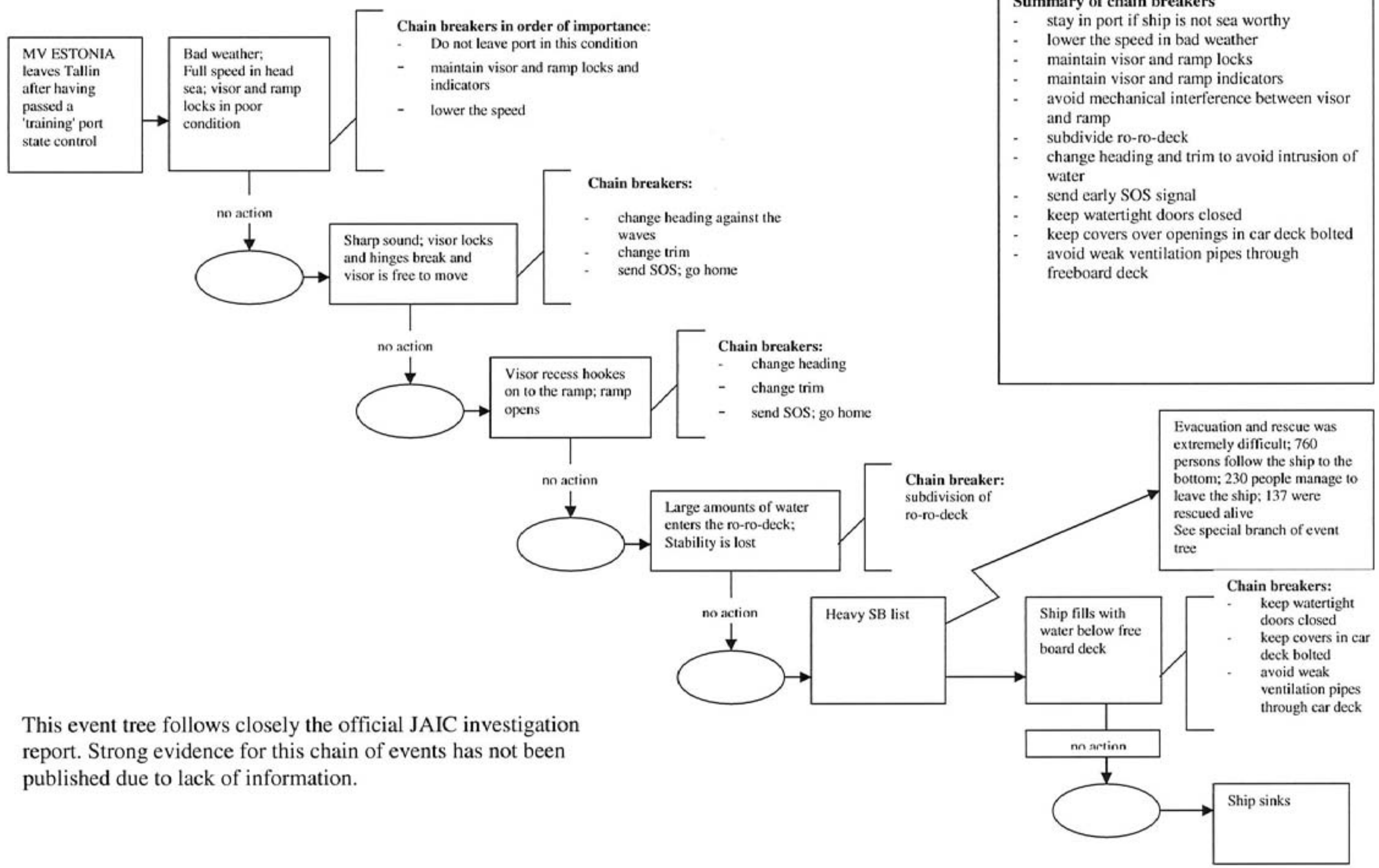
If the water, despite the safety barriers, enters the car-deck it should be led out from the deck back to the sea. Non-return scuppers or the possibility to freeing the ports, i.e. open the bowdoor or/and the aft ramp have been suggested. It is better to get rid of the water from car-deck than to allow and keep a specific level of water. Draining the water out would be possible as long as the deck is above the waterline, however if the ship is damaged and is floating with the car-deck below the waterline, other measures e.g. downflooding to compartments below, have to be considered.

