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# SRtP 2.0 — The Evolution of the Safe Return to Port concept

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### Abstract

In 2010 IMO (International Maritime Organisation) introduced new rules in SOLAS with the aim of intrinsically increase the safety of passenger ships. This requirement is achieved by providing "safe areas" for passengers and "essential services" for allowing ship to Safely Return to Port (SRtP). The entry into force of these rules has changed the way to design passenger ships. In this respect big effort in the research has been done by industry to address design issues related to the impact on failure analysis of the complex interactions among systems. Today the research activity is working to bring operational matters in the design stage. This change of research focus was necessary because human factor and the way to operate the ship itself after a casualty on board may have a big impact in the design of the ship/systems. Also the management of the passengers after a casualty is becoming a major topic for safety. This paper introduces the latest techniques addressed to improve passengers ship safety and systems design reliability. An overview of present tools and methodologies will be offered together with future focuses in the research activity.

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# 1 Introduction

Between 2006 and 2010, IMO issued a series of regulations with the aim of intrinsically increasing the safety of passenger ships in case of fire or flooding casualties, following the concept that the ship herself is the best lifeboat. These rules outline two new scenarios:

- Safe Return to Port ”SRtP” [8, 10], a ship that suffers a fire or flood casualty (within a defined threshold) should be able to return to a safe port with her own power system and the necessary comfort avoiding people to evacuate.
- Orderly Evacuation and Abandonment of the ship “OEA” [9], if the casualty threshold defined for the SRtP is exceeded, the ship should still maintain the capability to allow people to safely evacuate and abandon the ship.

These rules are mandatory for the new passengers ships exceeding a length of 120 meters or with 3 or more Main Vertical Zones. The entry into force of these rules has significantly changed the way to design, build and operate passenger ships giving to the operators more awareness of the capability of the ship in case of flooding and fire emergencies. In this context, CETENA (FINCANTIERI Maritime Research & Consultancy centre) is developing dedicated researches for supporting industry in the process of ship design & approval and to setup the necessary ship operational documentation for the operators. CETENA, SISSA (International School for Advanced Studies) and Lloyd’s Register (Class Society) have recently been involved in a challenge aimed at developing “smart” algorithms capable to analyse, for design purpose, the functional chains of a complex systems and their optimal reconfiguration after a fire or flooding casualty. These algorithms may also be used in the decision making process during ship operation in order to support the crew in taking the most appropriate choices to manage the ship after a casualty and how to optimize the ship residual capability accordingly.

# 2 Regulatory Framework

In 2000 the Secretary General of the IMO set up a Working Group on safety of ‘Large Passenger Ships’. Inspiration was “future large passenger ships should be designed for improved survivability, based on the time-honoured principle that a ship is its own best lifeboat”. The Working Group agreed that evacuation to the sea was the most hazardous risk passengers were likely to experience.

- Transfer to, and launching of the LSA.

- Exposure to the elements.
- Recovery from the sea.

The following concepts were considered the basis for the development of the new requirements:

1. The ship itself should be the safest place for all passengers in all situations.
2. Avoid evacuation as long as possible.
3. In case of evacuation time and technical systems must be available for executing the evacuation in good order.

The SOLAS amendments with the aim to increase the level of safety in passenger ships were adopted in December 2006 and finally introduced in by MSC Resolution 216(82), entering into force on 1 July 2010. The new regulations give criteria to allow a vessel to safely return to port under its own propulsion after a casualty not exceeding any of the defined casualty thresholds and criteria for systems required to remain operational for supporting the orderly evacuation and abandonment of a ship, if the casualty thresholds for SRtP fire is exceeded. Requirements related to the safe return to port for passenger ships are actually goal-based in their design and as such open to different interpretations. On the other hand they are open to innovative and fit for purpose solutions as well. This scenario puts challenges for the cost estimation of a new ship and different shipyards/designers may have different views on how to achieve compliance, depending also on actual projects specific requirements. To support in defining level of compliance required at the concept stage, together with details principles and criteria to be adopted for the performance of the individual essential systems, IMO Explanatory Notes and associated interpretations were developed and completed in early May 2010, released with MSC/Circular 1369 [6], entitled Interim Explanatory Notes for the Assessment of Passenger Ship Systems' Capabilities after a Fire or Flooding Casualty. Lloyds register has developed a dedicated chapter of the rules and regulations for the classification of ships on Part 5 Chapter 23, entitled Additional Requirements for Passenger Ships fully dedicated to the SRtP and safety abandonment. At the design stage a qualitative risk based failure analysis is to be conducted. After the compliance demonstration at the design stage, verification, testing and trials process is to be established as well. Ship owner/operator involvement is necessary for definition of the acceptable performance of the ship in SRtP condition in order to establish an acceptable level of safety. During ship lifecycle there will be requirements by flag administration for the crew to perform drills in order to demonstrate knowledge of SRtP procedures in terms of restoration in the SRtP configuration, and Operate the vessel in SRtP degraded mode.

