SafePASS

Next generation of life Saving appliances and systems for saFE and swift evacuation operations on high capacity PASSenger ships in extreme scenarios and conditions

MG-2-2-2018 Marine Accident Response No. 815146

D2.1: Evacuation processes: Best practices, tools and gaps

Deliverable number:	**D2.1**
Deliverable title:	**Evacuation processes: Best practises, tools and gaps**
Nature[1]:	**R**
Dissemination Level [2]:	**PU**
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Official submission date:	**January 31st, 2020**
New submission Date	**June 4th,2021**

[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified, as referred to in Commission Decision 2001/844/EC

Modification Index			
Date	Version	Description	Edited by
09/12/2019	0.1	TOC	Elena Krikigianni (SEAB), Vasiliki Palla (SEAB), Geli Latsa (SEAB)
17/01/2020	0.2	Input on chapters 1,2,3 and 4	Elena Krikigianni (SEAB), Vasiliki Palla (SEAB), Geli Latsa (SEAB), Lazaros Karagiannidis (NTUA),
06/02/2020	0.3	Input throughout the document	Elena Krikigianni (SEAB), Vasiliki Palla (SEAB), Geli Latsa (SEAB), Lazaros Karagiannidis (NTUA), Alexandros Rammos (NTUA), Fotios Stefanidis (MSRC), Paul Bersans (DXT)
21/02/2020	0.4	Comments and input provided	Elena Krikigianni (SEAB), Vasiliki Palla (SEAB), Geli Latsa (SEAB), Lazaros Karagiannidis (NTUA), Alexandros Rammos (NTUA), Fotios Stefanidis (MSRC), Evangelos Boulougouris (MSRC), Rainer Hamann (DNVGL), Juan Latzke Blake (RCCL)
27/02/2020	0.5	Peer review version	Alessandro Maccari (RINA_S), Juan Latzke Blake (RCCL)
03/03/2020	0.6	Comments integrations and final refinements	Elena Krikigianni (SEAB)
10/03/2020	1.0	Final Version	Lazaros Karagiannidis (NTUA)
03/06/2021	2.0	Re-submission: Reviewer's comments addressed in section 3 and sub sections 3.1.3 and 5.1.2.	Elena Krikigianni (SEAB), Lazaros Karagiannidis (NTUA), Rainer Hamann (DNV), Alessandro Maccari (RINA), Juan Latzke Blake (RCCL)

This work is a part of the SafePASS project. SafePASS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 815146.

Acronyms and Abbreviations

Acronyms and Abbreviations	
2D	Two-Dimensional
3D	Three-Dimensional
AB	Abled-bodied seaman
AD&A	Alternative Design and Arrangements
AER	Active Evacuation Route
AR	Augmented Reality
ASET	Available Safe Egress Times
CAD	Computer-Aided Design
CCTV	Closed-Circuit TeleVision
CFD	Computational Fluid Dynamics
Ch.	Chapter
CO_2	Carbon dioxide
COP	Common Operational Picture
CSSF	Cruise Ship Safety Forum
DECT	Digital Enhanced Cordless Telecommunications
DSS	Decision Support System
Dx.y	Deliverable y belongs to Work Package x
EC	European Commision
ECR	Engine Control Room
EMCIP	European Marine Casualty Information Platform
EMSA	European Maritime Safety Agency
FDS	Fire Dynamics Simulator
FP7	Seventh Framework Programme
FSS	Fire Safety Systems
GBS-SLA	Goal-Based Standards-Safety Level Approach
GDPR	General Data Protection Regulation
GISIS	Global Integrated Shipping Information System
GSRT	General Secretariat for Research and Technology
GT	Gross Tonnage
HIS	Information Handling Services
HW	Hardware
ICAO	International Civil Aviation Organization
ICT	Information and Communication Technologies
IGF	International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels
IMO	International Maritime Organization
IP	Intellectual Property
ISM	International Safety Management
JRCC	Joint Rescue Coordination Centre
LES	Large-Eddy Simulation
LSA	Life-Saving appliances
MAIB	Marine Casualty Investigation Board
MCI	Maritime Casualties and Incidents
MCIB	Marine Casualty Investigation Board
MIT	Ministry of Infrastructure and Transports

MSR	Merchant Shipping Regulations
MSC	Maritime Safety Committee
MVZ	Main Vertical Zone
NTSB	National Transportation Safety Board
PSA	Personal Life-saving Appliances
PU	Public
RCOs	Risk Control Options
RSET	Required Safe Egress Times
SAR	Search and Rescue
SMCS	Safety Management Control System
SMS	Safety Management System
SOLAS	Safety of Life at Sea Convention
SoTA	State-of-The-Art Analysis
SPSC	Self Propelled Survival Craft
SRtP	Safe Return to Port
SS	Steam Ship
SSE	Ship Systems & Equipment
SSP	Ship Safety/ Security Plans
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
SW	Software
TTP	Tactics, Techniques, and Procedures
UK	United Kindom
USCG	United States Coast Guard
UWB	Ultra-Wide Band
VDR	Voyage Data Recorder
VR	Virtual Reality
VTS	Vessel Traffic Services
WP	Work Package
WTC	WaterTight Compartments

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Executive Summary

State-of-the-art (SoTA) analysis is a preliminary step to specify the baseline with respect to demonstrate the novelty of the upcoming research results. Funded under the European Union's Horizon2020 Framework Programme, the aim of SafePASS is to radically redefine the evacuation processes, evacuation systems/equipment and international regulations for passenger ships in all environments, hazards and weather conditions, independently of the demographic factor, by developing an integrated system that will collectively monitor, process and inform during emergencies both crew and passengers of the optimal evacuation routes, coupled with advanced, intuitive and easy to use LSA, resulting as such to a significant reduction of the total time required for ship evacuation and increased safety.

The current document provides a review of the existing tools and products used for evacuation, as well as an identification of regulatory gaps and accident investigation. It is connected to Task 2.1: *Ship evacuation current practices and regulation-gaps and needs* within Work Package WP2: SafePASS Design, User and System requirements. The present document is considered as a guiding and referenced document for the whole project. The concluding remarks presented within this study have been discussed and evaluated during the SafePASS stakeholders' workshop, conducted on 29th of January 2020, in Glasgow, Scotland.

The identification of the evacuation processes in the context of the best practises, tools and gaps is crafted by conducting a State-of-the-Art analysis of the evacuation of the large passenger ships, using a five-step approach. The five discrete concurrent steps are referring to:

i. the recording of the evacuation regulatory framework,
ii. the documentation of the recent publications in the field of evacuation of the large passenger ships,
iii. the identification of existing systems used during the evacuation,
iv. the reporting of the recent evacuation incidents, and
v. the review of previous project results and outcomes.

1. Introduction

This deliverable (D2.1) results from SafePASS's Task 2.1 – Ship evacuation current practices and regulations – gaps and needs. This task is part of the WP2 – SafePASS Design, User & System Requirements, which aims at identifying the current practices and problems in ship evacuation, deriving the mission and the operational requirements following a stakeholder driven approach, defining the system requirements along with the functional specifications and eventually at designing the overall SafePASS system architecture.

The current deliverable, titled as 'D2.1 Evacuation processes: Best practises, tools and gaps', is a key reference document for all the activities to be implemented within WP2 of SafePASS project. Its main focus will lie both on technical and procedural aspects, towards identifying existing systems used during the evacuation such as the use of Personal Life-Saving Appliances (PSAs), the ease of access to the survival craft, their layout on the ship, the release mechanism of lifeboats and liferafts and the appearance of bottlenecks, during mustering and embarkation on survival craft. Concurrently, it deals with the identification of gaps in the related regulatory framework, composed of SOLAS Chapter III, LSA Code and MSC.81(70), and the review of recent evacuation incidents, previous project results and recent publications in the field.

1.1 Purpose of the document

The purpose of this deliverable is to provide a thorough overview of the current State of the Art of the evacuation of large passenger ships by exhaustively investigating the landscape of passenger ship evacuation in terms of LSAs/PSAs used, evacuation procedures/best practices, and regulatory framework in place. This investigation mainly aims at spotting any existing gaps to speed-up but also make safer the overall evacuation process from the point of general alarm to the embarkation on the lifeboats and liferafts and their launching into the sea.

1.2 Intended readership

This deliverable is addressed to any interested reader. Although it is a literature-based deliverable, it constitutes a fundamental step, in order to design the SafePASS system and the overall architecture.

1.3 Document structure

The document is structured in eight main sections, as follow:

Section 1, introduced the purpose of this document, as well as the intended readership;

Section 2, defines the ship evacuation terminology and provides an overview of the current research conducted in the field of ship evacuation;

Section 3, analyses the evacuation regulatory framework;

Section 4 investigates the recent publications in the ship evacuation field;

Section 5, analyses the existing evacuation technical, safety, simulation and supervision systems;

Section 6, provides an analysis of the last decade incidents;

Section 7, describes the previous ship evacuation research projects;

Section 8, provides the final conclusions.

2. Ship evacuation overview

The social pressure from tragic accidents is often the driving force for significant developments in the maritime industry. Accidents from SS Titanic back in 1912 to the tragic loss of M/V Estonia in 1994, have brought cataclysmic changed to the shipping industry and led to the establishment and strengthening of a regulatory framework that upholds maritime safety, covering also the ship's evacuation.

Since the loss of SS Titanic, it has always been recognized that the best way of improving safety at sea is by developing international regulations that are followed by all shipping nations. It was then that the International Convention for Safety of Life at Sea was developed, as an initial step for further regulatory developments. The same shared vision has been the cornerstone for the foundation of the International Maritime Organization (IMO) and the introduction of its Safety of Life at Sea Convention (SOLAS) with its current form in 1974. Since then, IMO has introduced and adopted a series of regulations, global standards and guidelines for safety requirements, including those relating to fire safety measures (e.g. escape routes and fire protections systems) and life-saving appliances and arrangements.

When the '***Evacuation***' term comes in mind, reference is made to a temporary but rapid removal/relocation of people, individually or in an organized manner, from a disaster (or threatened) area to a safe place as a rescue or precautionary measure[1]. In comparison with any other kind of evacuation, ***ship evacuation*** [2] in an emergency is vital in the occurrence of an accident on the ship and presents a number of differences (with respect to the evacuation onshore e.g., in buildings, in stadiums etc.) in several aspects. It can be described as a process that follows the decision of her captain/commanding officer to abandon the ship because she is not safe anymore for the people (passengers and crew) on board. It is the "last resort" in case of an emergency and a procedure is very different from the evacuations of other occupied spaces (i.e. buildings, stadiums, aircrafts or buses).

One of the most distinct characteristics, is the use of Life saving Appliances and survival craft (lifeboats and liferafts), which are used as means of rescue for passengers and crew, during the ship abandoned process. In addition, passengers are requested to orient themselves through the various decks in order to find the indicated muster station and to collect their personal survival equipment, which may require to move to the other side of the ship and/or in other deck, to reach muster station and subsequently the embarkation deck, ending up to use unfamiliar means like lifeboats or liferafts. The ship evacuation process can also become even more complicated and challenging, if in addition to the vessel's emergency, the ship motions and inclination are substantial and the prevailing weather conditions are bad[3].

An indicative overview of the ship evacuation process, which consist of a significant number of phases from ACCIDENT to RESCUE is presented in figure 1 below:

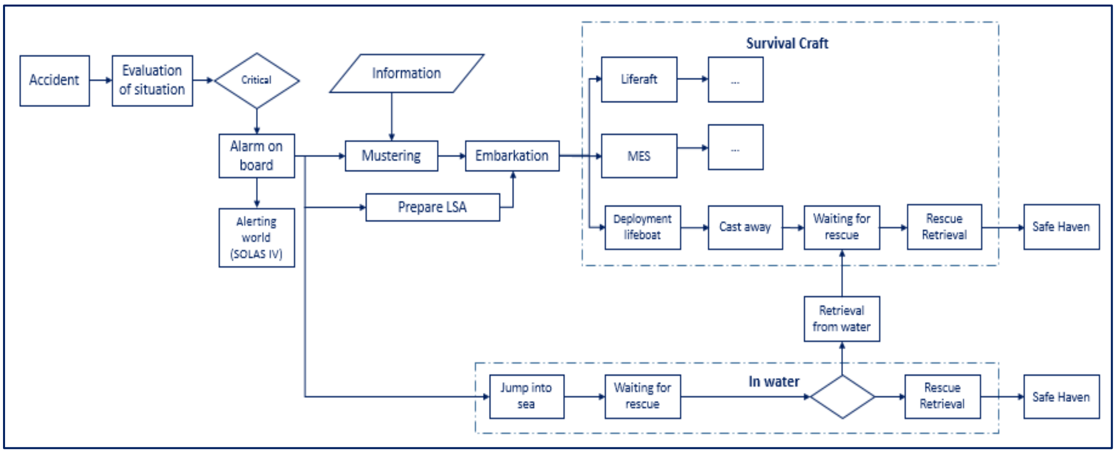


Figure 1 Evacuation process from Accident to RESCUE

The occurrence of an incident is always followed by the evaluation of situation. In emergency phases the basic situation awareness creates the starting point for the real-time awareness created to support mission coordination. When the assessment is considered critical, an emergency alarm on board is sound (refer also to the ALARM to RESCUE timeline in figure 2, section 3.2). The assembly to muster stations as well as the transfer to embarkation stations are then initiated, along with the preparation of the LSAs and the survival crafts (launching) (a detailed description of the LSAs-PSAs and Survival Crafts (e.g. MES) is given in sections 5.1.1 and 5.1.2). When the “Abandon Ship” announcement is made by the Captain, the ship abandonment process is started. Finally, the rescue retrieval guarantees the mission’s accomplishment. A thorough description of the overall evacuation process in cruise ships as well as of the safety management plan is provided in D2.2 ‘SafePASS mission and operational KPIs’.

Depending also on the casualty types as they are considered in HIS [4] (Foundered (FD), Fire/explosion (FX), Collision (CN), Contact (CT), Wrecked/stranded (WS), Hull/machinery damage (HM)), they are cases when orderly and not orderly evacuation is applied. More specifically, FX, CN, CT and GR are accident categories allowing orderly evacuation, while Foundering not.

Taking also into consideration that the capacity as well as the size of large passenger ships are increasing, and the complexity of the evacuation process which is both a safety-critical and a strictly time-bound task, higher demands, in first place, are put on the prevention of a casualty from occurring through the compliance of the available standards and regulations and the development comprehensive post-inside approach from ALARM to RESCUE, by evolving and using integrated systems and advanced dynamic support tools.

2.1 Challenges and needs

It is evident from the description of the evacuation process from Accident to RESCUE, that passenger ship evacuation is a peculiar research area and a dynamic, multi variable process. Realising the importance of the evacuation process as the "last line of defence" in case of an emergency, as well as its constantly changing parameters (e.g. time, ship's position and condition, weather conditions, people's behaviour etc.), EC has supported the research on this area with a significant number of projects and tenders and considerable funding. Projects like SAFEDOR, SAFECRAFTS, eVACUATE, LYNCEUS, PICASSO, FIREPROOF, FLOODSTAND, SafeGUARD etc. (extensive reference is given in chapter 7), paved the way for significant developments in IMO (e.g. Guidelines for Alternative Design and Arrangements for LSAs) and brought disruptive changes to the passenger ship industry (e.g. novel survival craft and Life-saving Appliances, risk analysis for different means etc.).

Advanced numerical simulation is considered nowadays as an essential step [5] towards the performance-based design approach. As matter of fact, current research activities are mainly focused on identifying appropriate tools, capable of taking into consideration the peculiarities of both the maritime environment and maritime operations, such as human behaviour, human mobility and human interaction [6] as well as of supporting the various design stages towards increasing the level of safety. Several studies [7] have been conducted by emerging the need of integrating human factors analysis for maritime emergency evacuation [8] even on the ship design stage [9]. Efforts have been also made towards the passenger route optimization within a maritime emergency [10][11][12].

Besides, based on the fact that simulation is a fast and cost-effective tool (comparing to the high cost and the ethical issues raised when performing ship evacuation experiments[3]) for modelling maritime emergency evacuation in complex ship environment including different hazards such as heel/trim and fire, research progress is currently being conducted in executing various simulations of advanced evacuation analyses (please refer to chapter 5 for more information). These simulations are using different models consisting in individual, crowd, and counter flow avoiding behaviours in passenger ships [13], but selectively using disruptive technologies such as VR and evacuation-specific functionalities. Other research studies are focused on the

[3] The ethical issue, as shown by the evacuation test required by FAA, is that a demonstration of successful evacuation must be done within 90 seconds. The industry standard 90-second evacuation certification trial assumes that each passenger is socially unconnected to other passengers, and the majority of experimental trials that have been conducted have also been based on individuals. Taking into consideration that of all people using 50% of the exits, this can cause frequently severe injuries and even fatalities [15].

development of simulation models for evaluating the effectiveness of transportation facilities for evacuees on a ferry including disabled persons in an emergency situation.

Concerning the survival crafts, challenges are mainly focused on an alternative design of MES that could allow their installation in wide range of vessel configurations. Their next generation is envisage to go hand in hand with the next generation of lifeboats in terms of ensuring the same or higher performance standards in trim and listing conditions and decreasing the deck footprint.

In the same direction of research, efforts were also made towards demonstrating the advantages for real-time emergency response management via using prototyped smart devices, such as wireless bracelets and lifejacket-embedded sensors, as well as ultra-low power wireless area network technologies for people localization [14].

2.2 Patents in ship evacuation field

It is also worth mentioning that following the research direction, a ''patenting explosion" has been observed worldwide. According to Mikalsen et al. (2011)[16] '*the legal protection of intellectual property is becoming increasingly important for developers of new technology, and the highly international marine industry faces some particular challenges in obtaining effective worldwide protection of innovation*'. It is remarkable that a number of patents (as presented in table 1) related to the life-saving devices and equipment has been granted, while a significant number is in application stage (table 2) [17].

