PROJECT DELIVERABLE REPORT

Introducing advanced ICT
and Mass Evacuation Vessel design
to ship evacuation and rescue systems

D2.1 Report on the analysis of SoA, existing and past projects/ initiatives

A holistic passenger ship evacuation and rescue ecosystem

MG-2-2-2018

Marine Accident Response

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Contents

Abbreviations

ABS	American Bureau of Shipping
AIS	Automatic Identification System
AR	Augmented Reality
ASM	Application Specific Messages
AtoN	Aids to Navigation
BLE	Bluetooth Low Energy
BN	Bayesian Network
BSL	Bootstrap Loader
CAD	Computer-Aided Design
CCTV	Closed-Circuit Television
CDC	Centres for Disease Control
CLIA	Cruise Line International Organisation
CRC	Cyclic Redundancy Check
CSR	Common Structural Rules
DEM	Discrete Element Method
DOC	Document of Compliance
DoS	Denial of Service
DSS	Decision Support System
EC	European Commission
ECDIS	Electronic Chart Display and Information System
EEA	European Economic Area
EGC	Enhanced Group Calling
EMSA	European Maritime Safety Agency
ENISA	European Union Agency for Cybersecurity
EPIRB	Emergency Position Indicating Radio Beacon
EU	European Union
FSEG	Fire Safety Engineering Group
FSS	Fire Safety Systems
GDPR	General Data Protection Regulation
GL	Germanischer Lloyd
GMDSS	Global Maritime Distress Safety System
GPS	Global Positioning System
IALA	International Association of Maritime Aids to Navigation and Lighthouse Authorities
ICT	Information and Communication Technology
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
IoT	Internet of Things
IPS	Indoor Positioning Systems
ISM	International Code for Safety Management Code
ISPS	International Ship and Port Facility Security code
ITU	International Telecommunication Union
JIT	Just-In-Time
LED	Light-Emitting Diode
LRRS	Lifeboat Release and Retrieval System
LSA	Life Saving Appliances
MAC	Media Access Control
MAD	Mutual Authentication with Distance-bounding
MANET	Mobile Ad-hoc Network

MARPOL	International Convention for the Prevention of Pollution from Ships
MES	Marine Evacuation System
MEV	Mass Evacuation Vessel
MLC	Maritime Labour Convention
MOB	Man Over-Board
MRCC	Maritime Rescue Coordination Centre
MSC	Maritime Safety Committee
NASF	Non-Accidental Structural Failures
NM	Nautical Mile
P&I Club	Protection & Indemnity Club
PA	Public Address
PDA	Personal Digital Assistant
PECS	Physical Conditions, Emotional State, Cognitive Capabilities and Social Status
PKI	Public Key Infrastructure
REFIT	Regulatory Fitness and Performance
RF	Radio Frequency
RFID	Radio Frequency Identification
RO	Recognised Organisation
RoPax	Roll-On Roll-Off Passenger
ro-ro	Roll-on/Roll-off
RSSI	Received Signal Strength Indication
SAR	Search and Rescue
SART	Search and Rescue Transmitter
SHEBA	Ship Evacuation Behaviour Assessment
SHM	Ship Hull Monitoring
SIRC	Seafarers International Research Centre
SMC	Safety Management Certificate
SMS	Safety Management System
SOLAS	International Convention for the Safety of Life at Sea
SSRC	Ship Stability Research Centre
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TDMA	Time Division Multiplex Access
UWB	Ultra-wideband
VDES	VHF Data Exchange System
VDL	VHF Data Link
VDR	Voyage Data Recorder
VHF	Very High Frequency
VR	Virtual Reality
VTS	Vessel Traffic Service
WHO	World Health Organization
WLAN	Wireless Local Access Network
WSN	Wireless Sensor Network
YLD	Years Lost due to Disability
YLL	Years of Life Lost

1 Summary

The main objective of this report is to identify the main problems and challenges with the current state-of-the-art in maritime evacuation. The methodology used for this report included: 1) reviewing the relevant international literature, and 2) conducting a workshop with stakeholders. The workshop was coordinated by NTUA and hosted by ANEK. It was conducted on November 25 and 26, 2019, onboard ANEK's RoPax Ferries (KRITI II and ELEFTHERIOS VENIZELOS) that were moored at the Port of Piraeus in Greece. The purpose of the workshop was to get feedback through a structured questionnaire and discuss various aspects for the improvement and the problems of the evacuation process in brainstorming sessions.