Recently the issue of how to demonstrate efficiency of the SRtP designed ship during lifecycle is becoming more and more subject of a deeper investigation. Proper maintenance plan is a mandatory requirement with the aim to ensure that all the features normally not in use during normal ship operation, and supposed to be operable in SRtP only, are maintained in an efficient status. Another important aspect that has been recently taken more and more into consideration is when important pieces of machinery are supposed to undertake maintenance during navigation. This may render the availability of systems after a SRtP casualty not available. Since there are no clear indications in the rules on the matter, and official guidelines are not available at the moment, this subject will have to be developed at IMO or at IACS level in the future since already happened that stakeholders have challenged the compliance mentioning the problem above exposed.

# 3 Technical and Operative Aspects

## 3.1 Implications of SRtP and OE on Systems Design

The design of a ship compliant with the SRtP and OEA requirements involves a simultaneous evaluation of the ship functional capabilities requested by SOLAS, the redundancy of the systems components, their level of segregation, the philosophy of passive and active fire protection of the ship and of the role of the crew in the emergency process. SOLAS main request is to have a ship capable to preserve navigation, safety and comfort capabilities after a fire or flooding casualty (not exceeding a certain pre-defined casualty threshold) so as to bring the embarked people to the closest safe port. To achieve the above goal the design of the ship general arrangement plan, the systems layout, their architecture and their interconnections become a complex and challenging task for the designers that could only be pursue with the aid of specific software tools. These tools should have the capability to take into consideration all the SRtP requirements and constraints and evaluate the effect of each failure mode - simply called fire/flooding scenario - on the systems capability. In case after a casualty SOLAS requirements could not be guaranteed, the systems design or the ship layout in terms of structural passive fire protection, need to be reviewed and corrective actions should be implemented. This process is usually called the SRtP assessment. The documentation used for the assessment activity needs to be kept updated along the whole assessment process. This imply a continuous cross check activity (design vs installations) that follows the whole ship construction process. Misalignments between design and construction could have virtually severe implications in the feasibility of the ship or may lead to an important increase of costs of the ship.

## 3.2 Implications of SRtP and OE on Ship Management

Beyond the above engineering requirements, the SRtP criteria introduce an additional challenge: matching the systems design with the operator/crew procedures in case of emergency. The crew should have a deep knowledge of the ship capability after a casualty and how to recover it. For this purpose SOLAS regulations require the yard to develop a set of instructions, known as “operational manuals”, which help the crew to reconfigure the systems involved in the casualty to restore their functionality. The level of residual capability after the casualty must be well defined and evaluated during the design phase and is subjected to the formal approval of the Class Societies. The content of the operational manuals is mainly a check list of the manual actions that the assigned crew team must perform in order to recover each system affected by the casualty. In this framework, the level of automation plays an important role in defining the list of manual action. The research activity carried out by CETENA and FINCANTIERI in recent years allowed to define a technique to setup the operational manual starting from the design and assessment activity. The contents and the layout of the Operational Manuals is designed with new IMO requirements which put the human at the centre of the design for enhancing performances and reliability during operations (Human Centred Design).

## 3.3 Application Example: the Fire Main System

Fire Main system (FMS) is one of the most important safety related system onboard and for this reason is one of the essential system/function requested by SOLAS in both SRtP and OEA scenarios. Its main purpose is to supply large quantities of sea water into the ship to extinguish fires. It also serves as an emergency or stand-by supply for salt water and sanitary service system and can also be used to supply the clean ballast system. SOLAS chap. II-2, reg. 21 [8] and 22 [9] establish that “FMS must remain operational in all the MVZ not affected by the casualty. In case that the casualty exceeds the defined threshold, an OEA is foreseen. In these circumstances the casualty can be considered to involve an entire MVZ.