If the ship is damaged by e.g. collision or grounding, traditional watertight sections are there to stop the water from flooding the whole ship, but this could increase the risk of healing. The watertight compartments have to be arranged in order to avoid healing. Cross flooding or other arrangements for specific damage scenarios should be analyzed and implemented.

3.1 Possible chain breakers

Regarding the Estonia accident, the DESSO team made the following analysis of chain breakers that could have avoided the accident:

The Estonia accident. An event tree with chain breakers



This event tree follows closely the official JAIC investigation report. Strong evidence for this chain of events has not been published due to lack of information.

Some further discussion on the course of events leading to the sinking of Estonia brings up the following events and possible chain breakers:

1. **Event:** The bow visor locks and hinges brakes and the visor falls off. The visor recess hooks on to the ramp and opens it.
   Comment: The arrangement with the ramp replacing the watertight bulkhead was an exemption from the described geometry in the SOLAS 74 and 81 amendment. Compliance without exemption would have been safer, since the visor couldn´t have ripped the WT-door open.
   Chain breaker: Watertight bulkhead placed according to SOLAS 74 and 81 amendment, without exemption.

2. **Event:** Large amount of water entering the car deck.
   Comment: According to Chapter II-1 of the 1983 SOLAS amendments, the freeboard-deck should have scuppers of suitable size discharging directly overboard. How was suitable size determined? According to the JAIC report there were twelve closable 4" scuppers installed along each side of the deck. The scuppers were normally left open according to the report, however they could be closed. "The research studies on the sinking sequence of MV Estonia" have estimated that the scuppers where too small to discharge the amount of water shoveled in through the bow door.
   Chain breaker: Large scuppers discharging overboard in seconds. (need for new interpretation of suitable size of scuppers in 1983 SOLAS amendment).

3. **Event:** When water entered the freeboard-deck (car-deck) the ship lost stability and heeled over to at least 30 degrees list in short time.
   Chain breaker: The ship should maintain stability with large amount of water on car-deck. (ref. Stockholm agreement).

4. **Event:** The passengers and crew could not evacuate or move to muster-stations due to the heavy list.
   Chain breaker: Arrangement with handrails that could serve as ladders for climbing. Technical solutions on how to arrange open spaces to allow passage also with heavy list. Avoid heavy list.

5. **Event:** The people onboard MV Estonia could not go to the rescue stations due to heavy list.
   Comment: Already at an angle of 20 degrees it is very difficult to move around in a ship. When the ship is heeling more than 45 degrees it is almost impossible. Transversal corridors becomes dangerous shafts and open areas impossible to pass. In addition furniture and loose equipment falls down threatening to injure people in its way.
   Chain breaker: Healing should be avoided. SOLAS regulation 8, "Stability of passenger ships in damaged condition" allows maximum 7 deg heel. The

Administration may allow additional heel due to unsymmetrical moment, but in no case shall the final heel exceed 15 degrees.

Watertight sections and doors

6. **Event:** In the heeled condition the water ingressed to the lower decks from above through ventilation ducts and the stair casings.
   Comment: Below freeboard deck the ship was sectioned in watertight compartments in order to stop the water from filling the whole ship if the hull was damaged from e.g. collision or grounding. In the Estonia case however the water ingresses through the bow-door above freeboard deck causing heavy list.
   Chain breaker: The ships layout should consider and avoid water ingression possibilities through ducts, staircases etc. in heavy list condition. Most important - Healing should be avoided!