Table 1 Patents granted

Name	Code/ID	Application granted	Application status is Expired - Lifetime	Current Assignee
Device for inflating floating bodies of life-saving equipment	US3526339A	1970	2020	BERNHARDT APPARATEBAU CO GmbH Co
Automatic inflating device for lifesaving devices	US3997079A	1976	2020	Niemann Wolfgang
Ship escape and survival system	US4187570A	1978	2020	US Secretary of Navy
Life rafts on ships	US5765500A	1992	2020	VIKING LIFE-SAVING EQUIPMENT BERGEN
Arrangement for evacuation of persons from a ship	EP0879172B1	1999	2020	Koppernaes AS

Mooring of a floating unit to a vessel side	US7159527B2 Patent number: 7159527	2002	2023	VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Container for storing an inflatable liferaft	US8192243B2 Patent number: 8192243	2012	2025	VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Escape system with self-adjusting length	US8312967B2 Patent number: 8312967	2012	2029	VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Floatable unit for evacuation purposes	Patent number: 8512089	2013		VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Inflatable unit for a life-saving equipment	US20140087610A1 Patent number: 9067656	2015	2032	VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Inflatable floatable unit	US20140256197A1 Patent number: 9150292	2015	2032	VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Evacuation system	Patent number: 9272757	2016		VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Inflatable floatable liferaft for marine rescue	US9352813B2 Patent number: 9352813	2016	2032	VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Evacuation system	Patent number: 9533739	2017		VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS
Drone-type life-saving equipment dropping device	JP6366743B2	2018	2035	オー、インソン
Evacuation system	Patent number: 10526051	2020		VIKING LIFE-SAVING EQUIPMENT AS Viking Life Saving Equipment AS

Table 2 Patents in application status

Name	Id/Code	Publication Date	Current Assignee
Container for Storing an Inflatable Liferaft	US20070243779A1 Publication number: 20070243779	2007	Viking Life Saving Equipment AS
Sensor equipped flame retardant clothing	US20090188017A1 Publication number: 20090188017	2009	Viking Life Saving Equipment AS
Escape System for Emergency Evacuation	Publication number: 20100213006	2010	Viking Life Saving Equipment AS
Bag for hermetically enclosing an inflatable liferaft	Publication number: 20100252196	2010	Viking Life Saving Equipment AS

Inflatable liferaft	Publication number: 20100297897 Publication number: 20100311292	2010	Viking Life Saving Equipment AS
Inflatable unit	Publication number: 20110011673 Publication number: 20110039462	2011	Viking Life Saving Equipment AS
Liferaft system	Publication number: 20120061265	2012	Viking Life Saving Equipment AS
Inflatable unit for a life-saving equipment	Publication number: 20140087610	2014	Viking Life Saving Equipment AS
Inflatable floatable liferaft for marine rescue	Publication number: 20140199901	2014	Viking Life Saving Equipment AS
Inflatable floatable unit	Publication number: 20140256197	2014	Viking Life Saving Equipment AS
Evacuation system	Publication number: 20140283729	2014	Viking Life Saving Equipment AS

3. Evacuation regulatory framework

IMO (International Maritime Organization) [19] is the main agency in United Nations, which is responsible for maritime regulations. IMO was founded in 1948 since then has worked continuously towards the improvement of the safety of ships and environmental safety. In 1965, IMO established an updated version of the existing SOLAS regulations (International Convention for the Safety of Life at Sea), addressing regulations related to the fire protection, life-saving appliances, safety of navigation and the transportation of dangerous goods. Following the adoption of SOLAS, several conventions have been developed containing regulations, either new or amendments to existing in order to adapt regulation to the technological advances. Additionally, new SOLAS chapters have been adopted mostly in order to make new Codes mandatory, like High-Speed Craft Code, IGF Code, ISM Code, Polar Code [22].

In 1979, IMO released an additional convention called SAR Convention (International Convention on Maritime Search and Rescue), which led to the release of additional regulation in relation to the safety of evacuees. At the same time, it introduced the STCW convention (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers), which addresses the training of crewmembers and personnel. In 1998, IMO entered into force the International Safety Management (ISM) Code in its mandatory form, as a step for the provision of an international standard for the safe management and operation of ships and for pollution prevention. In 2002, the Maritime Safety Committee recognizing the need to continue the mandatory application of the fire safety systems required by the revised chapter II-2 of the Convention, adopted the International Fire Safety Systems Code (FSS-CODE) [18].

In general, IMO's ship safety related provision aims on a) mitigating the probability of an incident and b) mitigating the consequences of an incident with respect to persons on board and environment. Excluding personal incidents, the provisions of the second category can be further categorized into means mitigating the impact on the ship (ship remains a safe place), i.e. minimizing ship's vulnerability and means mitigating the impact to person after ship lost her "safe place" function, i.e. provide a safe place other than the ship. It is noted that IMO provisions are not structured according to these categories, but follow a more system orientated approach and are spread over a variety of Conventions, Codes and Circulars, towards making things even more challenging, containing both mandatory regulations and non-mandatory recommendations.

Due to the high number of persons concentrated on board of a passenger ship and the IMO goal of protecting life at sea, passenger ships are subject to a vast array of regulations and standards covering every aspect of ship construction and operation.

According to IMO (SOLAS Ch. I, Part A, Reg.2), a passenger *is every person other than the master and the member of the crew or other persons employed or engaged in any capacity on board a ship on the business of that ship; and a child under one year of age.* And a passenger ship is a ship carrying more than twelve passengers. Typically, the following types of passenger ships can be distinguished (considering ship categories in IHS/Markit Ship register [4])

A. *Passenger/Cruise ship:* ship certified to carry more than twelve passengers, all may be accommodated in cabins
B. *Passenger ship:* ship certified to carry more than twelve passengers, only some may be accommodated in cabins
C. *Passenger/Landing craft:* a landing craft certified to carry more than twelve passengers
D. *Ro-Ro/Pax:* a ro-ro cargo ship for additional carriage of vehicles (rail) and with accommodation for more than twelve passengers
E. *General cargo/Pax:* cargo ship with accommodation for more than twelve passengers.

With respect to SAFEPASS only types A, B and D are relevant.

IMO provides the regulatory framework for international shipping and ships on international voyage must comply with all relevant IMO regulations, including those in the SOLAS and Load Lines Conventions. The next subsection 3.1 provides an overview of the main conventions and codes mainly referring to the new amendments that address the even arising requirements of the ships during evacuation.

3.1 Conventions and Codes

SOLAS convention (International Convention for the Safety of Life at Sea) is a treaty, which according to IMO, "*is generally regarded as the most important of all international treaties concerning the safety of merchant ships''*[19]. The first version was adopted in 1914, in response to the Titanic disaster, the second in 1929, the third in 1948, and the fourth in 1960. The current version of SOLAS was adopted in 1st of November 1974 and entered into force in 25 May 1980 [20] and since then continuously amended. SOLAS convention is mandatory for all merchant ships traveling on international voyages and of more than 500 GT. Today the SOLAS regulations addresses the following (some of these chapter refer to Codes containing the regulations):

- Technical provisions
- Chapter I - General Provisions
- Chapter II-1 - Construction - Subdivision and stability, machinery and electrical installations
- Chapter II-2 - Fire protection, fire detection and fire extinction

- Chapter III - Life-saving appliances and arrangements
- Chapter IV – Radio communications
- Chapter V - Safety of navigation
- Chapter VI - Carriage of Cargoes
- Chapter VII - Carriage of dangerous goods
- Chapter VIII - Nuclear ships
- Chapter IX - Management for the Safe Operation of Ships
- Chapter X - Safety measures for high-speed craft
- Chapter XI-1 - Special measures to enhance maritime safety
- Chapter XI-2 - Special measures to enhance maritime security
- Chapter XII - Additional safety measures for bulk carriers
- Chapter XIII - Verification of compliance
- Chapter XIV - Safety measures for ships operating in polar waters

With respect to SAFEPASS the following chapters/parts are regarded as relevant:

- SOLAS Chapter III specifies the international requirements and it is considered as a higher level area for the life-saving appliances supplemented by the requirements of the LSA code (International Life-Saving Appliances Code) (MSC.48(66))[21].
- SOLAS chapter II-2 with the regulation for escape.
- SOLAS chapter IV with respect to radio communication (distress signal and communication between ship and survival craft.
- SOLAS chapter V: with respect to provide assistance for other ships/people in distress as well as search and rescue.

LSA Code (Life Saving Appliances Code) was brought into force as mandatory in 1998, regulating the life-saving evacuation appliances of ships. The LSA code, includes a description of personal life-saving appliances (such as lifebuoys, lifejackets, immersion suits, anti-exposure suits and thermal protective aids), visual aids, such as parachute flares, hand flares and buoyant smoke signals, survival craft, rescue boats, marine evacuation systems (MES), launching and embarkation appliances and general alarm and public address systems. The LSA code is of real value for SafePASS research activities.

The **SAR convention (International Convention on Maritime Search and Rescue)** was adopted in 7 April 1979 and entered into force for the first time in 22 June 1985. A revised Annex to the SAR Convention was adopted in May 1998 and entered into force in January 2000, while the latest one was adopted in May 2004 and entered into force in July 2006, with the aim to enhance the safety for people being in distress at sea [23] and to contribute to an increased efficiency of maritime rescue operations. It is worth mentioning that until the adoption of the SAR Convention there was no international system covering search and rescue operations, although the obligation of ships to provide assistance to vessels in distress has been demanded by the International

Convention for the Safety of Life at Sea (SOLAS 1974). The latest revised Annex includes five Chapters:

- Chapter 1 - Terms and Definitions
- Chapter 2 - Organization and Co-ordination
- Chapter 3 - Co-operation between States
- Chapter 4 - Operating Procedures
- Chapter 5 - Ship reporting systems

Along with the latest revision of the SAR Convention, the IMO and the International Civil Aviation Organization (ICAO) have proceeded with the joint development and release of **the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual**, as many ship and aircraft accidents involve both ships and aircraft in the search and rescue operations, with the aim to ensure the effective and efficient operational cooperation between the areas of operation and the different organizational and rescue units. With respect to SafePASS's chapters two and five are considered as more relevant.

The **STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers)** [24] is another treaty that came into force in 1984. It was the first attempt towards the establishment of the basic requirements on training, certification and watchkeeping for seafarers on an international level. It applies to all passenger ships on domestic and international voyages. Major revisions have been occurred both in 1995 and 2010. The STCW Convention chapters are the following:

- Chapter I: General provisions
- Chapter II: Master and deck department
- Chapter III: Engine department
- Chapter IV: Radio communication and radio personnel
- Chapter V: Special training requirements for personnel on certain types of ships
- Chapter VI: Emergency, occupational safety, medical care and survival functions
- Chapter VII: Alternative certification
- Chapter VIII: Watchkeeping

One of the main aspects of the STCW convention is that that the personnel operating on passenger vessels should have be trained in crowd and crisis management and human behaviour, and thus, in relation to SafePASS, the whole convention is of great importance.

The **ISM Code** [25] was the successor of the "Guidelines on management for the Safe Operation of Ships and for Pollution Prevention" (A.647(16)). Its mandatory form was adopted in 1993 by the resolution A.741(18) and it entered into force on July 1st, 1998 (SOLAS chapter X). A number of safety-management objectives are recommended by the Code, which requires a safety management system (SMS) to be also established by the responsible for operating the ship. The procedures that are required by the Code should be documented and compiled in a Safety Management Manual, a copy of which should be kept on board. Since ISM considered all operations, operators are urged to initiate procedures to prepare for and respond to emergency situations, e.g. evacuation, it has a relation to the SAFEPASS topic.

The International **Code for Fire Safety Systems (FSS Code)** in chapter 13 provides detailed requirements regarding the arrangements of means of escape, i.e. completes the relatively imprecise SOLAS II-2 requirements. For instance, for passenger ships the minimum clear width of stairways is 900 mm and need to be increased according to the number of persons using this escape route (+10 mm for every person in excess of 90 persons). Further, passenger distributions are specified to be used for capacity calculations. Finally, FSS Code provides many details with respect to:

- So-called landing areas, i.e. areas at beginning and ending of stairways and intermediate platforms;
- Superposition of passenger flows from different decks;
- Occupant load calculation for public spaces; and,
- Routes from assembly (muster) station to embarkation position.

Last but not least, IMO has developed a set of ‘’Guidelines for evacuation analysis for new and existing passenger ships” (MSC.1/Circ.1533, 2016), in order to standardise the analysis of evacuation on passenger ships.

3.2 Foreign Passenger Vessel procedures by USCG

United States Coast Guard (USCG) is the coastal defence, search and rescue, and maritime law enforcement branch of the United States Armed Forces [106]. In March 2019, USCG released the updated version of the Tactics, Techniques, and Procedures (TTP) publication [107], with the aim to provide guidance to the maritime industry and Coast Guard personnel. Although it represents the view of a specific Flag Administration outside EU, its applicability to foreign passenger vessels (ref. Certificate of Compliance Exams) emphasises their importance in the interpretation of several provisions of SOLAS chapter II-2 and LSA Code (annex 1 presents the extensive reference list upon the TTP publication is based). The TTP publication is not a substitute for applicable legal requirements, nor is it itself a rule. On November 2019 the US Coast Guard issued a new circular for providing guidance to the maritime industry and Coast Guard personnel on how vessel owners and operators may comply with amendments to SOLAS Chapter III, Regulation 3 and 20 regarding life-saving appliances, that will enter into force from 1st January 2020 [108].

3.3 Legislation analysis

This chapter deals with the current legislation review analysis, which aims at presenting an overview of the provisions that arise from the abovementioned instruments in relation to the SAFEPASS objectives and impact, as well as at identifying possible existing gaps and subsequent areas of improvement. Thus, the current analysis is mainly concentrated on giving primarily an overview of the legislation background and then providing an indicative categorization of the regulatory framework in five subjects in order to achieve better understanding of the regulations. The five categories are:

- The design, construction phase and evacuation modelling,
- The safety plans,
- The estimated and required time for evacuation,
- The crew and training certificates
- and The LSAs.

This categorization has been made in order to cover the maximum spectrum of the ship evacuation activities and to provide an effective overview of the current legislative ship evacuation framework towards being of added value to other upcoming activities and deliverables.

3.1.1 Design, Construction phase and evacuation modelling

Ship design is a process of economically optimising a vessel that fulfils a transport task specified by the operator and complying with regulations (international/national), which are dealing with the handling of emergencies (mitigate consequences), as well as evacuation. Ship design is considered also as a process of synthesis bringing together a wide range of disciplines and analysis methods, since ships are complex environments and their design must be approached in a methodical manner. To this end, starting from the early design stages certain technical requirements must be established and obligatory regulations must be followed, in order to effectively cope with both the fire safety and ease of crowd movements during an emergency.

As a matter of fact, ship designers must comply with the regulations, while flag states are responsible for proper enforcement. The Safe Return to Port (SRtP) regulation that entered into force in 2010 underlines the need for different early phase activities and performance standards as well as the need for a more multi-disciplinary / system-based approach throughout the new-building projects [26]. The performance standards provide additional guidance for the uniform implementation of SOLAS regulations II-2/21.4 and II-2/21.5.1.2 (MSC.1/Circ.1214), requiring that, after a fire or flooding casualty, basic services should be provided to all persons on board and that certain systems remain operational for safe return to port. SRtP also highlights the idea that a ship is its best lifeboat. It requires that ships of 120 m length or more or having three or more main vertical zones should be able to return to port under its own propulsion after a casualty that does not exceed a certain threshold, given also several specified functional requirements and performance standards (casualty thresholds) for safe operation [27].

SOLAS Chapter II-2 covers all the topics of the fire protection, detection and extinction including escape (routes dimensions are specified in II-2), while MSC/Circ.1168, provides the interim guidelines for the testing, approval and maintenance of evacuation guidance systems used as an alternative to low-location lighting systems. SOLAS Regulation II-2/13.7.4 'Means of escape', requires that "*at least one of the means of escape shall consist of a readily accessible enclosed stairway which shall provide continuous fire shelter from the level of its origin to the appropriate lifeboat and liferaft embarkation deck …*" and describes the means of escape so that people on board can safely escape to the lifeboat or/and life raft, towards requiring escape routes on ro-ro and passenger ships to be evaluated by an evacuation analysis early in the design process, and recommends the use of MSC.1/Circ.1533 (2016) when conducting the analysis. According to the same regulation, all spaces or group of spaces should provide at least two widely separated and ready means of escape (lifts not to be considered as mean of escape). Dead-end corridors or corridors with only one route are prohibited. Stairways also are specified by certain requirements and shall not be less than 800mm in clear width [28]. It is also important to note that the FSS Code, Ch.13/2.4.1 specifies that "… *the evacuation routes to the embarkation deck may include an assembly station*".

The structural characteristics of the ship are the ones that define the fire containment in the space of origin. Thus, in order to minimize consequences of a potential fire, ship designers must divide spaces by thermal and structural boundaries, maintaining the fire integrity of these boundaries including openings and penetrations [29]. The International Code For Fire Safety Systems (FSS Code), provides also more technical requirements and calculations methods about the means of escape. The code includes arrangement of means of escape and covers the specification requirements for the width of stairways, doorways, corridors and landing areas calculation methods.

In 2002, the IMO published the "Guidelines for a simplified evacuation analysis for new and existing passenger ships"[30], which supersede the interim guideline for SOLAS Regulations (2001) [31]. However, it has been demonstrated that the response time data was not sufficiently detailed, as passengers are not reacting immediately when the emergency announced. This delay between the announcement of the evacuation and passenger starting to move off to the assembly station, known as the response time, is of major importance for the evacuation analysis. In addressing the above need, IMO in 2007 published the (IMO, 2007b) [32] in which an advanced evacuation analysis is described. However, later in 2016 IMO approved the "Revised Guidelines on evacuation analysis for new and existing passenger ships" (MSC.1/Circ.1533) [33], which supersedes the previous Circulation and serves as a guide for the implementation of amendments to SOLAS regulation II-2/13.3.2.71, which makes the evacuation analysis mandatory not only for ro-ro ships but also for other passenger ships which carry more than 36 passengers and are constructed (keel lay date) on or after 1st January 2020. The new guidance encourages the conduction of the evacuation analysis on existing passenger ships in order to identify congestion points and/or critical areas so that revised operational measures can be implemented, (in case the analysis results reveal that the maximum allowable evacuation duration has been exceeded).

Last but not least, the high number of non-harmonized shipboard contingency plans justified the development of an integrated system and the harmonization of the structure of contingency plans. Thus, as Shipboard emergency preparedness is required under paragraphs 1.2.2.2 and 8 of the International Safety Management (ISM) Code, resolution A.1072(28) has provided the guidelines for the preparation and use of a module structure of an integrated system of shipboard emergency plans.

3.1.2 Safety plans

The existence of ship safety plans is of utmost importance during an evacuation procedure. Ship Safety/ Security Plans (SSP) are formulated to ensure that the measures laid out in the plan with respect to the safety of the ship are applied on board. They are mandatory and they serve the mean of protecting the people on board from any security related risks. The plans include specific responsibilities and outline the procedures to counteract any anticipated threat to the vessel.

Crew members must follow the established procedures to facilitate the movement of the passengers to their designated stations, in case an evacuation procedure is occurred. These should include plans for locating and rescuing passengers, including also those with impaired mobility or injured. SOLAS Chapter III Regulation 37 [34] describes the requirements of muster lists, including the emergency instructions that could be needed. In addition, Regulation 29 (SOLAS, Chapter III) [35] highlights the importance of the existence of a decision support/ emergency management system to assist the mustering during the emergency. This decision support system can either be in physical form (such as printed emergency plans) or software based. MSC/Circ. 699 provides the revised Guidelines for passenger safety instructions to ensure that adequate measures are taken to inform passengers of the procedures which would be adopted in the event of an emergency situation arising, and that the information is communicated to passengers prior to, or on departure from port.