The report is structured in the following sections.

Section 3 describes the stages of the maritime evacuation process, which is divided in five basic stages, human behaviour in emergency situations and onboard evacuation procedures and training requirements. In addition, this section outlines a state-of-the-art analysis for the evacuation and planning methodologies, in the context of the International Maritime Organization (IMO) framework for evacuation analysis.

Section 4 describes the different types and basic characteristics of evacuation systems and Information and Communication Technology (ICT)-related technologies used in the maritime domain. Evacuation systems include liferafts, lifeboats, and Marine Evacuation Systems (MES). The ICT-related technologies include ship condition monitoring, communications infrastructure, ICT infrastructure onboard ships, and indoor positioning technologies for passengers.

Section 5 presents selected case studies of major marine casualties and incidents involving lifeboats. The identification of main contributing factors assists in mapping the challenges related to maritime evacuation and the potential conditions that the PALAEMON system will be expected to operate in.

Section 6 presents past and on-going EC-funded research projects/initiatives related to maritime evacuation and specifically to innovative ICT technologies.

Section 7 outlines the regulatory framework that governs maritime evacuation at the International and European levels. These regulations include issues regarding ship design, lifesaving appliances and equipment requirements, and crew training requirements.

Section 8 briefly summarizes the main conclusions of this report. These include the identification of the major challenges in the maritime evacuation process, the limitations of simulating and modelling in evacuation analyses (especially relating to the unpredictability of human behaviour in emergency situations), and the most important constraints determined by the International and European regulatory framework.

2 Introduction

In recent years, the capacity of Cruise and Roll-On Roll-Off Passenger Ferries (RoPax) ships has followed an increasing trend and the number of passengers onboard is up to several thousands. Even though accidents involving such large passenger ships are rare, in the view of great human losses due to major maritime disasters, issues regarding the evacuation of crew and passengers on board have received increased attention (Wang et al., 2014). The high passenger-carrying capacity leads to several challenges for a successful evacuation that mainly relate to a significant increase in the required evacuation time. The additional time required may be owed to the congestion that may occur due to the movement of crew and passengers along escape routes and the wide demographic spectrum, which includes people with reduced motor or physical capabilities. Considering that the ship structure may be unstable in an emergency situation, the survival time of the vessel is very uncertain; this puts an additional strain on the evacuation process.

The main objective of this report is to identify the main problems and challenges with the current state-of-the-art in maritime evacuation. This is accomplished by thorough reviewing the relevant international literature and selected major marine casualties with evacuation-related issues. This report also identifies problems related to the technologies and systems that are currently employed in a maritime evacuation and includes an analysis of incidents that have mainly taken place during onboard evacuation drills. The information in this report will provide the basis for identifying user needs and determining user requirements for every PALAEMON component. Finally, the basis for determining design constraints for the PALAEMON system components is formed by identifying all the relevant international and EU regulations that govern maritime evacuation.

3 Evacuation process and analysis

This section provides a description of the evacuation stages in the maritime domain, including what happens in each one, an initial identification of the actors and their roles, relevant training requirements, and how human behaviour affects the evacuation process. In addition, this section describes different analysis approaches used for planning an effective maritime evacuation, including the mandatory IMO evacuation analysis framework, and an overview of existing models and software packages.

The main objective of this section is to identify trends and challenges related to maritime evacuation, which will subsequently be used as an input for determining the requirements of the different components in the PALAEMON system.

3.1 Stages of the evacuation process

The following is a brief description of the stages of the maritime evacuation process (Figure 1). The evacuation process was described by also considering the questionnaire answers and the expertise of the people who attended the PALAEMON workshop on 25/11/2019 in Piraeus.