The FMS SRtP assessment consists in evaluating the effects of any possible SRtP casualty on the system and in particular that after each casualty scenario, the reconfiguration of the main distribution ring (by performing the related manual actions) and the supply of water to all the unaffected MVZs is always possible. The complexity of the SRtP scenario in relation to the layout of the ship makes the FMS one of the most complex systems in terms of pipes routing, positioning, management of the valves (manual actions) and redundancy of the power system. As a result of the stringent SRtP requests the FMS must be designed with an higer level of redundancy. The OEA assessment of the FMS consists in simulating the loss of the whole

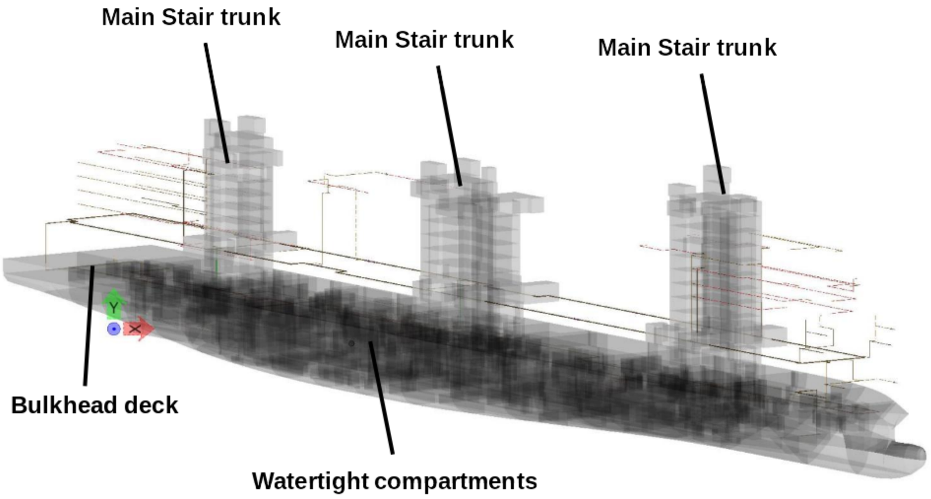

Figure 1: Example of Fire-Main System model/layout

MVZs (one at a time as described in SOLAS) and verify that the remaining available system can continue to supply water to fire hydrants in all the other unaffected MVZs during the ship abandonment operations, safely and for at least 3 hours.

# 4 Future Trends and Requirements - Limits of the Present Approach

As the ship design is changing to meet the SRtP regulations, the focus of the community involved in SRtP related aspects of ship design is moving from the design aspects to the operational issues. This reflects also the work of the International Maritime Community that has brought the design requirements to a sufficient level of details (thanks to the contribution of class societies interpretation and industry experience) and now are aware that also the operational aspects have to be addressed. Engineering has covered the technical and cultural gap that was present at the time of the entry into force of the SRtP regulations. Now the maritime community is aware that operational aspects may be an important driver in ship design and, especially in safety related matter, the ship, the crew and the operational procedure must be considered as one design driver (human centred design).

## 4.1 Limitation of present design and assessment approach

The current technique of designing and verifying the systems capabilities to fulfill the SRtP requirements after a fire or flooding casualty is still a process that suffers a lack of information during the early design stage, when details of the systems layouts may not be fully available and engineering choices are not well defined. Moreover the choice of how to reconfigure the system after a casualty is the result of a complex decision making process, often a compromise between the designer experience and time and tools constrains/limitations. The designer in charge of assessing one system uses software tools that can simulate all the possible casualty scenarios and compare the ship residual capability with the minimum level required by the rules. At the moment the degradation criteria and the level of residual capability are defined in a deterministic way by the designer/operator. It is easy to understand that both design and assessment stage are still highly dependent on the designers decisions/choices that can produce errors and limitations in the range of all the possible solutions. The current software tools and techniques available do not allow the designers to reach a desirable level of flexibility from the early design stage through the operational life. The development of smart dynamic algorithms, able to align the system design evolution (eg. component topography, interconnections and their nature, distribution networks, etc.) to the SOLAS requirements analysis, and then to automatically evaluate the possible and more efficient systems reconfiguration would certainly represent a big step forward in the SRtP compliance analysis.

### 4.2 Limitation of present ship management in emergency situations

In accordance to IMO MSC.1/circ.1369 [6], CETENA produces the Operating Manuals that allow the crew to reconfigure the essential systems after a SRtP casualty so as to be able to bring the ship to a port with adequate comfort and safety standards. However, the ship can be operated in a different way from what is foreseen in the design stage. In this scenarios, the present “static” Operational Manuals can be a limitation. In order to be effective during emergency operation, Operational Manuals must be dynamic so as to provide interactive information and suggestion to the crew about the reconfiguration of the ship and the recovery of the functions in accordance with to the systems configuration at the moment of the casualty. Future research effort is addressed to build new models capable to perform a Live Assessment and to provide interactive information to the crew.