Regulation 13 (SOLAS, Chapter II-2) “Means of Escape” [28] provides additional details on the means of escape from a vessel during an emergency such as doors in escape routes must open in-way of the direction of escape; at least two means of escape must exist at every room in order to reduce risk; at least one of the two means must provide access to a stairway forming vertical escape; access from stairways to lifeboat and life raft embarkation areas shall be protected either directly or with internal fire integrity routes; and escape routes should be marked by lighting indicators that are placed not more than 300 mm above the deck. MSC 404 (96), provides amendments to the SOLAS regulation 13 towards mentioning that escape routes shall be evaluated by an evacuation analysis early in the design process and that the analysis shall be used to identify and eliminate the congestion during an abandonment process. The amendments make the evacuation analysis compulsory to any new passenger ship constructed on or after 1st of January 2020. In addition, SOLAS II-2/28.3, recognising the importance of the evacuation procedures considering guiding, directing, mustering, and controlling of passenger movements, declares that a proper evacuation analysis shall evaluate on the board escape routes.

3.1.3 Estimated and Required Time for Evacuation

Another critical parameter to be taken into consideration in evacuation of passengers is the time. In 2002 IMO published the Resolution MSC.1033 “Interim Guidelines for evacuation analysis for the new and existing passenger ships” [30], where the regulatory framework has the intention to identify and mitigate the congestion during evacuation on certain routes on board the vessel, while considering that some escape routes may be unavailable due to extensive damage. However, the identification of the congestion was relied upon data and parameters derived from risk analysis of fires in buildings. As a result, in 2007 IMO published the Resolution MSC 1238 “Guidelines on the evacuation analysis for new and existing passenger ships” [32] by providing a correction parameter in mathematical model. A few years later, in 2016, IMO published the Resolution MSC 1533" Revised guidelines on the evacuation analysis for new and existing passenger ships” [33], which supersede the previous ones and includes more case studies and several scenarios (as a minimum, four scenarios should be considered for the evacuation analysis:

1. *case 1 (primary evacuation case, night) in accordance with chapter 13 of the FSS Code*
2. *case 2 (primary evacuation case, day) in accordance with chapter 13 of the FSS Code*
3. *case 3 (secondary evacuation cases, night) and*
4. *case 4 (secondary evacuation cases, day)*

The following additional scenarios may be considered as appropriate:

5. *case 5 (Open Deck)*
6. *case 6 (Embarkation)*

The calculation of the total evacuation time is calculated by the sum of the Response duration (R), the Total travel duration (T), the Embarkation and Launching duration (E+L). Each duration is multiplied with a proper correction coefficient, in order to be normalized. Response duration (R) is the duration it takes for people to react to the initial alarm. This duration begins when the initial notification (e.g. alarm) of an emergency sound and ends when the passengers have total awareness of the situation and initiate their movement the assembly station. The maximum response duration is expected to be 10 min for the night-time scenarios and 5 min for the day-time scenarios. Total travel duration (T) is the duration it takes for all persons on board to move from where they are when the emergency notification sound to the assembly stations.
Moreover, Embarkation and Launching duration (E+L) is the time required for the total number of persons on board to abandon the vessel, initiating when the ship signal is given and after all persons have been assembled, with their lifejackets on. E+L duration should be calculated separately based upon the results of full-scale trials and drills on ships with similar characteristics and installed evacuation systems; the results of a simulation-based embarkation analysis; or data which are provided by the shipyards. However, in this case, the method of calculation should be documented, including the value of correction factor that has been used. The embarkation and launching duration (E+L) should be clearly documented to be available in case of changes on the installed LSA arsenal. For cases where neither of the three above methods can be used, E+L should be assumed equal to 30 min.

In general embarkation and launching duration should not exceed in total the 30min in order to comply with SOLAS Chapter III. Regulation 21 mentions that all survival craft shall be capable of being launched with their full complement of persons and equipment within a period of 30 min from the time the abandon ship signal is given. The survival craft must be capable of accommodating the total number of passengers on board.

According to the above, the mathematical model for calculating the Total evacuation time is:

$$1{,}25\,(R+T) + 2/3(E+L) \leq n$$
$$(E+L) \leq 30min$$

Where n=60 for ro-ro passenger ships and for non ro-ro passenger ships, n=80 if the ship has more than three main vertical zones and n=60 if the ship has no more than three vertical zones.

Another quantity examined during the evacuation analysis is the Individual travel duration, which is the duration incurred by an individual in moving from its starting location to reach the assembly station. Individual assembly duration, which is the sum of the individual response and the individual travel duration and total assembly duration, which is the maximum individual assembly duration [33].

3.1.4 Crew Training and Certificates

The importance of crew training has been recognised internationally, as dealing effectively and efficiently with emergencies at sea is crucial for a successful ship evacuation. The STCW Convention, since 1978, has set the minimum qualification standards for masters, officers and watch personnel on seagoing merchant ships. It also designates crew training and qualifications as required, and since 2018, STCW Code set a new requirement for training and emergency familiarization of crewmembers on passenger ships. It provides the various specifications of the minimum standards of competence for the training on crowd control crisis, management and human behaviour for passenger vessels that should be suitably implemented.

Passengers engaged on a voyage for more than 24 hours should be instructed by the crew on the use of lifejackets and on the necessary actions in an emergency situation (muster drill) [37]. Additionally, all crew members should have undergone relevant training before being assigned to shipboard duties and they have to participate in at least one abandon ship and on one fire drill every month. SOLAS Chapter III-Regulation 30, which applies to all passenger ships, states, also, that an abandon ship drill and fire drill shall take place on a weekly basis, with no involvement of the entire crew in every drill, as they require to participate at least in an abandon ship drill and a fire drill every month. MSC/Circ. 544, provides the minimum standards for training and fire prevention practices. In addition, crew must follow the guidelines on training for the purpose of launching lifeboats and rescue boats from ships making headway through the water (A.624(15)).

It is also worth mentioning that Regulation 19 differentiates the muster drill from the "safety briefing." According to SOLAS rules, "*whenever new passengers embark, a safety briefing must be held immediately before sailing, or immediately after sailing*," including at least a PA announcement, "*in one or more languages, likely to be understood by the passengers*". It is also mentioned that the briefing may be supplemented with other info such as "information cards or posters or video programmes displayed on ships video displays".

3.1.5 Installed Equipment - LSA

The proper installation and use of the right equipment, plays a significant role during a proper passenger ship evacuation. SOLAS Chapter III describes the requirements of the LSA, the PSA, the mustering and embarkation procedures and the equipment launching arrangements. Additional requirements (concerning the ship's life rafts, the rescue boats and the means of rescue) are mentioned, especially for passenger ships. Is it, also, worth to note that the Polar Code [22] contains some (very high-level) requirements for LSA, e.g. specifying maximum expected time of rescue.

SOLAS has fairly extensive rules about the all aspects of lifesaving equipment including the location, number and size of lifeboats to be placed on a ship and how quickly the passengers should be able to be evacuated from the ship.

Modern passenger ships engaged on international voyages, after 1 January 2020 must carry totally enclosed lifeboats on each side to accommodate not less than 50% of the total passengers. Therefore, the sum of the lifeboats on both sides must equal at least to 100% of the passengers, while, in some cases, lifeboats may be substituted by life rafts. In addition, inflatable or rigid life rafts must accommodate at least 25% of the total number of persons on board [28] [33]. Passenger ships on short international voyages must carry partially or totally enclosed lifeboats for at least 30% of persons on board, plus inflatable or rigid life rafts to make a total capacity of 100% with the lifeboats. Moreover, they must carry inflatable or rigid lifeboats for 25% of total number of persons on board.

The International Life-saving Appliance Code [21], provides details about technical specifications of life-saving appliances, which includes a comprehensive set of minimum requirements for lifeboats to lifejackets. Life-saving appliances should follow certain requirements, such as certain marking in a permanently fixed plate. Moreover, lifeboats should be fully functional and operational under all conditions of trim up to 10° and list of up to 20° either way. The speed of a lifeboat when proceeding ahead in calm water fully loaded shall be at least 2 knots when towing the largest life raft. The maximum allowed persons onboard of a lifeboat should be 150. The arrangement of every lifeboat should be in a way that allows the boarding of all persons in less than 10 minutes from the time the instructions to board is given. Finally, the material of the hull and rigid covers should be fire-retardant or non-combustible.

Moreover, the IMO Subcommittee on Ship Systems & Equipment (SSE) [36], handles a wide range of technical and operational matters, related to systems and equipment on all types of ships. The Subcommittee organizes every year SSE sessions where agreements, revisions and conclusions are arranged. During its latest session that took place on March 2019, discussions took place in relation to LSA and fire safety as well as systems' operation and requirements.

Last but not least, due to the rapid technological advances and the emerging trends in the use of disruptive technologies, some life-saving appliances show possible deviations from the existing standards. To avoid limitations and remove innovation constraints, SOLAS III Regulation 38 and the corresponding guidelines from the Alternative Design and Arrangements provisions (AD&A) [38] opened the path for additional measures to be introduced - given that they provide, at least, equal level of safety and described the methodology that should be followed in those cases, in order to reduce the safety risks.

In addition, due to the fact that novel life-saving appliances are developed and installed on new cruise vessels, IMO, in 1983, published the Resolution A.520 [39] in order to evaluate, test and accept prototype novel life-saving appliances and arrangements. The use of novel equipment emerged the need for a more organized evaluation system, and thus, in 1991, IMO published the A 689 (17) “Testing of life-saving equipment” [40], followed by the Revised recommendation on testing of life-saving appliances (MSC.81(70)) in which extensive tests are recommended based on SOLAS Chapter III requirements, to ensure compliance of the non-deviating characteristics. Later, in 2001, IMO published [41] the resolution A.980 Standardized life-saving appliance evaluation and test report forms in order to standardize the life-saving appliances and test forms.

Currently, IMO is developing functional requirements for life-saving appliances in compliance with MSC.1/Circ.1394/Rev.1. Therefore, the IMO has agreed on a new work item on the revision of SOLAS chapter III and LSA Code (MSC 98) [38] based on the Goal-Based Standards-Safety Level Approach (GBS-SLA) [42].

3.4 Identified remarks

It has been acknowledged that the regulatory framework, related to passenger ship evacuation consists of a vast array of regulations. Table 3 below, summarises the regulatory references per studied category, attempting to give an overview of the evacuation legislation’s big picture.

Table 3 Summary of the main ship evacuation regulatory framework

	Regulatory reference
Design and Construction phase/Evacuation modelling	• SOLAS II-2A/ 9: Fixed fire detection and fire alarm systems • SOLAS II-2A/ 13: Fire control plans and fire drills • SOLAS Ch II-2 Reg. 13: Means of escape • MSC.1533: Revised Guidelines on evacuation analysis for new and existing passenger ships (superseded the MSC.1033: Interim guidelines for evacuation analyses for new and existing passenger ships and the MSC.1238: Guidelines for evacuation analysis for new and existing passenger ships) • MSC/Circ.1168: Interim guidelines for the testing, approval and maintenance of evacuation guidance systems used as an alternative to low-location lighting systems

	• MSC/Circ.1001: Interim guidelines for a simplified evacuation analysis of high-speed passenger craft • MSC.436(99): Revised explanatory notes to the SOLAS chapter II-1 subdivision and damage stability regulations • MSC.429(98): revised explanatory notes to the SOLAS chapter II-1 subdivision and damage stability regulations • A.1072(28): Revised guidelines for a structure of an integrated system of contingency planning for shipboard emergencies • Safe Return to Port (SRtP) adopted by MSC.216(82) • SOLAS ChapII-2 Reg. 21: Casualty threshold, safe return to port and safe areas • SOLAS ChapII-1 Reg. 8-1: System capabilities after a flooding casualty on passenger ships • MSC.1/Circ.1214: Performance standards for the systems and services to remain operational on passenger ships for safe return to port and orderly evacuation and abandonment after a casualty • FSS Code • ISM Code
Safety plans	• SOLAS II-2/28.3: Escape routes on-board Ro-Ro ferries shall be evaluated by a suitable evacuation analysis • SOLAS III/ 29: Decision support system for masters of passenger ships • SOLAS III/ 37: Muster list and emergency instructions • SOLAS Ch II-2 Reg. 13: Means of escape • MSC.404(96): Amendments to SOLAS (Reg 13) • MSC/Circ. 699 Revised Guidelines for passenger safety instructions • CSSF Recommendation 302/2018: Continuous improvement of safety barriers
Estimated and Required Time for Evacuation	• SOLAS Ch.III/21: Survival crafts and rescue boats • MSC.1533: Revised Guidelines on evacuation analysis for new and existing passenger ships (superseded the MSC.1033: Interim guidelines for evacuation analyses for new and existing passenger ships and the MSC.1238: Guidelines for evacuation analysis for new and existing passenger ships)
Crew Training and Certificates	• SOLAS Ch.III/30: Drills • SOLAS Ch.III/19: Emergency training and drills • MSC/Circ.544: Fire drills and on-board training • A.624(15): Guidelines on training for the purpose of launching lifeboats and rescue boats from ships making headway through the water • A.771(18): Recommendation on training requirements for crews of fast rescue boats • A.690(17): Periodical inspections of abandon ship and fire drills on passenger ships • A.657(16): Instructions for action in survival craft • STCW Code • IAMSAR Manual
Installed Equipment - LSA	• SOLAS CHAPTER III, life-saving appliances and arrangements • Polar Code • LSA-Code International Life-saving appliance Code (MSC.48(66)) • MSC.1\Circ.1212, Guidelines on alternative design and arrangements for SOLAS chapters II-1 and III • A.689(17): Testing of life-saving appliances

	• MSC.81(70): Revised recommendation on testing of life-saving appliances • A.520(13): Code of practice for the evaluation, testing and acceptance of prototype novel life-saving appliances and arrangements • MSC.402(96): Requirements for maintenance, thorough examination, operational testing, overhaul and repair of lifeboats and rescue boats, launching appliances and release gear • CSSF Recommendation 301/2018: Alternative design and arrangements • CSSF Recommendation 300/2015: Fit for Purpose • MSC.81(70): Revised recommendation on testing of life-saving appliances • MSC.216(82): amendments to the international convention for the safety of life at sea, 1974, as amended • A.830(19): Code on Alarms and Indicators • A.760(18): Symbols related to life-saving appliances and arrangements • A.658(16): Recommendation on the use and fitting of retro-reflective materials on life-saving appliances • MSC/Circ.570: Recommendation on maximum stowage height of survival craft on passenger ships • A.761(18): Recommendation on conditions for the approval of servicing stations for inflatable liferafts • MSC/Circ.614: Guidelines on inspection and maintenance of lifeboat on-load release gear • A.656(16): Guidelines for fast rescue boats • MSC/Circ.809 - Addendum to the Recommendations for Canopied Reversible Liferafts, Automatically Selfrighting Liferafts and Fast Rescue Boats including Testing on Ro-Ro Passenger Ship • MSC/Circ.980/Add.1 and 2 - Standardized Life-Saving Appliance Evaluation and Test Report Forms • MSC/Circ. 1006 – Guidelines on Fire Test Procedures for Acceptance of Fire Retardant Materials for the Construction of Lifeboats • CSSF Recommendation 301/2018: Alternative design and arrangements • MSC 98: Insight of the major outcomes of the 98th session of the IMO Maritime safety Committee

Apart from the aforementioned references, as from January 1st of 2020, a number of amendments to SOLAS Chapters as well as Code revisions has entered into force, based on lessons learnt from various accidents. A reference to the most important ones in relation to the subdivision and damage stability, lifeboat maintenance for preventing accidents with lifeboats and the planning for evacuation on cruise ships is described below.

The most significant changes, which are focused in particular on new passenger ships, are referring to the lessons learnt from Costa Concordia accident and are related to the damage stability requirements for new passenger ships in the event of flooding caused by collision or grounding (amendments to SOLAS II-1/19, III/30 and III/37 with MSC.421(98)). In addition, clarifications were given on the fire safety in passenger ships (amendments to SOLAS regulation II-2/20 with MSC.421(98)). Besides, new SOLAS paragraphs II-2/13.2.7.1 and II-2/13.2.7.2 (MSC.404(96) have been introduced and made the evacuation analysis mandatory for all passenger ships, not just ro-ro passenger ships, by requiring escape routes to be evaluated in order to demonstrate that the ship can be evacuated in the required time. In addition, the MSC.436(99) referred to the availability of essential systems in case of flooding damage.

Another amendment was made to the SOLAS regulations III/3 and III/20 (MSC.402(96)), towards providing clarifications on the requirements for the qualification, authorization and certification of service suppliers, procedures for maintenance and for what should be carried out at each stage of testing. More specifically, thorough examination, operational testing, repair and overhaul of lifeboats, rescue boats, launching appliances and release gear is required to be carried out by authorized service providers, to ensure that a reliable service is provided and to act as a preventing measure to potential crew injuries when crew members participate in lifeboat and rescue boat drills and inspections [43]. In relation to the LSA Code, the safety factor for which structural components used in connection with launching appliances has been aligned with that of other structural members for lifting appliances.

During the SafePASS stakeholders workshop in Glasgow, on January 2020, prominent representatives from classification societies and flag states, cruise operators and SafePASS advisory board members were consulted, in order to discuss the above referenced regulatory framework and its amendments and identify additional significant gaps in the passenger ship regulatory framework.

It has been widely agreed that the regulatory framework requires ships to be designed in a way that both passengers and crew can be normally able to evacuate safely and be provided with amenities to maintain a habitable environment. The recent regulations set the performance evacuation standard to 60 minutes for ro-ro vessels and passengers ships with less than three main vertical zones, whereas for vessels with more than three main vertical zones, the limit is set to 80 minutes. Taking also into consideration that the Embarkation and Launching time is going to take up to 30 minutes, as well as that there is a considerable amount of time lost looking for missing persons, after mustering is nearly completed, the above limits should be checked against some benchmark scenarios.

Further to the above, an emergency situation during an evacuation process consists of a significant number of phases from Alarm to Abandonment and then Rescue (figure 2). The already identified calculation of the total evacuation time, takes into account only three durations (Response duration (R), Total travel duration (T), and Embarkation and Launching duration (E+L)), without considering intermediate timeframes (e.g. time from muster station to embarkation station) and additional substantial static and dynamic conditions of the ship, such as ship position and condition (e.g. rolling, pitching, listing etc.) weather conditions, flood phenomena and people demographics and behavior. Also, it is evident from the analysis that the existing regulatory framework does not include any provisions for the duration before the alarm (Awareness Time) [45], which it is considered as a valuable timeframe for facilitating the whole evacuation process.