7. **Event:** Water ingression through watertight doors to staircasing. (Possible scenario on Estonia.)
   Comment: Also recently there have been discussions in the press about watertight doors on Ro-Ro ferries since it was revealed that many ships have exemptions from sailing with closed WT-doors. Also the water-resistance of the electrical control system (IP class) for closing the doors has showed to be insufficient. Insufficient watertight compartments may lead to loss of stability.
   Chain breaker: Make sure that watertight doors are closed. Minimize the number of watertight doors through design.

Situation awareness

8. **Event:** The locks for the visor broke and MV Estonia lost the bow visor.
   Chain breaker: Problems with the bow visors on Estonia and other ships was reported sixteen (16) times before. If the crew reads incident reports the situation awareness could be improved. (ref. ISM-code, incident reporting).

9. **Event:** There were several reports to the bridge about strange metallic noise from the bow.
   Comment: The only action taken was to order a crewmember to go down and have a look. The master commented that the ship was behind schedule in spite of all engines running.
   Chain breaker: Reduce speed and/or change course until the source of the noise was determined. Better situation awareness could have prevented the accident. Pressure from the management? (ref. ISM-code).

10. **Event:** According to the JAIC report the crewmember that went down to the car-deck reported that the indicator lamps at the bow door indicated that the door and the visor were closed.

Chain breaker: Indicator lamps on the bridge shall indicate if the bow visor and door are properly locked.

Life saving equipment and survivability

11. **Event:** None of the lifeboats could be launched due to heavy list.
    Comment: MV Estonia had 10 motor driven lifeboats from which one was a man-over-board (MOB) rescue boat.
    Chain breaker: Make sure that the lifeboats can be launched in heavy list. Avoid healing. Replace lifeboats with liferafts.

12. **Event:** Many life raft containers were released by the people that managed to come to deck 7 and 8 however the containers fell into the water and disappeared. Some were inflated on deck but flew away in the strong wind. 22 liferafts were found with people onboard. MV Estonia had 63 inflatable liferafts packed in containers on deck 7 and 8 and equipped with hydrostatic release mechanism.
    Comment: Liferafts worked better than lifeboats. Many liferafts were found upside down – self rightning rafts needed.
    Chainbrakers: Facilitate launching of liferafts, develop better methods for anchoring and entering the rafts.

13. **Event:** From 93 victims found during the rescue operations 91 had died from hypothermia or drowning with hypothermia as a contributing factor.
    Comment: There were 2298 lifejackets for adults and 200 lifejackets for children on board. They were stored in containers on the open passage on deck 7 by the rescue stations. Most of the people that were rescued had lifejackets on.
    Chainbraker: thermal protection should be provided in the same way as life jackets.

4 HUMAN FACTOR

4.1 Introduction

It is a commonly stated assumption that the human factor is a underlying cause of up to 80% of all accidents. Human errors have been identified as one of the main causes leading to maritime accidents. It is also evident that in last decades the awareness of human factor contributions in accidents has increased. It should, however, be recognized that the identification of human errors as a cause in many accidents may cover or hide the basic (or root) causes to the accidents. When investigating accidents, it is important to find the basic causes, as those are the causes which show where the system has failed, and give the basis for preventive actions.

It is a fact that human error is a contributory cause to serious accidents. Despite this, the term "human error" is not very useful in accident prevention. Such a vague concept can be counterproductive, because if it may indicate *where* in the system an error occurred, it provides no explanation *why* it went wrong. A "human error" can be caused by improper design, insufficient training, poorly designed procedures and instructions, misleading handbooks or by a lack of safety culture, so that negligence and ignorance of safety instructions are accepted. In many cases the "human error" would have been prevented by a more human friendly design, by better training and by more efficient procedures for operation and maintenance. The term "human error" is most frequently used when the operator(s) directly involved in the accident has made mistakes, or when the operator(s) has failed to cope correctly with an emergency or distress situation.