## 5 Development Of New Instruments to Support The Design And The Operational Life On Board The Ship

In the framework of developing a mathematical model that represents the functional behavior of the ship systems with sufficient accuracy, the CAD model of the ship and the functional features of the infrastructures are closely analyzed by means of complex network and graph theories tools to obtain the network topology. Such topology is in practice represented by a functional scheme composed by a set of nodes and edges with commodities flowing from node to node in the system through paths represented by collection of edges. More specifically, if the power network is the infrastructure considered the network graph will be composed by nodes represented by generators, main distribution stations and substations and by the edges linking such nodes. As for the water infrastructure, the nodes of the network graphs are reservoirs, compressor stations and distribution nodes, while the pipelines are the edges.

## 5.1 Network Efficiency and Vulnerability Analysis

The network model developed is typically the starting point for the evaluation of the infrastructure performance and of its vulnerability. The network efficiency is a measure of its exchange of commodity across the whole network in which that commodity is concurrently exchanged — for instance the flow of water in the water infrastructure. The local efficiency is instead a measure of how important a node is, obtained quantifying how well commodities are exchanged by its neighbors when the node is removed. The local efficiency measure provides information on the network resistance to failures at the small scale. Several formulas have been proposed in the literature to obtain efficiency evaluations (among others, we mention [3]). While these definitions are for the most part based on a notions like node betweenness — a measure of the number of shortest paths in the grid passing by a node [1] — and nodes geographical distances along the grid, they differ in particulars which make them able to account for different important aspects of the infrastructure at hand. We are currently considering such efficiency definitions to figure which one is most suitable for our purposes. A further important concept is the network vulnerability. Vulnerability has several definitions in the literature. Among others we report the one by Haimes [2]: "Vulnerability is the manifestation of the inherent states of the system (e.g. physical, technical, organizational, cultural) that can be exploited to adversely affect (cause harm or damage to) that system". So, there are several algorithms in the literature for quantifying vulnerability. Vulnerability can be analyzed to evaluate the global performance of a grid, or to find out what are its most critical components and geographical locations. Generally speaking, the first analysis is carried out removing nodes randomly and evaluating the network efficiency loss, while the latter one focuses on finding which nodes, if removed, cause the highest network performance drop.

## 5.2 Network Interdependence

The infrastructures of a ship that are considered in the project do not of course operate in isolated fashion. It is quite clear that systems such as the electrical, communication and water network operate in interdependence. Thus, interdependence among the infrastructure systems on board must be accounted in any model which aims at providing reliable information on the current operational state of the ship and on its possible vulnerabilities. There are several different reason for interdependence between networks, which of course lead to different characterizations and models. Physical, geograpyhcal or cyber interdependence (see [7]) are among the examples of possible interactions that need to be treated in different ways. Two infrastructures can also be one directionally or bidirectionally interdependent, depending on the fact that only one is affected by the other or that they are mutually dependent. In the models, interdependence is represented by introducing links in the networks, which indicate the nodes of a system that are depending on nodes of a different infrastructures [12]. Such links have different mathematical representation depending on the kind and the level of systems interdependence.

## 5.3 Dynamic Algorithms

An important aspect of the present study is that the algorithms developed must be able to account for the current state of the ship infrastructures considered. More specifically, the algorithm must adapt to the actual configuration of the ship infrastructures, taking into account possible operation of the systems by the crew (such as, for instance, opening or closing valves in water system, or turning a switch in the power line) or the presence unavailable components or portions of infrastructures due to faulty behavior or maintenance. To this end, the most common and significant configurations of the infrastructures undergoing maintenance are identified, and the correspondent network graph is obtained and subjected to the analysis described in the previous sections.

## 5.4 Optimization Algorithm to Identify Actions Maximizing Residual Performance After Accident

A further element of the recent work regards the investigation on the possible actions taken by the ship crew to react to possible incidents occurring aboard and maximize the residual operativity of the systems. To this end, the model under development must include all the most relevant actions that the crew members use to operate the ship infrastructure system. An optimization tool is then being studied to evaluate which set of actions will maximize the residual efficiency of the systems in the aftermath of an incident impairing the functioning of one or more components of the ship infrastructures, and evaluate the necessity for a return to port or, in worst cases, to abandon ship.

## 6 Conclusion and Further Developments

As a consequence of SRtP requirements ship design process has changed. At present Maritime Community has brought the knowledge of SRtP to a sufficient level of detail so as to address issues such as rationalisation of the design and the way to operate at best the ship in real life. Aspects such as the knowledge of the configuration of the systems, the availability of systems components at the moment of the casualty, the foreseen maintenance are becoming early stage design drivers. In order to be able to evaluate these new scenarios, “smart” algorithms/models capable to analyse the casualties effects in a dynamic way should be developed. Industry research activity in these topics are ongoing with the aim to support shipyards and operators in coming years.

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