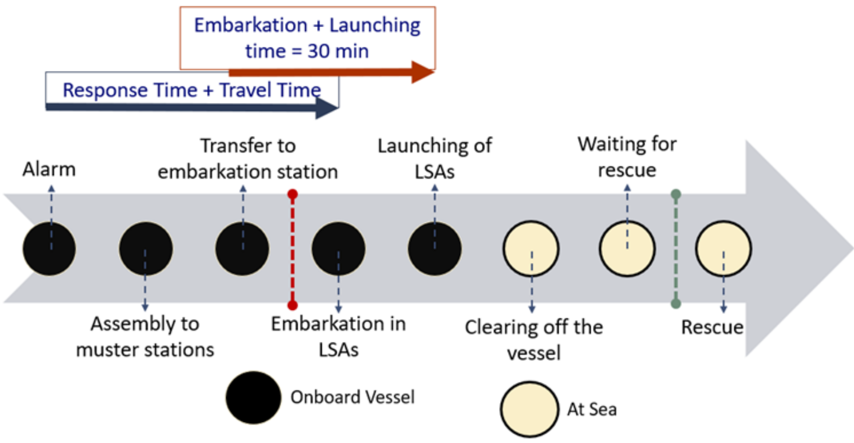


Figure 2 Alarm to Rescue Timeline, Source [44]

Another important observation lies on the fact that the existing regulations for ship evacuation, are solely based on the FSS code. Based on the fact that large-scale flooding (following a collision or grounding event) constitutes one of the main and principal hazards along with the onboard fires that may lead to passenger evacuation [44], it is evident that the regulatory framework does not consider these hazards in a detailed or systematic way, and tends to account for them using a safety factor[46]. It is also worth mentioning that fire as well as flood propagations are two different incidents that affect evacuation, and are not covered in the regulatory framework.

Concerning the training field, as technological trends are rapidly advancing, a wide range of new methodologies technologies are adopted by the training industry in general. VR and AR are good examples of the potential of innovative digital technologies in training [47]. However, in the maritime field there is still a reluctance in the adoption of such disruptive technologies even though they can offer tangible training benefits and they are both available and affordable. To this end, as the widespread adoption is getting closer and closer, the regulatory framework needs also to specify the corresponding provisions for their use.

It has been, also, spotted from the legislation analysis and mentioned as well during the SafePASS stakeholders workshop in Glasgow, that cruise ships spend approximately 33% of their time in ports. This fact results to the occurrence of a number of incidents that require direct response management, while the ship is berthed. Although the current regulatory framework provides a large set of provisions and guidelines in order to cope with incidents that take place at sea, it does not take into consideration incidents on the port side, namely a ship is berthed.

Last but not least, it is worth mentioning that the Cruise Ship Safety Forum (CSSF) in the spirit of continuous improvement, released in 2015 the Cruise Ship Safety Forum Recommendation 300/2015 "Fit for Purpose". Fit for purpose means a technology that can perform its role within its design limits, at a defined frequency, under specific ambient conditions when operated by trained personnel and maintained as initially specified. This Recommendation is not mandatory, applied on a voluntary basis as part of a contractual agreement, and outlines a process aimed at supplementing the applicable mandatory provisions, to provide evidence that shipboard technology will function within specified operational parameters with an acceptable level of confidence, towards providing a systematic approach on how to qualify selected technology in a transparent manner and to identify and manage risks in an effective and efficient way. This methodology is therefore appropriate to qualify innovation and novel technologies, including those specifically relevant to the LSA design and operation.

4. Recent publications in the ship evacuation field

This chapter is presenting a high level overview of the most recent under-investigation areas in ship evacuation literature during the last five years. Several publications have been conducted recognizing the importance of ship evacuation improvement, both in terms of systems and procedures.

4.1 Overview of recent publications

In the wake of the several disasters occurred the last decade, trends of largely increased capacity of passenger ships have brought the issues of effective and safe passenger evacuation in the center of attention of the maritime industry worldwide. The large passenger ship evacuation process is very complex, as it involves the management of a large number of people on a complex moving platform, of which they normally have very little knowledge [48]. However, problems arising from the evacuation of people in emergency conditions have been analyzed in literature in several dimensions, with main focus on passenger ships, encompassing several factors such as: the evacuation time, the identification of potential bottlenecks, the assessment of ship's layout, the LSAs, the passenger familiarization with a ship's environment, the crew training, the effective evacuation procedures/strategies, the intelligent decision support systems for crisis management and the alternative design/modification of systems and procedures for the ease of evacuation.

Passenger evacuation under ship fires constitutes a very complex and largely uncertain. As a matter of fact, Xie et. al. (2020) [49] recently proposed a new methodology to quantify the uncertainty of passenger's travel time, with an acceptable accuracy, based on a surrogate model. The method has a high potential to be used as a tool for facilitating passenger evacuation design under ship fires. Along with the ever-increasing challenges with respect to fire safety and evacuation, the increase of size and capacity of cruise ships requires alternative designs for the accommodation area and even the lifesaving appliances. Barber (2018) [50] has examined systems, including also LSAs, in common current use aboard merchant ships, along with their regulatory and practical aspects for their deployment.

In addition, Ademi & Holmberg (2017) [51], analyzed the difficulty of onboard navigation for passengers, especially in dark and smoke-filled environments, and proposed the use of a mobile application functioning complementary to the current evacuation systems.

As regards to regulatory aspects, finding realistic solutions for improving safety and emergency response in passenger ships requires an understanding of the current regulatory landscape and on the state-of-art projects and novel ideas on ship evacuation analyses [44]. Martin Pospolocki (2017)[3] stressed out the importance of reviewing the publicly available information of the most recent accidents, in order to improve mass evacuation with survival craft at sea. Additionally, the research carried out under SAFEGUARD project [97] resulted to the introduction into IMO MSC Circ. 1238, of a new degraded scenario, which requires passengers in the identified MVZ to evacuate from the zone horizontally into the neighboring MVZs [52].

Furthermore, for the successful evacuation simulation of a ship during a sinking, the slope angle change of the ship must be reflected during the simulation and focus should be also given on the test items suggested by International Maritime Organization (IMO) and SAFEGUARD Validation Data Set [53]. In the same context, Zhang et.al. (2017) [54], designed a series of evacuation trials, where ship rolling angle is modeled as a function of wind-wave dynamics. It has been observed that the human mobility varies under different ship rolling angles, with a particular attention to their walking speed reduction. The experimental observation found out that when the angle is very small, the impact on human behavior during evacuation can be negligible. However, as the angle increases, passengers are more prone to adjust their walking speeds in order to restore equilibrium.

Besides, many efforts have been carried out for the simulation of the evacuation processes in large passenger ships. Balakhontceva et. al.(2016)[55], developed a multi-agent model for the simulation of evacuation processes taking into account ship motions, sea waves dynamics and crowd dynamics. The obtained results demonstrate that the developed simulation system could be a very useful tool for designing contingency plans to assist crew members in the framework of decision support systems (DSS). Within the same context, Sarvari & Cevikcan (2017) [56], carried out a simulation of different scenario types, which indicated that passenger characteristics are the most dominant factor on ship evacuation performance.

Regarding this influential factor, a study conducted on 2015 used passenger ship accident investigation reports to map environmental factors, which have an impact on human behaviour under emergency. The outcome revealed that during an emergency human behaviour is guided by instinctual urge than by the given instructions. Furthermore, as indicated by Nevalainen et. al. (2015) [57], current evacuation modelling does not consider human-environment interaction in acceptable level.

Annex 2 includes a list with the most indicative last decade papers in the field of ship evacuation.

4.2 Concluding comments

There is a variety of publications in the field of ship evacuation (Annex 1), that considerably play a crucial role in drawing some important conclusions. First and foremost, the academic community obtained recently an active interest in investigating (further to the fire incidents) the flooding incidents and their impact on ship evacuation, along with flooding simulation tools, as they have a considerable high risk for persons on board [48].

Additionally, as passenger ship evacuation modelling is mostly based on mechanical simulation, which tends to ignore passengers as active agents, many publications are focused on studying social and behavioral aspects, highlighting the need for social- and behavioral- driven solutions, such as sociotechnical modelling, in accordance with the international legislation, standards and regulations (GDPR[4], IMO, SOLAS, etc.).

Ship evacuation is a multi-variable problem with constantly changing parameters and as resulting from the last decade publications, the need for design and development of advanced evacuation support tools and methods is considered critical and of paramount importance, in order to improve evacuation operations while enhancing situation awareness onboard. Attempts to use and test smart environments such as sensors, simulations, smart devices and monitoring elements are expected to significantly contribute to the enhancement of the real time situation awareness of end users and ships passengers.

It is also worth mentioning, that the cruise ships spend the one third of their lifetime in the ports (maintenance, reconstructions etc.), where a considerable number of accidents onboard takes place. However, there are not extensive references to them in the current publications. Subsequently, there is a great need for reporting these accidents, in order to raise awareness and therefore enhance the safety and effectiveness of the evacuation procedures even if the ship is in port.

Some of the recent publications draw also attention to the improvement of the existing technical evacuation systems such as LSAs, PSAs, as the ships' sizes and passenger capacity radically increase. This can be achieved by developing next generation LSAs for large capacity passenger ships including new cost effective LSA concepts based on the existing, new compact and easy-to-use PSAs like smart jackets, novel lifeboat designs and ship architectural layouts.

[4] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation)

5. Existing evacuation systems

Over the last decade, technological advancements, such as wireless communications and smart devices and also simulation environments and risk assessment tools, have a significant contribution to the development of ship evacuation analysis models. Towards this direction, the number of communication systems and intelligent tools supporting decision makers, information exchange and coordination during the evacuation process is getting higher and higher. However, their level of adaptability, adoptability and usability differs. This chapter aims at examining the variety of existing technical systems (MES and LSAs), on board safety systems, as well as simulation tools and supervision systems used in ship evacuation and operation, and their functionalities, by providing an extensive overview, with the aim to identify areas of improvement.

5.1 Technical systems

5.1.1 Marine Evacuation Systems

According to the International Convention for the Safety of Life at Sea 1974 (SOLAS), a Marine Evacuation System (MES) [58] is defined as an appliance for the rapid transfer of people from the embarkation deck of a ship to a floating survival craft. On-board ships and particularly passenger/cruise ships use widely these systems. The most important advantage of having a marine evacuation system on a ship is that people can get into the floats without getting soaked in the water or facing any danger and can save precious time. They are maintained in running order by annual servicing, however the system's deployment ability in an emergency can be assessed only during the installation and six yearly rotational deployments.

These systems are replacing traditional davit-launched life rafts used on ships and can be usually found on high speed craft, where weight and evacuation times must be kept to a minimum, although many conventional ferries and cruise ships are already fitting MESs to complement or replace lifeboats. MESs take very little space on deck, and is positioned on the front of the embarkation deck and on the sides of the ship. Additionally, MESs require little time and effort to assemble, which is very important in emergency cases.

There is a number of various companies that launch marine evacuation systems to the market [59][60]. Towards the same direction, there is a variety of marine evacuation systems that are available in the market. The most featured ones are named in table 4 below:

Table 4 Marine Evacuation Systems

System Name	Description
The Chute system	The Marine Evacuation Chute (MEC) System can be used for the evacuation of 565 people within half an hour. Chute systems are manufactured by Kevlar which ensures that the chute itself is protected during the harsh weather conditions. MEC constitutes one of the most efficient, easy-to-use, flexible, and cost-effective Marine Evacuation System available in the world market today. As a gravity launch system, the MES evacuates passengers and crew with the utmost safety in the shortest possible time.  *Source: survitecgroup.com*
The Mini-Chute system	The mini-chute has an evacuation capacity of 582 people within half an hour. It is made of Kevlar, which makes the mini-chute quite resistant in the emergency situations. The mini-chute system is flexible and can be easily set-up and packed up.  *Source: www.viking-life.com*
The Slide system	The slide system has an advantage, as it can be set-up anywhere – in both the extremities of the front (forward) and in the back (aft) of the ship. It can be set-up quite flexibly and has an evacuation capacity of 657 people within half an hour. The slide is set up at an angle of 30 degrees which allows a better movement for the evacuees.  *Source: survitecgroup.com*
The Mini-Slide system	The mini-slide system is suitable for those ships which have low deck height and has an evacuation capacity of 615 people within half an hour. The most important feature of the mini-slide system is that can be activated within two minutes of its inflation.  *Source: www.viking-life.com*

5.1.2 LSAs - PSAs

According to the SOLAS Convention, chapter III, the existence of Life Saving Appliances in a ship is mandatory. The International Life-Saving Appliance (LSA) Code [21] includes specific technical requirements regarding the manufacture, maintenance and record keeping of life-saving appliances. From vessel to vessel the number and type of life-saving appliances is different, and the code reports the categories of Life Saving Appliances as summarized in the Table below (table 5), as well as the minimum requirements for a seaworthy ship.

Life-saving appliances on all ships have to be fitted with retro-reflective material in order to facilitate the detection and to be in line with the recommendations of the Organization in A.658(16), "*IMO Res. A.658(16)*".

All LSA prescribed in this part shall in accordance with the LSA code (unless expressly provided otherwise in the opinion of the Administration):

- be constructed with proper workmanship and materials;
- not be damaged in stowage throughout the air temperature range -30°C to +65°C;
- if they are likely to be immersed in seawater during their use, operate throughout the seawater temperature range -1°C to +30°C;
- where applicable, be rot-proof, corrosion-resistant, and not be unduly affected by seawater, oil or fungal attack;
- where exposed to sunlight, be resistant to deterioration;
- be of a highly visible color on all parts where this will assist detection;
- be fitted with retro-reflective material where it will assist in detection and in accordance with the recommendations of the Organization in A.658(16);
- if they are to be used in a seaway, be capable of satisfactory operation in that environment;
- be clearly marked with approval information including the Administration which approved it, and any operational restrictions;
- where applicable, be provided with electrical short circuit protection to prevent damage or injury.

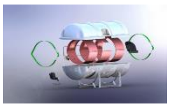
The acceptability period of the life-saving appliances, which are worn out over the years, shall be determined by the Administration. These life-saving appliances shall be marked in way that the expiry date in which they must be replaced is explicit. The most appropriate method of establishing the acceptability period is permanent marking with the expiry date.

Personal life Saving Appliances (PSAs) are included in the wider category of LSAs and consist of lifebuoys, lifejackets and immersion suits and anti-exposure suits, which are also briefly presented in the Table 5 below. According to SOLAS, Chapter III, Part B, the requirements for the PSAs are in brief the following:

- Lifebuoys:
  - Shall be so distributed as to be readily available on both sides of the ship and as far as practicable on all open decks extending to the ship's side and so stowed as to be capable of being rapidly cast loose;
  - At least one lifebuoy on each side of the ship shall be fitted with a buoyant lifeline;
  - Not less than one half of the total number of lifebuoys shall be provided with lifebuoy self-igniting lights;
  - Not less than two of these shall also be provided with lifebuoy self-activating smoke signals and be capable of quick release from the navigation bridge;
  - Lifebuoys with lights and those with lights and smoke signals shall be equally distributed on both sides of the ship and shall not be the lifebuoys provided with lifelines;
  - Each lifebuoy shall be marked in block capitals of the Roman alphabet with the name and port of registry of the ship on which it is carried.
- Lifejackets:
  - Every person on board the ship shall be provided with a lifejacket;
  - A number of lifejackets suitable for children equal to at least 10% of the number of passengers on board shall be provided or such greater number as may be required to provide a lifejacket for each child;
  - A sufficient number of lifejackets shall be carried for persons on watch and for use at remotely located survival craft stations;
  - Lifejackets shall be so placed as to be readily accessible and their position shall be plainly indicated;
  - The lifejackets used in totally enclosed lifeboats, except free-fall lifeboats, shall not impede entry into the lifeboat or seating, including operation of the seat belts in the lifeboat;
  - Lifejackets selected for free-fall lifeboats, and the manner in which they are carried or worn, shall not interfere with entry into the lifeboat, occupant safety or operation of the lifeboat.
- Immersion suits and anti-exposure suits:
  - An immersion suit or an anti-exposure suit of an appropriate size, shall be provided for every person assigned to crew the rescue boat or assigned to the marine evacuation system party. If the ship is constantly engaged in warm climates where, in the opinion of the Administration thermal protection is unnecessary, this protective clothing need not be carried.

Life Saving Appliances (LSAs) and Personal Life Saving Appliances (PSAs) are key infrastructures and equipment for safe and effective evacuation of a vessel. The main parameters that need to be taken into account when it comes to design and operation of LSAs and PSAs are their positioning and on-board arrangement, the required number, certifications, launching arrangements, drills, tests, inspections and maintenance. The table 5 below provides a brief summary of LSAs and PSAs.

Table 5 Categories of Life Saving Appliances

Life Saving Appliances and Personal Life Saving Appliances		
Category	**Product**	**Image**
Life rafts	Throw-Overboard	 *Source: gotco.com*
	Davit launchable	 *Source: www.viking-life.com*
	Polar	 *Source: www.viking-life.com*
Personal Protective equipment **(also available for infants and children)**	Immersion suits	 *Source: www.viking-life.com*
	Anti-exposure suits	 *Source: www.viking-life.com*
	Lifejackets	 *Source: www.viking-life.com*
	Inflatable lifejackets	 *Source: www.viking-life.com*
	Foam Lifejackets	 *Source: www.lalizas.com*
Boats	Conventional lifeboats	 *Source: www.viking-life.com*
	Inflatable Boats	 *Source: survitecgroup.com*

	Free fall lifeboats	 *Source: www.viking-life.com*
	Daughter craft	 *Source: www.viking-life.com*
	Rescue Boats	 *Source: www.viking-life.com*
	Fast rescue boats	 *Source: www.viking-life.com*
	LRRS	 *Source: survitecgroup.com*
Life Saving Appliances	EEBD	 *Source: www.viking-life.com*
	SCBA	 *Source: www.viking-life.com*
	Smokehoods	 *Source: draeger.com*
Transfer Descent and Recovery	Lifebuoys	 *Source: www.marinox.gr*
	Rescue Lines	 *Source: survitecgroup.com*
	Ladders and Gangway Nets	 *Source: www.viking-life.com*
	Rescue Sling	 *Source: survitecgroup.com*

Further to the above-mentioned Life Saving Appliances (LSAs) and Personal Life Saving Appliances (PSAs), it is also should be noted that the Cruise Lines International Association (CLIA), which is the world's largest cruise industry trade association, and it has been merged with International Council of Cruise Lines (ICCL) in 2006, has released some Industry Policies related (but not limited) to the Operational Safety and more particularly related to the LSAs and PSAs, for their members [109].

Regarding the LSAs, '*CLIA members have adopted a policy that at least one lifeboat on each ship is to be filled with crewmembers equal in number to its certified number of occupants at least every six months, in order to facilitate training for lifeboat operations. This policy applies to ships with crew sizes of three hundred or greater, with lifeboats installed. Ships with crew sizes of less than three hundred are to conduct similar and equivalent training evolutions, at appropriate intervals, that are consistent with operational and safety considerations*' [109].