A major difficulty in defining human error is to decide how far back in the chain of events leading to the accidental event the human factor should be traced. As an example a faulty design could result in an accident, however this would rarely be classified as a human error in the accident report. Another example could be that an inspector fails to discover a major deficiency, which leads to an accident. Also in this case the cause of the accident would seldom be attributed directly to human error. This is because the inspector was not an operator involved in the accident. It can, however, also be argued the other way, if an inspector fails to discover a major deficiency, this is a human error. An investigation into the causes should also try to seek an answer to the question "why did the inspector not detect the deficiency?" in order to improve the inspections. However, the relevant question to find the real causes is not "why did the inspector fail", but "why was the major deficiency present". Finding the answer to this question will bring clarity about the real causes of the accident. The failure of the inspector (assuming the inspector is a 3rd party inspector, e.g. Flag, Port or Class) must be considered as the failure of an additional "safety barrier".

Insufficient or neglected maintenance of the ship and its equipment is the result of decisions (or no decisions) by management on board and ashore and officers. Basic causes are either ineffective or insufficient maintenance procedures and instructions, inefficient implementation of the maintenance management system, or lack of support and resources from the shore based management. It may be debated if such maintenance related failures are "human error", but they are certainly deficiencies with respect to the requirements in the ISM code.

Human error is a an important concept in safety-critical systems but there is still a lack of a precise definition, see Massaiu (4.4), who also points out that " --*human errors statements are not about state of affairs or events that we can observe in the empirical world. Instead, human error is a normative category, judgments about the conformity of actions to standards*"

The normative character of human error can also be seen in the following definition: "Human error is defined as a departure from acceptable or desirable practice on the part of the individual or group of individuals that can result in unacceptable or undesirable risks".

IMO has defined Human Element as a complex multi-dimensional issue that affects maritime safety and marine environment pollution. It involves the entire spectrum of human activities performed by the ship's crew, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively. [IMO Resolution A.850(20), Annex, Principles (a)].

It is also important to note that the human factor in a dominant number of circumstances will in effect prevent deviations from developing into an accident. Statistics from operations of commercial aircraft show that during every flight 3 - 4 incidents/deviations that need corrective actions occur. Of these incidents/deviations more than 50% are crew errors and about 30% comes from external threats (bad weather etc). Most probably similar statistics are valid for ship operations.

4.2 Nature of human error

Human error has been addressed in recent years in several papers including topics like causes, how the errors develop into accidents and also to some extent how can human errors be prevented. From a short survey of relevant literature the following can be extracted

- Accidents are in general not caused by a single failure, but by multiple errors (Rothblum). Thus if one of the errors had not occurred the accident would not have happened. This is also expressed by the Swiss cheese model, which portrays the safety barriers as slices of Swiss cheese stacked in a pile. An accident can happen if the holes (in the cheese) overlap each other (see Gatfield et al.).

- Major accidents are seldom caused by a single direct action. Deep rooted underlying causes must be identified (Gatfield et al.)

- Failure of situational awareness and situation assessment dominate overwhelmingly. Human fatigue and task omission seem closely related to failures of situation awareness (Gatfield et al.).

- Comprehension of non-technical skills is immature in shipping (compared with civil aviation and other industries) (Barnett et al.).

The literature indicates quite clearly that human errors are the underlying causes in most accidents and the figures range from about 60% up to 100%, with a generally accepted mean of about 80%. The differences can be attributed to how the analyses of the accidents have been performed, especially as regards which analytic scheme has been used and how far back the events (causes) leading to the accident have been traced.