Concerning the PSAs, '*CLIA's oceangoing operators have adopted a policy of carrying additional adult lifejackets onboard each cruise ship in excess of these legal requirements. Under this policy the number of additional adult lifejackets to be provided must not be less than the total number of persons berthed within the ship's most populated main vertical fire zone. Implementation of this policy should result in spare lifejackets being carried in excess of the number required by SOLAS' [109]*.

At this point it is also worth mentioning that these policies are adopted by CLIA members on a voluntarily basis.

As for the industry-level use of LSA/PSE beyond SOLAS, CLIA members are primarily using new large capacity lifeboats beyond the current 150-person maximum in SOLAS, which are approved via the alternative design and arrangements process. These new large capacity mega lifeboats, which can carry approximately more than 350 persons, are currently used on large cruise ships [110].

Last but not least, within the IMO Sub-Committee on Ship Systems and Equipment (SSE), which deals with a wide range of technical and operational matters related to systems and equipment on all types of ships, vessels, craft and mobile units covered by IMO instruments, and during its 7th session [111], CLIA and RINA has proposed to amend existing survival craft capacity standards taking into account the increase in average human size.

5.2 On board safety systems

Safety systems [61][62] have become mandatory with the introduction of the International Safety Management (ISM) Code [25] and since then, there has been an increase in ships' size and complexity. Ship security and safety at the sea can be ensured by various maritime systems working together simultaneously. Each ship is equipped with safety systems onboard to an extend that depends on the ship's passenger capacity. These systems not only contribute to ensure safety to the ships, but also to provide important data for overall smooth running of the industry. These systems are described in table 6 below:

Table 6 On board safety systems

Name	Description
Safety Management Control System	Supervisory system, interfacing all the Safety Systems onboard the vessel and coordinating the activities among them. It may be used for monitoring safety systems, detecting alarms, triggering safety actions, and interfacing with decision support systems. The SMCS software is based on a set of standardized function blocks, validated with Classification Societies. The system (hardware and software) is approved by GL, LR, ABS, BV, DNV, KR, RINA [105].
Fire Protection, Detection and Fire extinction systems	Normally consist of a number of detectors (heat, fire, smoke, flame), local alarm stations and a distributed alarm system, central management units, fixed and portable fire-extinguishing systems, automatic sprinkler etc. The fire protection, detection and fire extinction systems are regulated as per SOLAS Chapter II-2.
Low Location Lights and Standard (SOLAS) Signage	Allows all evacuation routes to stay illuminated, and illuminates the location of firefighting equipment. The installation of the photo luminescent signs is regulated in IMO Resolution 752, ISO 15370, ISO 24409, SOLAS 2004.
Public Address and General Alarm System	Used for raising different emergency alarms onboard as per regulations (general alarm, fire alarm, man over board alarm). PA is defined by the rule 50 from chapter III-part C from SOLAS. The alarm system should be complemented by Public Address system as per regulations, which is a loudspeaker installation enabling the broadcast of messages into all spaces where crew members and passengers are present. (SOLAS Chapter III – LSA).
Fire Doors and Watertight Doors	Watertight doors are used to divide vessels into watertight compartments. Fire doors prevent fires to spread. Both types of doors should be capable of remote and automatic release. The arrangements of fire doors as well as their specific functions are regulated by SOLAS Chapter II-2, while the watertight doors are regulated by SOLAS Chapter II-1.
Stability & Loading Computer System	An onboard stability computer is an instrument installed on board by means of which it can be ascertained that stability requirements specified for the ship in Stability Booklet are met in any load or ballast condition. An onboard stability computer comprises of hardware and software. A Loading Computer System is a computer based system consisting of a loading computer (hardware) and a calculation program (software), by means of which it can be easily and quickly ascertained that in any ballast or loading condition (i) the longitudinal and local strength will not exceed the permissible values, and (ii) the stability complies with the stability requirements applicable to the ship. HW and

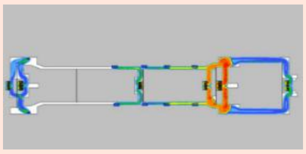
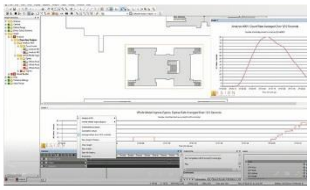
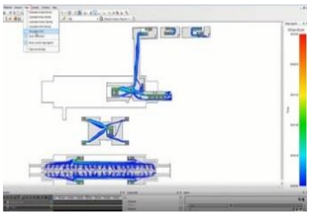
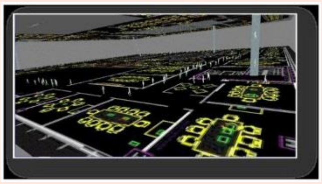
	SW should undergo certain test procedures and should be certified according to SOLAS.
Internal Communication system	The internal communication system on ships may consist of various systems such as: Voice over IP, Fixed & DECT phones, radio communication systems. A special category is the engine call systems, which is used to broadcast alarms in noisy areas like the engine. Another category is the Intercom system used for point to point or point to multi-point communications. It is mainly used for safety communications between the wheelhouse or the engine control room and the rooms that control the engines and the propulsion. It is also used as back up communication between the wheelhouse and the muster stations.
CCTV System	Purpose is predominantly for security issues and monitoring restricted and wide areas such as decks, lodging, casinos, restaurants, pools, gyms, shops etc. CCTV display consoles are strategically placed on the bridge, in ECR and Security Office and are equipped typically with a video management software.

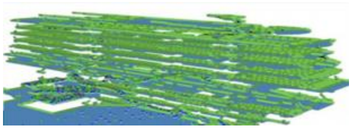
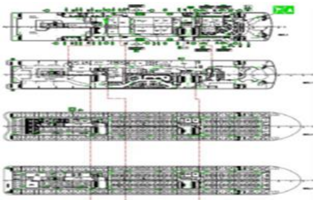
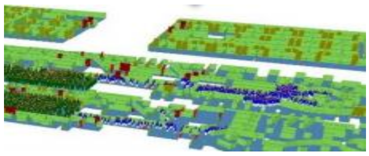
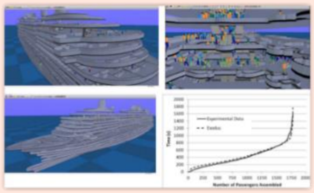
5.3 Simulation tools & supervision systems

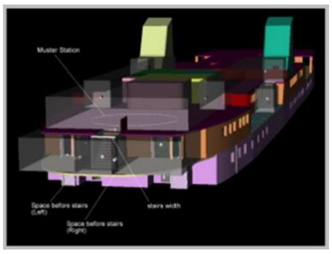
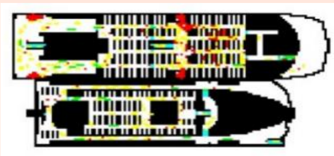
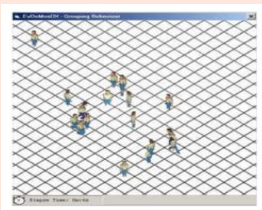
5.3.1 Dynamic Crowd Simulation Tools

Nowadays, Dynamic crowd simulation constitutes one of the best available tools to assess the passenger ships evacuation plans according to the new IMO MSC.1/Circ.1533, which supersedes the existing MSC.1/CIRC.1238, and the SOLAS II-2/13 regulation (2016) and certify ship's compliance with normative specifications. As a matter of fact, this regulation makes compulsory the assessment of passenger ships evacuation plans through escape routes, by computational means, during the design phase. Towards this direction, Pedestrian Dynamics is an example of this software category, which uses a simulation environment designed to model any kind of complex infrastructure as a ship. Dynamic crowd modelling enables users to assess the performance and safety of ships during normal and evacuation situations. The common outputs derived from this modelling are bottlenecks, flow analysis, evacuation times and can be quickly visualized in 2D and 3D to verify results to all stakeholders. The ship evacuation analysis is becoming more and more compulsory and therefore crowd modelling will play an important role to ensure that the existing and the new passenger ships are in compliance with the strict safety regulations. Some further information on existing Dynamic Crowd Simulation Tools is given on table 7 below:

Table 7 Dynamic Crowd Simulation Tools

Software Name	Description
INCONTROL software	INCONTROL [63] is a software that offers state-of-the-art simulation solutions which can accommodate the modelling of the ship's infrastructure and the analysis of pedestrian flows.  *Source: www.incontrolsim.com* INCONTROL explains how dynamic crowd simulation support architects and ship builders in the assessment of passenger ships and help them comply with the IMO and SOLAS regulations. It offers valuable insights on how the vessel must be designed to handle the required amount of passengers, how good flows of passengers can be achieved, even with a maximum occupancy of  *Source: www.incontrolsim.com* the ship, what time is needed to leave or transfer of the ship in case of evacuation, how many lifeboats are needed and where, etc.
LEGION software	Legion [64] pedestrian modelling software simulates and analyses the foot traffic on infrastructure assets. It generates simulations with predictive capacity across a wide range of scenarios and it has the ability to explore how pedestrians and crowds interact with  *Source: www.bentley.com*  *Source: www.bentley.com* infrastructure. It has the ability to perform virtual experiments on the design and operation of a site towards providing an impact assessment by taking into consideration different levels of pedestrian demand. Based on sophisticated modelling and analysis, LEGION software can optimize the use of space to improve safety, efficiency, and revenue, by allowing the users to test evacuation strategies at any point of the simulations.
Myriad software	Myriad [65][66] is a new version of Legion software tool, which is an evacuation model in 3D, that it is able to model crowd movement and behaviour for a variety of scenarios for crowd movement: evacuation of buildings/ships/public  *Source:[65]* spaces, measure areas for density and provide 2D/3D visual representations of crowds. Myriad II is, therefore, a crowd analysis tool, applicable to any market sector and crowd events, able to test how, when and where the system will fail, and as a result preventative measures and contingency plans can be produced in advance in order to cope with potential problems during a crowd event. One of the main strengths of Myriad II is the use of the three integrated modelling tools in one environment – i.e., network analysis, spatial analysis and agent-based analysis.

EVI software	The Evacuation Analysis software (EVI) [67] is a computer-based pedestrian and crowd simulation tool, that represents many individuals, assessing their behaviour and interaction with the surrounding environment, such as on a ship or in a building. It can be used during the design process to optimize design at an early stage in order to ensure safe and efficient evacuation, preventing costly redesign. EVI software allows the development of complex layouts and scenarios by using in built commands and scripting capabilities, making EVI an effective and powerful analysis and simulation tool. The ship passengers can be routed through the definition of primary or secondary routes, one way or blocked doors or confinement to within certain areas, such as fire zones. The initial location of passengers and crew, the escape plan, the state of escape routes (impaired or not) and the demographics of the passenger and crew population are feeding the evacuation scenarios and governing the response time and walking speed for all persons in the model. Fire data, such as visibility, air quality (CO/CO_2) and temperature from FDS software can be easily imported in EVI to simulate smoke and toxic atmospheres along with their impact on individuals as well. This software offers also time history for disabled people, which can be easily compared with the required and Available Safe Egress Times (RSET and ASET).  *Source: www.brookesbell.com*  *Source: www.brookesbell.com*  *Source: www.brookesbell.com*
Maritime EXODUS software	Maritime EXODUS [68] software can be used for both evacuation simulation and pedestrian dynamics/circulation analysis and has been developed to satisfy the requirements of performance-based safety codes. It breaks the mold of the traditional engineering analysis based on a highly sophisticated set of sub models, in order to produce realistic people-people, people-fire and people –structure interactions. Subsequently, the engineer can examine more designs in less time to reach the optimal solution, free of the high cost and potential danger interconnected with human evacuation trials. The software utilizes rule-based software technology to control the simulation. The rules have been categorized into five interacting submodels known as the Passenger, Movement, Behaviour, Toxicity and Hazard models. Maritime EXODUS can be used in the analysis of naval/passenger ship design for evacuation as well as in full-scale and experimental scale evacuation trials in ship environments.  *Source: fseg.gre.ac.uk*  *Source: fseg.gre.ac.uk*

AENEAS software	The AENEAS software [69] is able to perform evacuation analyses in compliance with IMO MSC.1/Circ. 1238 for yards, operators and authorities. AENEAS allows the analysis of the evacuation performance at any stage during the design process and ship life. Its user  *Source: dspace.lib.ntua.gr* interface provides efficient pre-processing from CAD data, ultra-fast simulation and transparent analysis. AENEAS offers, complementary to the IMO standard scenarios, the assessment of additional high complex scenarios, such as ship motion including static and dynamic heel and trim as well as group behaviour during the embarkation to the LSAs.
The intelligent model for extrication simulation (IMEX)	IMEX (intelligent model for extrication simulation) [70] model has been implemented in complex geometrical layout and motion of ship by confederation of three models: evacuation model, dynamic model and intelligent human behavior model. The validations of IMEX model have been made based on the three core aspects namely the effect of slope variation, width exist variation and exit flow rate to comply the basis of intuition. IMEX has the ability to simulate physical interactions between individuals using one dynamic model called *"Pynamics"*. It also offers a sophisticated way of evaluating the intended escape procedures and abandonment using a detailed human model behavior.
Virtual Environment for Life On Ships (VELOS)	VELOS [71] is a multi-user Virtual Reality (VR) system, which aims to facilitate the early ship design process by providing a representation of passenger and crew activities on a ship for both normal and hectic conditions of operations. VELOS includes a number of dynamic features such as the capability of multiple users' immersion and active participation in the  *Source: [71]* evacuation process, the real-time interaction and capability for making on-the-fly alterations of environment events and crowd-behavior parameters, and the enrichment of the ship geometrical model with a topological model suitable for evacuation analysis.
EVDEMON & BYPASS	EVDEMON (Evacuation Demonstration & Modeling) & BYPASS [72] are tiny models, which  *BYPASS, Source: dspace.lib.ntua.gr*  use cellular automata to simulate passengers' movement in space. In EVDEMON individuals are divided into two main categories: passengers and crew. The passengers are further categorized based on their age in children, adults and elderly. This categorization defines some individual characteristics of the passengers and mainly the response time to the danger signal and the

	maximum speed of movement. In BYPASS, the space is divided into square cells with a side length of 0.4 m and each cell can be occupied by only one person. Each person has different characteristics or abilities and its movement is described by speed and direction (speed and direction can change at any time based on specific probabilities. *EVDEMON,* *Source: dspace.lib.ntua.gr*

5.3.2 Flooding Time Domain Simulation (PROTEUS)

PROTEUS3 [73] is a time domain simulation software capable of capturing the vessel's dynamic behavior of intact and damaged ships in waves. It is capable to simulate the progression of floodwater in both transient and progressive flooding stages. It can model any damage compartment configuration and any shape and position of the openings through which flooding can occur. The complexity of floodwater's progression throughout the ship is shown in figure 3. The presence of sea waves, increases the complexity and the uncertainty of the final outcome.

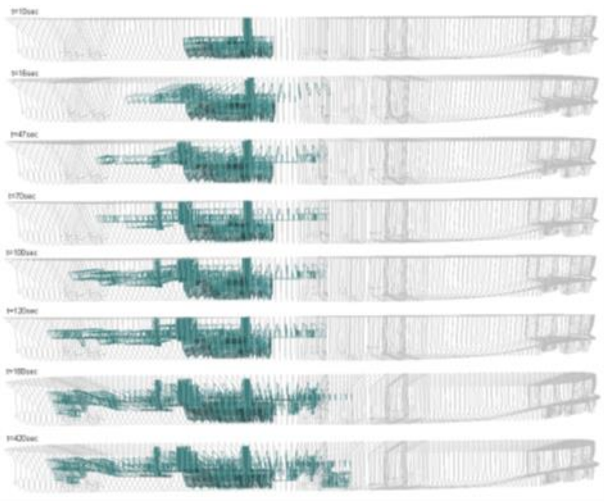


Figure 3 Damage case simulation in 4m significant wave height; water spread to half the ship length, in less than 7 minutes [74]

PROTEUS3 has been validated through numerous models and benchmarking tests and it has proven its capability to provide reliable results to this complex phenomenon. Its output includes time histories of the vessel motions and accelerations, as well as floodwater mass, elevation and attitude in every modelled compartment of the ship, and can be incorporated into the evacuation model environment (EVI) as explicit semantic information with the deck inclination, ship motions and inaccessibility effects.

5.3.3 Fire Dynamics Simulator (FDS)

The Fire Dynamics Simulator (FDS) [75] is a computational fluid dynamics (CFD) model of fire-driven fluid flow. FDS is a large-eddy simulation (LES) and solves numerically a form of the Navier-Stokes equations, with an emphasis on smoke and heat transport from fires, to describe the evolution of fire. In February 2000, the first version of FDS was released in public. Until now, approximately half of the model applications have been for design of smoke handling systems and sprinkler/detector activation studies. The other half consists of residential and industrial fire reconstructions. FDS, throughout its development, has been focused on solving practical fire problems in the fire protection engineering, while providing a tool to study fundamental fire dynamics and combustion.

In 2009, the evacuation module called Fire Dynamics Simulator with Evacuation (FDS+Evac) [76], was fully embedded in FDS. FDS+Evac is a stochastic modelling programme, as it uses stochastic distributions to generate the initial positions of the agents and their properties. The counterflow model was tested using the counterflow test case included in the IMO test cases for evacuation programmes for maritime applications, based on the IMO document "Interim Guidelines for Evacuation Analyses for New and Existing Passenger Ships''. FDS+Evac has been adapted to include also behavioural and event information such as familiarity with ship layout, ship rotation and lifeboats boarding.

5.3.4 High-level supervision systems

CRIMSON software suite is a software solution allowing key security actors to share a Common Operational Picture (COP) (figures 4 & 5) of the tactical situation in order to facilitate decision-making and to ease the transmission of orders as well as the follow-up on their execution. Information exchange is possible between different distant sites and their on-site actors, under a close management on the access right on shared information depending on the role of the user. The shared operational situation is built from the data fusion of the heterogeneous systems to retrieve only the useful information (captors, video surveillance, external systems, connected objects, drones, etc.), and the detailed information added by one or more users.

Figure 4 After-Action Crimson Analysis

Figure 5 eVACUATE's 3D COP during the STX evacuation pilot

Source: DIGINEXT

The CRIMSON solution satisfies different use cases:

- High level supervision: operational surveillance of a site / area, aggregation/fusion of data, alert/intervention and allocated resources management;
- Operational Management of an event / crisis: sharing of a situation helping decision-making, resource management of an operation, on-site feedback;
- Training: virtual situation to encourage actors throughout a crisis management exercise or a use case scenario.

CRIMSON COP for evacuation scenarios has been successfully tested during the FP7 project eVACUATE, which included a ship evacuation pilot. DXT aims to develop this component further in order to demonstrate it in an operational environment and deliver a pre-production component.

5.4 Concluding remarks

A tendency to build passenger vessels carrying more than 5.000 passengers can be seen as challenging for the safety record of the shipping industry. There are significant economies of scale and fast expansion of the cruise market that pave the way. The increase of the size, the increasing complexity of its arrangement and associated systems that provide a unique experience to the passenger, the operation to new sea areas (e.g. Artic) and the demographics of the passengers onboard, make ship evacuation and its modelling significantly more complex than shore-based building evacuation. These unique challenges related to the procedural, human behavior and environmental factors need to be properly addressed[44].

As a matter of fact, conventional evacuation modelling software and tools, developed for other industries, are not suitable for marine emergency evacuation, based on their low adaptability in such a versatile situation. Thus, for ship evacuation modelling there is a limited number of software tools, as descripted above, which have been adopted to assess the evacuation time and performance using different modelling methods and taking into consideration different factors and different assumptions.

Planning emergency evacuation operations in a proactive manner in marine transportation systems is a critical success factor for both passenger and crew safety. Despite the fact that there is a growing attention on safety issues for marine transportation systems, providing a real-time decision support for evacuation planning using real time passenger localization, health and behavioral data under different emergency conditions has not yet been addressed.

It is, therefore, obvious that there is still room for improvement in terms of human behavioral aspects, human mobility moves and human health condition, under a variety of complex scenarios. In addition, extreme environmental weather conditions must be also taken into consideration, acknowledging high sea state level. It is also of paramount importance, simulation systems to consider, in detail, on their evacuation flow, the forecast of evacuation time, the optimum evacuation route as well as the individual optimum evacuation route and mainly different demographics in emergency response such as children, elderly, handicap people etc. and their movements under extreme conditions such as fire, flood, smoke etc.

Another important note is the evacuation software based on the IMO does not make any distinction mustering between crew and passengers. It is considered essential in the evacuation modelling to include different functions of crew and how they affect the real evacuation process.

Regarding the on board systems, it has been observed that exit signs remain static and thus have no ability to convey information about congestion or danger between the sign and the actual exit door [77]. On the other side, the use of Dynamic information adaptive exit systems, which calculate and adapt the safest exit route depending on the location of the incident and the derived specific damage conditions, would facilitate the evacuation process, towards reducing evacuation times and thereby improving the crew's safety when compared with the static routes [78].

Concerning the MES systems [44], the most important recommendation is to have a flexible design that allows the installation in wide range of vessel configurations. Their next generation should go hand in hand with the next generation of lifeboats in terms of ensuring the same or higher performance standards in trim and listing conditions and decreasing the deck footprint. Another tendency is focused on the ability of lifeboats to be used also as tenders, while efforts are made towards minimizing the complexity in both the launching and operational phase of these boats so that no much training to be mandatory. Furthermore, there is a need for further development in the availability of these boats for launching and use even after extreme heeling angles or releases from considerable heights. The careful selection on the location of all boats and LSAs at the vessel plays also a crucial role in ensuring the maximum availability. Damage stability and fire analysis identify the most vulnerable areas on-board, which shall be taken under consideration to determining the location of the lifeboats and LSAs.

Regarding the PSAs, the research outcomes of the EC funded project LYNCEUS revealed the benefits of using smart devices, such as wireless bracelets and lifejacket-embedded sensors, in ship evacuation. More specifically the project is considered as a cornerstone in real-time emergency response management, as it investigated how ultra-low power wireless area network technologies can be utilized for people localization during emergencies. However, aspects related to passenger health status and behavior monitoring, as well as indoor localization techniques, need to be further improved and tested.

Undoubtedly, in order to accommodate the novelties, revision of regulations will be required for approval and installation. The concluding remarks of this chapter have been discussed and crossed checked during the stakeholder’s workshop in Glasgow, Scotland on 29th-30th of January 2020.

6. Incident Analysis

The marine industry experiences incidents that range from major accidents to near misses. The desktop study presented in this chapter is mainly focused on the analysis of the last decade (2009-2019) most widely known and examined in literature, passenger ship casualties and incidents. This analysis is using indicative noticeable examples, focused in understanding what process was followed during the evacuation of the passenger ships and what were the main reasons for their outcome. Moreover, it can be used as reference for further work to be conducted both within the SafePASS consortium, as well as by all the interested stakeholder communities.

The methodological approach implemented in this desktop study starts with the identification of the most important criteria, in order to select and analyze the major incidents of the last decade. The identified criteria are the following:

- **Size and passenger capacity**: The Gross Tonnage (GT) and the number of passengers the ship receives. The analysis is mainly focused on large passenger ships, with at least 3 main vertical fire zones and length of above 150 meters.
- **Fatalities, societal impact**: The number of people that lost their life in an incident.
- **Degree of deviation from the procedure**: The extent to which the procedures followed during the evacuation differ from the already established evacuation procedures.
- **Total evacuation time**: The total time required for the evacuation of the ship.
- **Weather conditions during the incident**: The conditions that prevailed when the accident occurred (season, day or night, extreme weather conditions etc.).
- **Presence of human errors and human limitations**: Presence of disabled persons or older people, which obviously address movement restrictions.

Furthermore, all the information used for the description and the analysis of the incidents has been retrieved from the following sources:

- **The IMO Global Integrated Shipping Information System (GISIS)** [79] includes a Maritime Casualties and Incidents module database with data on Maritime Casualties and Incidents (MCI). The MCI module contains information collected through MSC-MEPC.3/Circ.4/Rev.1, as well as full investigation reports.
- **The Marine Accident Investigation Branch (MAIB)** [80] investigates marine accidents involving UK vessels worldwide and all vessels in UK territorial waters. MAIB receives between 1,500 and 1.800 reports of accidents of all types and severity each year. On average this leads to 30 separate investigations being launched. The investigations and the published reports are in compliance with the Merchant Shipping Regulations.

- **The Marine Casualty Investigation Board (MCIB)** [81] examines and if necessary carries out investigations into all types of marine casualties to, or on board, Irish registered vessels worldwide and other vessels in Irish territorial waters and inland waterways. The legislative framework for the operation of the MCIB, the reporting and investigating of marine casualties and the powers of MCIB investigators is set out in the Merchant Shipping (Investigation of Marine Casualties) Act, 2000.
- **The European Marine Casualty Information Platform (EMCIP)**[82] is a database and a data distribution system operated by EMSA. EMCIP provides the means to store data and information related to marine casualties involving all types of ships and occupational accidents. This platform aims at delivering a range of potential benefits at national, European and global level by improving safety investigations, widening and deepening the analysis of the results of casualty investigations and providing at-a-glance information, enabling general risk identification and profiling.
- **The US National Transportation Safety Board (NTSB)** [83] investigates and reports among others on ship and marine accidents.
- **SafePASS advisory board members, from classification societies and flag states representatives and from cruise operators** during the SafePASS stakeholders' workshop in Glasgow, on January 2020.

6.1 Last decade widely known incidents

The incidents that has been reported within this chapter are presented along with some key information in the table 8 below. Subsequently, follows a further analysis for each one based on the availability of the related investigation reports, including more specific information about the incident.

Table 8 List of the last decade well known incidents

Ship's Name	Type	Dimensions (Length/Beam/GT)	Date (m/y)	Day/Night	Route
MV LISCO GLORIA [84]	RoPax passenger ferry	199.1 m/25 m/20.140 GT	October 2010	Night	From Kiel to Klaipėda
COSTA CONCORDIA [85]	Cruise ship	247 m/35.5 m/114.147 GT	January 2012	Night	From Civitavecchia on a 7-night cruise
GRANDEUR OF THE SEAS [86]	Vision-class cruise ship	279 m/36 m/73.82 GT	May 2013	Day	From Baltimore, Maryland to the Bahamas

MV SEWOL [87]	RoPax passenger ferry	146 m/22.00 m/6.825 GT	April 2014	Day	Island of Jeju
NORMAN ATLANTIC [88]	RoPax passenger ferry	186 m/25.6 m/26.904 GT	December 2014	Morning	Sailing in the Adriatic Sea
CARNIVAL LIBERTY [89]	Cruise ship	290.2 m/35.4 m/110 GT	September 2015	Morning	Sailing in the US Virgin Islands
MV VIKING SKY [90]	Cruise ship	228.2 m/28.8 m/47.842 GT	March 2019	Day	SW from Tromsø to Stavanger in Norway

MV LISCO GLORIA

Figure 6 MV LISCO GLORIA Sourse:[84]

On 9 October 2010, Lisco Gloria (figure 6) was on its way from Kiel to Klaipėda, carrying 204 passengers and 32 crew members. Just after midnight, as the ship was travelling in the Fehmarn Belt, some 8–10 km south of Lolland, an onboard explosion occurred on the car deck, which resulted in a fire that later engulfed the entire ship. All passengers and crew were rescued from the ferry by the German Coast Guard and some smaller vessels, that had hurried to the scene, and transferred to other ferries, most of them on board Germany. There was a total of 28 injured people, of whom 23 were treated in hospital. As referred to the investigation report of Lisco Gloria, the AB (Abled-bodied seaman) noticed an inconsistency concerning the temperature of the refrigeration unit. However, he did not consider it was necessary to inform the officer on watch or the driver about this malfunction, although the general procedures define it.

COSTA CONCORDIA

The Italian cruise ship Costa Concordia (figure 7) ran aground and overturned after striking an underwater rock off Isola del Giglio, Tuscany on January 13th, 2012. The incident resulted in the death of 32 persons and the injury of 157 others of the total 3229 passengers. The incident occurred when the vessel struck an underwater rock, causing damage to the hull, and then flooding the engine room resulting in power loss.

Figure 7 COSTA CONCORDIA

Sourse: safety4sea.com

According to the investigation report by MIT, the human element as well as the lack of alertness were the root causes in the Costa Concordia casualty, both while contacting with the rocks, and when the general emergency management occurred. More specifically, during the navigation phase, which is considered as the most crucial aspect, the Master made a hazardous pass from shallow waters. A number of additional cumulative factors such as the maintenance of the ships' high speed, the inappropriate selection of the reference point for turning, the use of an unsuitable cartography, the improper handover between the Master and the Chief Mate as well as the overall passive attitude of the Bridge Staff, resulted in Costa Concordia accident.

The initial report to the port authority described an electrical "black-out". The General Emergency Alarm was not activated immediately after the impact. This fact has led to a substantial delay in the organization of the subsequent phases of emergency (flooding-abandon ship process). It is also noted that the general emergency and the abandon ship signals were activated with delay (approximately 1 hour) in reference to the awareness moment that at least three contiguous WTC of the ship were flooded.

It is also evident from the analysis, that key crewmembers were characterized by poor proficiency. More in detail, several Officers belonged to the deck staff failed to execute their 'safety' duties during the management of the emergency, probably because of the lack of the necessary skill or simply because they were unfamiliar with the ship lay-out and procedures (video recordings showed passengers wearing life-jackets in panic while being instructed by the crew to return to their cabins). It is also perplexing that crew avoided lowering the lifeboats while the ship was moving for 45 mins, while at a later stage crew started preparing the lifeboats prior to the abandon ship order.

Additional factors that hindered the management of the general emergency-abandon ship phase and contributed to initiatives taken by the individuals (jumping into the water) were the communication problems between the passengers and the crew members (although all of them spoke at least basic English, most spoke no Italian) and the individuals' condition and reaction (e.g. bewildered behavior -such as confusion, denial, freezing, insecurity, hesitation, competitiveness, stereotypical, inappropriate, memory loss [91], health problems, personal relationships, motivation, sense of danger) which was not taken into consideration.

According to the evidences found at the end of the investigation report, Costa Concordia resulted in full compliance with all the SOLAS applicable regulations towards matching all the related requirements upon its departure from Civitavecchia

Port. It is, also, worth mentioning that no passenger evacuation drill had been performed prior to the incident.

The local fire department rescued over 100 passengers from the water, as well as 60 more who were still trapped inside the vessel. The total evacuation time was 6 hours and was finally completed with the aid of five helicopters that airlifted the remaining survivors.

GRANDEUR OF THE SEAS

Figure 8 GRANDEUR OF THE SEAS

Sourse: bermudasun.bm

Grandeur of the seas (figure 8) departed on May 24, 2013 from Baltimore, Maryland, en route to the Bahamas, on a seven-night cruise, including stops to Port Canaveral, Florida, CocoCay, and Nassau, Bahamas. The ship was sailing in calm seas with full power having on board 2224 passengers and 796 crew. On 27 May 2013, a fire started at 2:50 a.m. (local time) in the mooring area of deck 3 and was extinguished within three hours. Major damage was limited to the aft most sections of decks 3, 4, and 5. As a precautionary measure, all passengers and crew were called to the muster or assembly stations before the fire was extinguished. No evacuation was necessary, and the ship was able to continue under her own power to the Bahamas with no reported injuries. The remainder of the cruise was canceled, and passengers were flown back to their point of origin from Freeport, Bahamas. The ship just before the incident returned after undergoing a major renovation.

According to the investigation report the source of the fire ignition has not been definitively identified. A potential scenario was that a lighted cigarette discarded from an upper deck and powered by the cross wind was blown near to combustible materials in the mooring area of deck 3, where it set light. The fire was significantly increased, spread and extent due to the failure of the aluminum hatches in Decks 4 and 5.

The passengers and crew were gathered in the mustering stations without having any serious incident, however the failure occurred in the electronic mustering system caused a considerable time delay in ensuring all crew and passengers were safely accounted for. It is also worth mentioning that the firefighting capability, the effective co-ordination and the professionalism of the crew staff (who did not make use of external assistance) can be considered as an outcome of the effective training and management programs.

MV-SEWOL

Figure 9 MV-SEWOL

Sourse: www.maritime-executive.com

On 16 April 2014, MV SEWOL, (figure 9) a South Korean vehicle-passenger ferry, was following a frequent route heading to Jeju, sailing in calm seas. Just after 8:46 a.m. the ship started taking multiple sharp turns to the right, leading to an increase of angular velocity and a list to port up to 30 degrees, causing the cargo to shift to one side, causing, in turn, further list. The result was that the ship lost the restoring force allowing water to flow inside, through the side openings of the cargo loading bay as well as the car entrance, which was located at the stern. MV-SEWOL sank after capsizing at 1:03 a.m. Totally, 476 persons were onboard and more specifically 325 high school students, 14 teachers, 108 other passengers, 15 sailing crew members and 14 service crew members. The majority of the victims were high school students who obeyed the announcements. During the incident, announcements instructed the passengers to stay put, which ultimately led to them being trapped in the capsizing ship. The disaster ended with 299 fatalities and 7 more from the search and rescue units.

There were different aspects and perspectives regarding this incident. Firstly, the vessel was not maintained by the principles, there was no safety training to crews and passengers. Furthermore, the ship was overloaded by cargo (maybe for profit maximization), carrying an estimated 2,142.7 tons of cargo, more than three times the limit of 987 tons. Meanwhile, Sewol was carrying only 580 tons of ballast water, much less than the recommended 2,030 tons, which made it more prone to list.

Moreover, during the emergency the safety equipment of the vessel didn't work effectively and the MV Sewol stopped the communication with VTS, while useful time was lost because the sounding of the alarm was delayed. Particular attention was given after the tragedy on the fact that the crew was repeatedly recorded as instructing the passengers to stay put, even when water started entering the vessel. The captain and crews escaped early, abandoning the passengers, while the coast guard didn't enter to the vessel.

NORMAN ATLANTIC

The ROPAX passenger ferry (figure 10) owned by the Italian ferry company Visemar di Navigazione, caught fire on December 28, 2014 while sailing in the Adriatic Sea. The incident resulted in 30 fatalities; 10 passengers found dead, 18 missing and 2 casualties from the Albanian tug Illiria during the salvage operations. According to the ship's manifest, the total number of passengers and crew onboard was 475, while in reality 487 passengers and 55 crew -as well as 222 vehicles- were onboard. Although the origin of fire has been thoroughly investigated, it has not been fully specified. The most likely possibility is that the fire started from a defect in electric system of a track. More specifically, the team in charge of connecting the reefer sockets was made of two units (the Greek unit and the Charterer unit), which seemed to act autonomously and not synchronized, probably because of communication and comprehension language problems, which may have resulted in difficulties/misunderstandings during the execution of their tasks.


Figure 10 NORMAN ATLANTIC

Sourse: www.pagenews.gr

It is important to highlight that, during this accident, the evacuation process initiated four hours after the fire initiation. During the evacuation, a limited number of passengers were instructed to embark on the lifeboats on the portside, as it was realized that the survival equipment on the ship starboard side were partly destroyed and/or damaged by flames (which were facilitated by the adverse sea and weather conditions) after few minutes. For the rest, the evacuation was possible only through air rescue means.

The investigation report also describes that the human factor negatively influenced the overall situation, under the following point of views: the emergency took place at night, the crew, due to the stressful situation, acted without abiding by the procedures established despite the training and familiarization they had upon joining the vessel and the time available to face the emergency was reduced, considering when the fire broke out. Survivors described the evacuation as a damaging experience where chaos and panic prevailed, instead of orderly evacuation.

CARNIVAL LIBERTY

On the morning of September 7, 2015, a fire broke out in the engine room aboard cruise ship Carnival Liberty (figure 11), originated from the fuel supply inlet flange. At the time of the incident, the vessel was alongside the dock in the Port of Charlotte Amalie, US Virgin Islands. Crew members were unaware that the related system (HI-FOG) was incapable of delivering total flooding to both engine rooms simultaneously, and that they then had to use the CO_2 system to extinguish the fire. Furthermore, they did not consider, nor did any checklist specify, to return the HI-FOG system to automatic from manual mode immediately after the confirmation of a fire.


Figure 11 CARNIVAL LIBERTY

Sourse: www.maritime-executive.com

After assessing the situation, the master ordered the passengers aboard the vessel to evacuate to the dock. The fire was extinguished by the crew using the water mist and carbon dioxide firefighting systems. Luckily, the incident concluded without any injuries. To an extent, this was due to preplanned procedures for such an event, and all passengers aboard were promptly accounted. It is also noted that the day before ship's departure a general emergency and evacuation drill was held for all passengers, as required by the International Convention for the Safety of Life at Sea (SOLAS).

MV VIKING SKY

MV VIKING SKY (figure 12) is a cruise ship, operated by Viking Ocean Cruises, that was launched in 2016 and entered service in 2017. Viking Sky was manned by 458 crew and was carrying 915 passengers. At approximately 13:40 on 22 March, the staff captain, on the master's instruction, informed the crew about the forecast weather and instructed them to start preparing the vessel for the deteriorating weather conditions. On 23 March 2019, the ship was en route southwest from Tromsø to Stavanger in Norway, when strong winds and rough seas with 15 meters high waves. Around 13:50 the ship suffered a loss of oil pressure, without trigger the alarms for low lubricant level, resulting in an automatic shutdown of all four engines. The bridge team immediately called the engine control room but, at that early stage, the engineers were unsure of the cause, or causes, of the blackout and therefore could not estimate when it would be possible to restore power. The officer on watch called the master, who quickly made his way to the bridge.