On the issue of how human errors can be avoided the literature is less informative and in general only qualitative. It is, however, generally agreed that competence and training are important factors although it is difficult to quantitatively assess their influences. Barnet et al. have some comments and suggestions, which are quoted here:

- Crew Resource Management (CRM)[5] training is often applied as a retroactive ´dose´ of post incident remedial training. Officers are sent on the courses in the hope that their erroneous behaviour can be un-learnt and replaced with more appropriate behaviour. However, there is a danger that the point is missed; different ships, different teams, different individuals, but the same sort of incidents keep occurring. Something more fundamental, more deep rooted than

[5] Bridge Resource Management (BRM) is a part of the wider concept CRM

operator error is at fault. Little or no research is done to analyse whether solutions other than training are more appropriate.

- Problems with communication as regards sharing of situational awareness between members in a team and also between distributed teams (as for example the bridge team and the engine room team).

- Effects produced by cultural factors and how can they be characterized. What is the safety performance of a team consisting of individuals from different cultures?

- Organisational factors play a significant role in accident causation. For example there is limited knowledge about the governing functioning of and performance of different management systems.

An important fact as regards human performance is that human beings are great at pattern discrimination and recognition as for instance interpreting a radar screen. On the other hand humans are fairly limited in their memory capacity and capability to calculate numbers quickly and accurately. In addition human performance is also influenced by the knowledge and skills they have acquired as well as by internal regulators such as motivation and alertness (Rothblum).

Several authors also discuss the concept of a safety culture and its importance as regards human errors. Kuo gives the following practical definition of safety culture: *The belief or philosophy on safety matters held by organizations, teams and individuals which is demonstrated in practice through their attitudes, actions and behaviour.*

Several factors influence the safety culture in an organisation, and the two extreme types are based on respectively “the blame philosophy” and “the collaborative philosophy” (Kuo). In short the blame culture sees it to be important to find the responsible person and let her/him face the consequences if an accident occurs. The collaborative philosophy, which is also often referred to as “a blame free culture” focuses on finding best solutions in collaboration between the stakeholders (authorities, users, etc) (Kuo), thus all involved in an operation have a responsibility. A general observation is that the blaming philosophy is most commonly used in practice but it is now more and more appreciated that the collaborative philosophy will result in higher standards of safety.

In conclusion it can be stated that it is generally accepted that human errors are the main cause(s) in about 80% of all maritime accidents. As regards the root causes of the human errors there is limited knowledge but the following factors are considered important:

- Lack of situation awareness
- In general accidents are not caused by a single failure (error), but rather by a chain of errors
- Fatigue

An important factor in reducing human error and achieving higher standards of safety is the role of the safety culture, where a shift from a blame philosophy towards a more collaborative philosophy can be observed.

It should also be observed that a basic step as regards reducing human error is to fully comply with the regulatory requirements in SOLAS[6] and in particular with the STCW 95 Code as well as the ISM Code[7]. Of special importance as regards the human factor are the requirements of manning levels, competence and experience of the crew.

Finally the problem of complacency should be addressed, which is especially important in routine operations (cf the collision Diamant – Northern Star)

4.3 Human factors in the Estonia accident

The analyses of the Estonia accident focus to a large extent on technical provisions to reduce the consequences of the accident. Identifications of the causes which lead to the accident have also to a large extent concerned technical factors as the design and construction of the bow visor locks and similar. The question arises, however, could the Estonia accident been avoided, did the crew have the knowledge, experience and preparation to be able to handle the ship in a safe way in all reasonable realistic conditions?
Using the methodology above to analyse the "accident chain of events" and "chain breakers", to identify human factor related practices, immediately reveals the importance of e.g. situation awareness, standard operating procedures and management responsibility.

[6] SOLAS = The international convention of Safety Of Lives At Sea 1974 including amendments , annexes etc
[7] ISM Code the International Safety Management Code (part of SOLAS)

5 RECOMMENDATIONS

We strongly believe that further analysis of " chains of events" and "chain breakers" from known accidents and the comparison of them with existing rules, will give us a set of issues that still need to be addressed in future development of maritime safety regulations. This will certainly be reflecting the need of human factor related improvements. Regarding the technical regulations some gaps could be identified and possible improvements defined through this methodology.

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