Figure 12 MV VIKING SKY

Sourse: www.dailymail.co.uk

Having assessed the situation, the master broadcasted a mayday at 14:00. He then instructed the crew to drop both anchors. However, the anchors did not hold, and the ship continued to drift astern towards the shore at a speed of 6–7 knots. The General Alarm was activated at 14:13 and the passengers and crew began to muster.

In the initial stages of the emergency the rescue boat as well as the mini-chute on the starboard side ware destroyed in short time by the flames coming out of the wide openings on deck 4. Also, the life rafts placed on the portside of the ship were launched in water, without any authorisation. Also, some passengers might had use the MES, placed on the portside of the ship, and boarded on the liferaft. However, after a while the liferaft detached from the vessel and, two persons were blocked inside, making its use impossible.

On receipt of the mayday, Southern Norway Joint Rescue Coordination Centre (JRCC) launched a major rescue operation and started scrambling resources, including six helicopters, on a large scale. The evacuation of 479 passengers by airlift off the ship during 30 helicopter trips was successful. Sixteen people had been taken to hospital, three of them suffering serious injuries.

6.2 Closing remarks

The ship incident analysis, which is based on the available investigation reports, provides, undeniably, remarkable lessons learnt to help organizations learn from past performance and develop strategies, regulations and systems to improve passengers' safety. However, the accessibility of the investigation reports in the various databases is neither an easy process, nor time efficient. The available databases have always a different data harvesting method, while in most of cases there is no advanced search multi-criteria/ filter options. It would be, therefore, of added value the research, design and development of a global framework for a standardized reporting system which will enable the commonality of data collection, monitoring and reporting of shipping accidents and detentions at various levels [92].

Concerning the occurred marine casualties and incidents, during the last decade, EMSA in the Annual Overview report of Marine Casualties and Incidents, provides high level statistical figures for the period 2011-2018. According to them, 426 accidents occurred, which resulted in a total of 696 lives lost. Almost half of the casualties occurred on board of a passenger ship (involved a ro/ro passenger ship). The mid-water, arrival and anchored are the least safe phases, representing two thirds of the total. It was noted that the highest numbers of casualties and incidents in passenger ships have been occurred within internal waters. Navigational accidents (such as collision, contact and grounding) represented 47% of events that affected passenger vessels. Loss of control represented 26.8% of the total with the sub-category loss of propulsion with 16.8%. From the EMSA analysis of a total of 720 accident events in passenger ships, during the investigations, 59.4% were attributed to a Human action and 29% to System/equipment failure.

From the analysis of the above-mentioned incidents, it is evident that the evacuation modelling can be enhanced through incorporating real time data concerning both the type and the propagation of damage, as well as human behavior characteristics and mobility impediments. Another area of improvement concerns the acknowledgement of the awareness time as well as the calculation of the time required for the lifeboat embarkation, as the majority of the models calculate the time required for the evacuation until the assembly station gathering [44].

Additionally, the analysis highlighted the necessity of improving the preparedness and readiness of both the crew and the passengers during an emergency. In this context, special attention has been given to the required consideration of the awareness time, as it can effectively determine the efficiency of the evacuation process. Also, recommendations are given towards the broadcasting of multilingual recorded messages on the public address system. Complementary to this, the value of implementing measures to ensure that the staff on board is actually familiar with the working language has been highlighted.

Besides, the necessity of crew members to report immediately any equipment malfunction, even minor, in order to allow for maintenance and repair work to be carried out has been acknowledged, along with the rechecking of reported and resolved malfunctions during the regular internal ISM audits. In addition to that, the importance of the maintaining and regular testing of the ship and its safety equipment in accordance with the principles has been noted.

Moreover, focus has been given on strengthening the specialty of human resources in the disaster management area as well as the specialized and integrated rescue team. It appears that the recruitment of crew members along with the division of duties and the consultation for sharing of data and risk analysis play a fundamental role in the management of emergencies. It is proved that comprehensive crew training and familiarity to effectively address any emergency situation that may arise on board as well as the provision of specific instructions on the evacuation procedures and the safety equipment use, are of utmost importance. More specifically, it was indicated that it is essential crew members to be equipped with safety vests during evacuation, to make them recognizable as a point of contact for passengers.

The analysis also indicated the significance of revising the guidelines taken by the various Conventions (SOLAS, STCW, ISM Code), and included with the ISM procedures on board, as well as the policies in relation to fire safety, evacuation modelling etc. Additionally, the value of reviewing the operational restrictions with reference to the MES, and the criteria for evaluating the functioning of such devices has been indicated.

Special focus has been given on reviewing all the technical, operational and control/monitoring systems based on the emerging safety requirements and the latest technological developments (new simulation software, AR developments, VDR updates etc.). For example, review, test and confirmation of the electronic tagging system used during the muster of passengers and crew to show its effectiveness and time saving capability, review of the safety management control systems (fire safety plans, evacuation plans etc.). Along with these systems, an analysis/study has been recommended for the development of solutions, different from the existing ones, concerning the aspects and structural/constructive criticalities.

In terms of the LSAs, a new generation cost effective, more compact and ergonomic personal survival equipment with localization and pairing abilities and health status monitoring (e.g. hand bands and earplugs) would be of real use to the crew during an evacuation emergency. This can be also combined with the development of innovative life boat design, by taking into consideration the spatial constraints in place [44].

Finally, the importance of assessing scenarios involving the vessel during the time spends at the port has been acknowledged as paramount. The National Transportation Safety Board recommends the development and/or improvement of the procedures to manage and account for all persons aboard in the event of a mass evacuation of a ship while is berthed in port.

The passenger ship evacuation constitutes a dynamic multi-variable process. It is composed of a variety of parameters that are constantly changing and are closely correlated to time, environmental conditions, type of emergency and human behavior and response. In this context, it is essential to develop and implement a dynamic evacuation analysis model. The dynamic approach of this model can ensure the effective calculation of the available time for evacuation (ASET) and the required time to evacuate (RSET) taking into consideration a variety of parameters such as the state and location of fire, flooding or security threat, for instructing accordingly the passengers on the process. A simultaneously approach from all perspectives could improve ship evacuation challenge. Therefore, the development of a Decision Support System (DSS) that will integrate the multiple parameters and emergency cases is necessary for the efficient coordination of the evacuation process.

7. Ship evacuation research projects & studies

The evacuation process in general has been a research subject in many EU funded projects. Thus, a number of systems (e.g. technical, safety, simulations systems etc.) that are facilitating and improving the efficiency of the evacuation procedure has been investigated and tested in specific environments (e.g. buildings, airplanes, stadiums, train stations, etc.), with potential applicability in other fields as well. In this chapter, an attempt to highlight the results and the outcomes of previous evacuation EU research projects and studies, focused on passengers' ships, is made, having as an ultimate aim to unveil areas for improvement.

The purpose is to reveal what kind of systems haven't yet been taken into consideration for ship evacuation in previous related research projects and, therefore, should be developed to facilitate the safe and swift evacuation process, within stressful environments, with a large number of persons, from a wide demographic range within poor or extreme weather conditions. A description per project is given below, following a shortlisting as per their starting year.

7.1 Project's overview

PICASSO - Preventing Incidents and Accidents for Safer Ships in the Oceans (Motorways of the Sea Action, 2016-2018)

PICASSO [93] project aimed at creating a more sustainable shipping industry by reducing the environmental impact and improving safety and efficiency. Thus, it encompassed not only the study and test of effective ICT tools that can enhance safety and empower the human element of maritime transportation but it also provided better training to the crews, the operators and the ship-owners. PICASSO was organized in four core activities: 1) On board safe, efficient and secure operations; 2) On shore safety and security; 3) Event Management; and 4) Training and human factors.

The first three activities aim at addressing issues arising in on-board operations, in on-shore operations, and in emergency situations. The final activity in its turn is focused on training and human factors and will be addressing the tools developed and results achieved in the previous referenced activities.

Through this project, alternative solutions to deal with mass evacuations were studied. A simulation of an incident on a cruise liner at sea which was followed with a mass evacuation was carried out in the Port of Valetta, in the context of PICASSO project. The exercise which was held during Malta's EU presidency provided emergency planners the opportunity to test the port emergency response and best practices in case of such accidents.

FIRESAFE I & II (EMSA Project Studies, 2016-2018)

FIRESAFE I [94] is a study commissioned by the European Maritime Safety Agency, EMSA. It investigates risk control options (RCOs) for mitigating the risk from fires on ro-ro decks. It considers RCOs in relation to Electrical Fire as ignition risk, as well as RCOs to mitigate the risk of Fire Extinguishing Failure (with focus on drencher systems). The study considers both new buildings and existing passenger ships. The project developed three risk models to be used to investigate the effects of RCOs on the PLL and costs. Six RCOs were selected for quantitatively analysis in the risk models for the risk of electrical fire ignition and six for drencher failure. These RCOs were analyzed in a cost benefit analysis. The main objective of FIRESAFE II [95] was to improve the fire safety of ro-ro passenger ships by cost-efficient safety measures reducing the risk of ro-ro space fires, with an aim to discuss specific proposals for rule making.

LYNCEUS2MARKET Project - An innovative people localization system for safe evacuation of large passenger ships (H2020, 2015-2018)

LYNCEUS Project [13] addressed the challenge of timely and effective evacuation of large passenger ships during emergency through a revolutionary system for safe evacuation based on innovative people localization technologies (real time location of the passengers and provision of a centralized evacuation control system with crucial data about their position and health status). More specifically, the developed system consisted of: Localisable life jackets able to provide passenger location in real-time during emergency; Smart smoke detectors able also to act as base stations of an on-board localisation system; Innovative localisable bracelets able to send activity data to the emergency management team; Low cost fire and flooding escalation monitoring sensor notes; Novel mustering handheld devices for automatic identification and counting of passengers during evacuation; Smart localisable cabin key cards; Intelligent decision support software for fusing all localisation, activity and disaster escalation data to provide an integrated real-time visualisation, passenger counting and evacuation decision support; Innovative shore or ship-launched Unmanned Aerial Vehicle for localising people in the sea in short time and assisting search and rescue operations when accident occurs in extreme weather, during the night or in a remote location and Low-cost rescue-boat mounted radars for people localisation in the vicinity of the boat.

The main objective of this project was the optimization and improvement of the current technologies and prototypes, in order to develop innovative wireless devices than can be easily integrated in new and existing passenger ship infrastructure and provide a low-cost and robust safe evacuation system. Consequently, this innovative system will allow on-board and overboard localisation, person activity monitoring, real time disaster escalation, monitoring and adaptive decision support.

eVACUATE - A holistic scenario –independent, situation-awareness and guidance System for sustaining the Active Evacuation Route for large Crowds (FP7, 2013-2017)

The general concept of eVACUATE project [96] referred to the dynamic capture of situational awareness as regards to crowds in specific mass gathering venues and its intelligent enablement into emergency management information systems, which is critical for implementing rapid, timely guidance and safe evacuation of people out of dangerous areas. This is feasible by using smart communication devices and spaces. Subsequently, the intelligent fusion of sensors, geospatial and contextual information along with advanced multi-scale crowd behavior detection and recognition were developed. Through eVACUATE project the needs of safety for passengers during complex evacuation processes have been addressed following normal and abnormal events towards the development of a holistic system that aimed at enhancing the effectiveness of complex evacuation operations at any type of venue or infrastructure, adapting evacuation plans to the current conditions, surveying dynamically how an evacuation is evolved and supporting civil protection authorities.

The framework implemented in eVACUATE uses all key elements in the design and operation of the envisaged system: Crowd models, the Simulator Tools, the Emergency Operations Control Centre and the Smart Spaces, which are the most important outreach of the proposed actions. The goal achieved through this project was the identification and sustainability of an Active Evacuation Route (AER) consisting of the most recently generated evacuation route, which adapts dynamically according to current and growing circumstances.

SAFEGUARD Project - Ship evacuation data and scenarios (FP7, 2009-2012)

SAFEguard project [97] provides comprehensive assessment and analysis services to identify gaps and vulnerabilities, including evaluation and prioritization of personnel, functions and resources. The derivative outcome is applied to formulate comprehensive organizational, procedural and technological advancements for situational awareness and crisis management. SAFEguard planning experts work directly alongside our clients to illustrate precise planning, training and technological requirements achieving a pro-active response posture capable of rapid deployment to mitigate events as they occur.

The SAFEguard Instant Viewer provides the ability to simultaneously view real time events on a digitized facility display. Live streaming video may be viewed alongside emergency procedures and communications instructions to maximize response activities. This single emergency response resource provides a single platform from which to formulate instantaneous response actions in situations where every minute counts with unmatched speed and precision. The system is housed in a cloud-based web portal and operates as a single pane of glass to provide the ultimate platform from which to control facilities and coordinate actions in both routine and emergency situations.

FIREPROOF - Probabilistic Framework for Onboard Fire-Safety (FP7, 2009-2012)

FIREPROOF project [98] developed a universally applicable regulatory framework for maritime fire safety based on probabilistic models and numerical models of ignition, growth and impact of fires. More specifically the project aimed at enhancing the fire safety regulations by developing of a probabilistic framework for fire safety and presenting the referenced framework to IMO and the Maritime Safety Committee for future enforcement. The proposed methodology consisted of a mathematical model that generates instances of fire scenarios according to the correct probability distribution of the elements of the scenario. It provided also numerical models to assess the consequence of the scenarios generated. For any given ship (traditional or novel) a large number of scenarios were generated, and their consequences assessed, and the results were aggregated to give rise to fire risk metrics. Constraints based on such risk metrics served as statutory regulations that were completely applicable to novel and unprecedented designs.

FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management (FP7, 2009-2012)

FLOODSTAND project [99] aimed at identifying the most of the missing data for validation of time-domain numerical tools for the assessment of ship survivability and at developing a standard for comprehensively measuring the damages of the ship's stability as a means of addressing systematically, rationally and effectively the flooding risk. Within FLOODSTAND project the reliability of flooding simulation tools in both in design and onboard use by establishing modelling principles and uncertainty bounds has been increased. This was achieved through the establishment of new experimental and computational data and guidelines for modeling leakage through closed doors and the critical pressure head for collapsing under the pressure of floodwater, the simplified modelling of pressures losses in flows through typical openings, the feasible and realistic modelling of complex ship areas such as cabin areas and the use of flooding monitoring systems and time domain simulation for assessing the damage and the flooding extent onboard the ship.

SURSHIP-FIRE - Survivability for ships in case of fire (European research Program on Maritime safety, 2007-2009)

Survivability of ships in case of fire has been studied within the SURSHIP-FIRE research project [100] as a part of the SURSHIP cooperation, a coordinated European research program on Maritime safety. The work was performed in four subprojects related to materials used in shipbuilding, fire hazards on board, ship structures, and evacuation in ship conditions. Fire test data of products commonly used in shipbuilding were stored to a free-of-charge accessible database for the use of design engineers. Guidelines were defined for using fire test data in simulation and product development. Procedures for quantitative fire risk analyses of cabins and cabin areas were defined, applicable also to other cases with different features and details.

A methodology for defining design fires for various ship spaces was formulated and applied to shops on board as a practical example. The sophisticated simulation and risk analysis tools utilized in the work were the FDS5 fire simulation program with its evacuation module FDS+Evac, the Probabilistic Fire Simulator, and the method of time-dependent event trees. The effects of engine room fire on car deck structures were analyzed in detail since the situation was identified as critical for the structural integrity of the ship. Thermal and mechanical analyses of the structures with different dimensions and insulation extents were performed considering both the standard fire curve and the hydrocarbon curve. A survey of specific features of ship evacuation was carried out. The main outputs of SURSHIP-FIRE were guidelines for using fire test data as input of simulations, a methodology for estimation of design fires, practices for quantitative risk analyses, a summary of critical fire situations for structures, and suggested improvements of the IMO guidelines for evacuation analyses.

SAFEDOR - Design, Operation and Regulation for Safety (FP6, 2005-2009)

SAFEDOR [101] aimed at providing additional design freedom for ship and systems and an appropriate approval process that defines safety as additional objective. As supplementary element to the approval process, an updated regulatory framework was introduced to the risk analysis. Within SAFEDOR project new developments and refinements in several engineering tools to predict the safety performance of vessel in extreme and accidental conditions took place. These tools responded to the main accident categories, more specifically collision and grounding, fire and explosion, intact and damage stability and systems' failures. The output of SAFEDOR included the integration of all operational, technological, environmental and human related factors taking into account safety at sea during the vessel's life cycle. More specifically, the demonstration of the potential of risk-based frameworks for safety assessment techniques, integrated design environments and optimization of ship operation processes for safe and economic shipping.

SAFECRAFTS - Safe abandoning of ships, Improvement of current Life Saving Appliances Systems (FP6, 2004-2009)

SAFECRAFTS project [102] was focused on reconsidering evacuation systems on passenger ships. The costs associated with ship evacuation systems are high, while the size of cruise passenger ships along with the number of passengers are increasing. This project was initiated with two objectives. Firstly, the development of an assessment methodology for evaluating the performance of life saving appliances, which can cope with systems of very different concept and secondly, the creation of two novel concepts. The assessment method was a critical challenge for the project and was addressed by identifying a non-specific parameter, which quantifies the performance of ship evacuation systems. This was achieved by understanding that the only common factor that associates these systems, is the human factor. Out of many ideas, two concepts, as the most promising, were selected and further developed. The first one, was called Self Propelled Survival Craft (SPSC), consisted of multiple modules stored at or near the center line, in the aft of the mother ship. The other concept included a life raft with partially rigid sides, called Hard sided life raft, that was located at the "boat" deck although the required storage space is substantially smaller.

FIRE EXIT - Collected full-scale passenger response time data on a ship at sea (FP5, 2001-2005)

FIRE EXIT project [103] proposed to equip the marine industry with a Ship Evacuation Simulator, which is a valuable tool of reliability, realism and design utility of today's ship evacuation software. The developed Ship Evacuation Simulator, was the maritime EXODUS, also mentioned in paragraph 5.3.1. This software can address issues of mustering, ship motions, fire and abandonment. This research project combined the very leading edge of the current state-of-the-art in ship evacuation simulation (maritime EXODUS) with the fire simulation (SMARTFIRE) and the large scale experimental facilities and significantly improved these capabilities.

PYXIS -Increased situation awareness in case of emergency using the Smart Spaces paradigm and Augmented Reality techniques (General Secretariat for Research and Technology (GSRT)) – (1309-BET-2013)

The purpose of PYXIS project [104] was to increase the situational awareness of the passengers and the crew in a ship, in case of an emergency (fire, flood etc.). It made use of "smart spaces" based on sensor networks, computer vision technologies, as well as decision support and intelligent content distribution, utilizing augmented reality methods. The project aimed to increased passenger and crew safety and better accident response management.

7.2 Concluding observations

A large number of previous research EU funded projects have contributed to go ship evacuation one step further. Although crucial outcomes and developments have taken place until now, there is always room for improvement.

Many of the research projects had as main goal the enhancement of safety and efficiency in large vessels (table 5). PICASSO project has also included the environmental impact and the human element of maritime transportation, as well as training activities to the crews, operators and ship owners. At the same time, the research project FIRESAFE I addressed safety and efficiency issues by developing risk models to investigate the effects of risk control options and enhancing fire safety by cost efficient measures, reducing the risk of ro-ro space fires. The LYNCEUS project came up against the challenge of timely and effective evacuation of large passenger ships by demonstrating the benefits of using smart devices, such as wireless bracelets and lifejacket-embedded sensors, in ship evacuation. Additionally, during the eVACUATE project an Active Evacuation Route (AER) consisting of the most recently generated evacuation route has been identified, while the exploration of Ultra-Wide Band (UWB) technologies has been suggested. Developments and refinements in several engineering tools for the prediction of the vessel's safety performance in extreme and accidental conditions (collision and grounding, fire and explosion, intact and damage stability, systems' failures) took place during the SAFEDOOR project. Furthermore, SAFECRAFTS project aimed at reconsidering the evacuation systems on passenger ships.

Another category of projects (table 9) gave emphasis on the regulatory framework, the identification of guidelines along with potential gaps and vulnerabilities regarding ship evacuation. A universally applicable regulatory framework for maritime fire safety based on probabilistic models and numerical models of ignition, growth and impact of fires has been developed during FIREPROOF project. SURSHIP-FIRE project has contributed to the investigation of the survivability of ships in case of fire. Guidelines for fire test data use in simulations have been created and suggestions have been made for improving the IMO existing guidelines for evacuation analyses. Moreover, within SafeGUARD project assessment and analyses of services took place in order to identify gaps and vulnerabilities, including evaluation and prioritization of personnel, functions and resources.

Furthermore, FIRE EXIT has succeeded to develop a Ship Evacuation Simulator, Eudoxus software. This came up from the combination of the very leading edge of the current state-of-the-art in ship evacuation simulation (maritime EXODUS) with the fire simulation (SMARTFIRE) and the large scale experimental facilities and significantly improved these capabilities.

Table 9 EU Project's per category

General Category	EU Projects
Enhancement of safety & effectiveness	**a. PICASSO** **b. FIRESAFE I & II** **c. LYNCEUS** **d. eVACUATE** **e. SAFEDOR** **f. SAFECRAFTS**

	g. **PYXIS**
Regulatory framework/guidelines/gaps & vulnerabilities	h. **FIREPROOF** i. **SURSHIP-FIRE** j. **SafeGUARD**
Simulations (software) & Modelling	k. **FIRE EXIT** l. **FLOODSTAND**

Up to now, many research studies and projects contributed to the identification of gaps in the ship evacuation procedures. However, there is still room to improve the level of safety and emergency response. Therefore, some of the identified gaps and more specifically what is needed in each case, are summarized below.

First of all, focus should be given on the creation of innovative lifeboat designs, including the development of different release mechanisms and davits with as few moving parts as possible, so that less maintenance to be required. Additionally, the lifeboats design could be changed by enhancing the boats' ability to be used as tenders, while maintaining the expected robustness and reliability. The launching and operational phases of these boats could be less complex, thus leading to the minimization of the required training activities. The boats' launching and use availability even after extreme heeling angles or releases from considerable heights is important to be ensured. Furthermore, as lifeboats represent a significant percentage of the total ship building cost, it is essential cost effective and safe alternatives to the conventional boats to be assured. The arising requirements from the ship owners lead to the necessity of changes on the design of lifeboats, while serving the challenge of not taking over much deck area and not obstructing the view.

Moreover, as regards to MES, the next generation should follow higher performance standards in trim and listing conditions, while decreasing the deck footprint. In addition, the review of the heat insulation of these systems of MES is considered crucial.

The effective decision-making during emergency conditions is becoming more and more necessary. Therefore, ship officers should receive sufficient and reliable information for effective decision making (actual real time state of damage and passenger distribution within the vessel). Also, more compact designs in lifejacket innovations that can also include survival kits, should be designed. There are still several technical challenges to be addressed related to passenger health status monitoring and communication system protocols due to the large number of wireless sensors and bandwidth availability. The on-going EU-funded PALAEMON project is working on innovative technologies for providing real-time data about the situation on a damaged or sinking vessel, towards monitoring the localisation of persons on board, detecting potential dangers and providing guidance about the best evacuation route.

Besides the above, there is also room for improvement on the investigation of human's behaviour under panic, along with the corresponding changes in the walking speed and the effect of disabled people on the evacuation flow. From the standpoint of ship evacuation modelling, the trim and heeling angles effect in the availability of the LSAs and the corresponding effects on passenger flow remain to be modelled. However, more importantly, a dynamic enough model capable of assessing the total time to evacuate based on real time passenger localization data should be developed. In addition to the above, the real time coupling of passenger tracking and for evacuation time calculation constitutes a critical gap.

The evacuation process would be significantly enhanced by developing a new generation of a cost effective personal survival equipment. This should be combined with the identification of innovative concepts in ship design layout for the accommodation of novel lifeboat designs and increase of the evacuation efficiency. Moreover, Augmented Reality (AR) technology could be employed to securely guide the passengers throughout the evacuation stage.

Besides the aforementioned suggestions, there is need for a more dynamic evacuation analysis. More precisely, the existing non-static effect of ship motions should be associated with real time flooding simulation and "live" flooding risk assessment (as currently examined by the on-going EU FLARE project), so as the time-to-evacuate with the time-to-capsize to be truly linked.

Last but not least, the integration of all the systems under one Decision Support System to widely cover all the emergency cases and coordinate the evacuation process more efficiently, remains as one of the biggest challenges.

8. Final Conclusions

The current deliverable D2.1, provided an in-depth overview of the current State-of-The-Art of large passenger ships evacuation, by thoroughly investigating the landscape of passenger ship evacuation, in terms of LSAs/PSAs used, evacuation procedures/best practices, and regulatory framework in place. Additionally, this investigation targeted at spotting any existing gaps to speed-up, and also make the overall evacuation process safer.

Ship evacuation has been defined including an overview of the process' steps during an emergency. The regulatory framework has been investigated, while the existing regulations have been presented. In addition, an indicative categorization of the framework in five subjects has been made and finally an important number of regulatory gaps has been spotted and discussed during the stakeholder's workshop in Glasgow, Scotland on 29th -30th of January 2020.

Moreover, a variety of last decade publications in the field of evacuation has been reported, driving to the conduction of important conclusions on the research area of ship evacuation. It has been observed that the most recent publications focus on enhancing the ship evacuation procedures, the simulation methodologies, the human behaviour, as well as the use of novel survival equipment.

A wide range of existing evacuation systems adapted to the current technological advancements has been specified, including technical systems (MES and LSAs), on board safety systems, as well as simulation tools and supervision systems used in ship evacuation and operation, and their functionalities. The identified gaps and the remarks have been also evaluated during the stakeholder's workshop in Glasgow, Scotland on 29th -30th of January 2020.

In addition, the most widely known incidents have been presented and described based on the available investigation reports and constituted the source for remarkable lessons learnt to help organizations to develop strategies, regulations and systems to improve passengers' safety. The standardization of a reporting system to enable the commonality of data collection, monitoring and reporting of shipping accidents and detentions at various levels would be very useful for future developments.

Within this document, a significant number of previous research projects and studies in the field of ship evacuation mainly in passenger ships has been investigated, while their main results and outcomes have been highlighted. These projects have been mainly focused on the enhancement of safety and effectiveness, on the regulatory framework, as well as on simulations and modelling. It is evident that these research EU funded projects assisted to take ship evacuation even one step further, through vital developments, leaving however always room for improvement.

Thus, the improvement of ship evacuation cannot be considered without giving each parameter the appropriate prominence. Novel approaches and use of disruptive technologies in simulation/modelling tools, in dynamic systems, in LSAs and in PSAs, supported by the existence of a well-defined regulatory framework could significantly improve the overall ship evacuation process. The biggest challenge though is the integration of all evacuation and emergency response systems under one Decision Support system, which can be of use in every emergency scenario and effectively coordinate the evacuation process.

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10. Annexes

Annex 1: TTP references

(a) USCG Marine Safety Manual, Vol. II: Materiel Inspection, COMDTINST M16000.7 (series)

(b) Prevention of Departure, 46 U.S.C. § 3505

(c) SOLAS: Consolidated Text of the International Convention for the Safety of Life at Sea, 1974, and its Protocol of 1988: Articles, Annexes and Certificates (Incorporating all amendments in effect), International Maritime Organization (IMO)

(d) Scheduling Foreign Vessel Examinations, MPS-PR-SEC-02

(e) Preparing for Inspections and Examinations, MPS-PR-SEC-04

(f) Conducting Foreign Vessel Examinations, MPS-PR-SEC-06

(g) MISLE Data Entry Requirements for Foreign Vessel Arrivals, Examinations and Operational Controls, MMS Work Instruction,

(h) Revised List of Certificates and Documents Required to Be Carried on Board Ships, International Maritime Organization (IMO), MSC.1/Circ. 1409

(i) International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), Including 2010 Manila Amendments, STCW Convention and STCW Code

(j) Guidelines for the Coast Guard Evaluations of Compliance with the U.S. Environmental Protection Agency's (EPA) Vessel General Permit (VGP) for Discharges Incidental to the Normal Operation of Vessels, COMDT (CG-543) Policy Letter 11-01

(k) Navigation Safety Regulations, 33 CFR Part 164

(l) Marine Safety Center (MSC) Guidelines for Review of Locks and Latches in Doors in Escape Paths, Procedure Number: SOLAS-49

(m) Marine Safety Center (MSC) Guidelines for Review of Room-In-Room Construction, Procedure Number: SOLAS-25

(n) Guidelines for the Evaluation, Testing, and Application of Low-Location Lighting on Passenger Ships, International Maritime Organization (IMO) Assembly Resolution A.752(18)

(o) Cruise Vessel Security and Safety Act (CVSSA) of 2010

(p) MSC Guidelines for the Use of Flammable Liquid & Gas Storage Cabinets, Procedure Number SOLAS-05

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(s) Cruise Vessel Security and Safety Act (CVSSA) of 2010 Implementation Procedures, COMDT (CG-543) Policy Letter 11-09

(t) Guide to Maritime Security and the International Ship and Port Facility Security (ISPS) Code, International Maritime Organization (IMO)

(u) Maritime Security: Vessels, 33 CFR Part 104

(v) Adoption of the International Code for Fire Safety Systems (FSS) Code, Annex 6, Resolution MSC 98(73) (as amended)

(w) Port State Control Guidance for Examination of Fixed CO2 Firefighting Systems and Conducting Fire Drills onboard Cruise Ship during Scheduled Examinations, CG-CVC-2

(x) International Code for Fire Safety Systems (FSS Code),

(y) Marine Safety Center (MSC) Guidelines for Review of Overhanging Decks, Procedure Number: SOLAS-29

(z) Marine Safety Center (MSC) Guidelines for Protection of Deck Openings in Two Deck Spaces, Procedure Number: SOLAS-13

(nn) Life-Saving Appliances (LSA) Code, International Maritime Organization (IMO)

(oo) Revised Recommendation on Testing of Life-Saving Appliances, Annex 6, Resolution MSC.81(70)

Annex 2: Last decade publications in ship evacuation field

No.	Title	Year	Author/s	Open Access
1	An uncertainty analysis method for passenger travel time under ship fires: A coupling technique of nested sampling and polynomial chaos expansion method	2020	Qimiao Xie, Pengcheng Wang, Shanshan Li, Jinhui Wang, Weili Wang	OA
2	Ship Evacuation and Emergency Response Trends	2019	Fotios Stefanidis, Evangelos Boylougouris, Dracos Vassalos	OA
3	Passenger evacuation simulation considering the heeling angle change during sinking	2019	Hyuncheol Kima, Myung-Il Rohb, Soonhung Han	OA
4	Efficient target detection in maritime search and rescue wireless sensor network using data fusion	2019	H. Wu, Y. Zhang, J. Xian et al.	
5	Passenger evacuation simulation considering the heeling angle change during sinking	2018	H. Kim, M. Roh, S. Han	
6	An experimental study on individual walking speed during ship evacuation with the combined effect of heeling and trim	2018	J. Sun, Y. Guo, C. Li et al.	
7	Agent-based evacuation model incorporating life jacket retrieval and counterflow avoidance behavior for passenger ships	2018	B. Ni, Z. Lin, P. Li	
8	Prediction based opportunistic routing for maritime search and rescue wireless sensor network	2018	H. Wu, J. Wang, R. Ananta et al.	
9	Quantification of the maritime security problem onboard passenger ships	2018	I. Gypa, E. Boulougouris, D. Vassalos	
10	Towards real-time human participation in virtual evacuation through a validated simulation tool	2018	G. Montecchiari, G. Bulian, P. Gallina	
11	Survivability, Escape and Evacuation Systems	2018	D. Barber	
12	Safety of Ro-Ro Passenger & Cruise Ships	2018	Bureau Veritas	OA
13	A study on how to improve mass evacuation at sea with the use of survival crafts	2017	Martin Pospolicki	OA
14	An evacuation model considering human behavior	2017	Dezhen Zhang, Ning Shao, Ying Tang	
15	A Simulation-Based Methodology for Evaluating the Factor on Ship Emergency Evacuation	2017	P A Sarvari, E Cevikcan	OA

16	Studies on emergency evacuation management for maritime transportation	2017	P A Sarvari, E Cevikcan, A Ustundag, M Celik	
17	A method for breach assessment onboard a damaged passenger ship	2017	P. Ruponen, A. Pulkkinen, J. Laaksonen	
18	Evacuation on board passenger ships with the use of mobile application	2017	Suzanna Svensson Ademi, Niclas Holmberg	OA
19	Multi-agent Simulation of Passenger Evacuation from a Damaged Ship under Storm Conditions	2016	Marina Balakhontceva, Vladislav Karbovskii, Serge Sutulo, Alexander Boukhanovsky	OA
20	Quantitative human error assessment during abandon ship procedures in maritime transportation	2016	Emre Akyuz	
21	A Study on the Standardization of ASETon Deck of Ro-ro Passenger Ship through Simulation Analysis of the SEWOL Ship Turnover Accident	2016	H.J. Park, Y.J. Lee	
22	Safety in passenger ships: The influence of environmental design characteristics on people's perception of safety	2016	M. Ahola, R. Mugge	
23	Modeling Passenger Ship Evacuation from Passenger Perspective	2015	J Nevalainen, M K Ahola and P Kujala	OA
24	Enhanced Evacuation Scenarios - Background and Recommendations	2015	A Breuillard	OA
25	Multi-agent Simulation of Passenger Evacuation Considering Ship Motions	2015	Marina Balakhontceva, Vladislav Karbovskii, Dmitrii Rybokonenko, Alexander Boukhanovsky	OA
26	Validation of advanced evacuation analysis on passenger ships using experimental scenario and data of full-scale evacuation	2015	Kwang-Phil Park, Seung-Ho Ham, Sol Ha	
27	Passenger Ship Evacuation Simulation and Validation by Experimental Data Sets	2014	W. L. Wang, S. B. Liu, S. M. Lo, L. J. Gao	OA
28	Safety procedure and equipment considerations on large cruise ships	2014	Captain Michael Lloyd	OA
29	Preparing for Airport Collaborative Decision Making (A-CDM) implementation: an evaluation and recommendations	2014	S. Corrigan, L. Martenssson, A.M. Kay, S. Okwir, P. Ulfvengren, N. Mcdonald	
30	On-board Decision Support System for ship Flooding Emergency Response	2014	J.M. Varela, J.M. Rodrigues and C. Guedes Soares	
31	Advanced ship evacuation analysis using a cell-based simulation model	2013	Myung-Il Roh, Sol Ha	

32	Passenger Ship Evacuation Simulation Considering External Forces due to the Inclination of Damaged Ship	2013	S. Ha, Y.O. Cho, N. Ku, K.Y. Lee, M.I. Roh	
33	A probabilistic occupant evacuation model for fire emergencies using Monte Carlo methods	2013	X. Zhang, X. Li, G. Hadjisophocleous	
34	The Safeguard Fire Scenario Evacuation Benchmark and Recommendations to IMO to Update MSC Circ 1238	2012	E R Galea, A Grandison, D Blackshields, G Sharp	
35	The Safeguard Heel Scenario Evacuation Benchmark and Recommendations to IMO to Update MSC Circ 1238	2012	I. Nicholls, Y. Hifi, B.S.Lee, E.R.Galea, S.Deere	
36	Safety Development – The Feasibility and Challenges Facing Life Saving Appliances in Polar Regions	2012	I Nicholls	
37	Cell-based evacuation simulation considering human behavior in a passenger ship	2012	Sol Ha, Nam-Kug Ku, Myung-Il Roh, Kyu-Yeul Lee	
38	Organization of evacuation from passenger ships – a concept of safety enhancement	2012	Dorota Łozowicka	OA
39	Validation of reported events from a vertical chute marine evacuation study	2012	D. Harwood, A. Farrow	
40	Cell-Based Discrete Event and Discrete Time Simulation for Advanced Evacuation Analysis Considering Human Behavior in a Passenger Ship	2011	A-Ra Jo, M Friebe , S Ha, K Lee, N Ku, K Park	
41	Probabilistic Modelling of the process of evacuation for ship crises management	2011	Yasmine Hifi	
42	A Flow-Dependent Secondary-Shortest Path Algorithm for Naval Ship Evacuation	2011	Chong Liu, Chang Hua Qiu	
43	Evacuation simulation of shipboard fire scenarios	2011	C Azzi, APennycott, G Mermiris, D Vassalos	
44	Evaluation of offshore emergency preparedness in view of rare accidents	2011	Jan Erik Vinnem	
45	VELOS: A VR platform for ship-evacuation analysis	2010	A. I. Ginnis, K. V. Kostas, C. G. Politis, P. D. Kaklis	
46	Evaluating the cost-effectiveness of a monitoring system for improved evacuation from passenger ships	2010	Erik Vanema, Joanne Ellis	

47	Software Tools Enabling Design Optimisation Of Mustering And Evacuation For Passenger Ships	2009	P Berseneff, J Huberty, U Langbeckerm, J J Maisonn	
48	Decision analysis of emergency ventilation and evacuation strategies against suddenly released contaminant indoors by considering the uncertainty of source locations.	2009	Cai H1, Long W, Li X, Kong L, Xiong S.	