Maritime evacuation is a time-sensitive process that is affected by factors such as, the variability of the weather conditions, the potential instability of the ship structure after an incident (e.g., fire/explosion, flooding, etc.), and the difficulties related to internal conditions that potentially affect the passengers ability to evacuate (e.g., list angle, presence of smoke, high temperatures and toxic fire effluents, etc.). The maximum allowable evacuation duration according to SOLAS requirements is 60 minutes for Roll-on/Roll-off (Ro-Ro) passenger ships.

For other categories, the maximum allowable evacuation duration is 60 minutes if the ship has no more than three main vertical zones and 80 minutes if the ship has more than three.

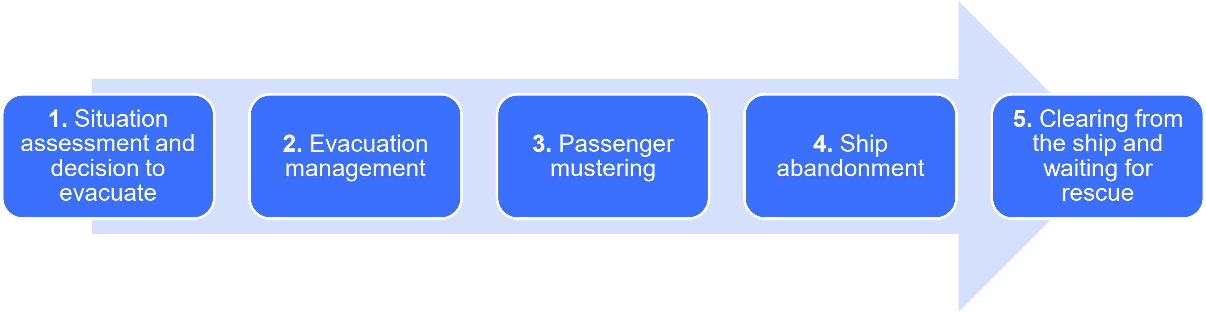

Figure 1: Stages of the maritime evacuation process.

3.1.1 Situation assessment and decision to evacuate

In case of emergency (e.g., fire, flooding, grounding, collision, pollution, heavy weather damage, security threat, failure of critical machinery, etc.), any first reaction depends on the nature and extent of the incident. The criticality of the incident and its evolution are assessed continuously by the Master of the ship, who shall first ensure the safety of passengers and crew.

The assessment of the situation includes an evaluation of the information about the nature of the incident, in which part of the ship it took place, damage assessment and feasible mitigation actions, the location of the vessel, and the weather conditions. The level of information about the actual state of the situation is important for the Master to plan and decide whether to deal with the incident or proceed with evacuation; this would be the right time to sound the alarm (Stefanidis et al., 2019). The early identification of the incident and the knowledge of the exact steps, according to regulations and planned evacuation procedures, as well as the experience and leadership of the ship's personnel are very important. When the Master has an adequate understanding of the ship's condition and the severity of the situation, he/she may sound the alarm in order to inform the passengers that an evacuation may take place. The alarm sounding will not necessarily lead to an evacuation, but it is preferable for the passengers to be in the muster stations in case that is needed.

Crew members who are at the place of the incident must communicate and co-operate with the bridge and send feedback. All the information must be accurate, and the update should be fast, so that the officers and the Master have a clear view of the damage and danger and assess the situation successfully. Quick reference and decision on the actions to be taken is crucial. The communication between all the ship's personnel and the shore management and authorities is a key factor for a successful evacuation.

For the sake of illustration, a sequence of initial actions in case of a large-scale incident or an incident that poses a serious threat to the safety of the passengers and the crew might be the following:

- Initiation of the general alarm to alert the crew, the passengers and all other persons on board the ship;
- Identification of crew members, passengers and other persons on board the ship in danger;
- Preparation and briefing of the shipboard response team;
- Preparation and briefing of personnel and equipment to support the response team;

- Initiation of response actions;
- Keeping all persons informed: passengers, other persons onboard and crew not directly involved in response actions. The passengers should be informed about the situation as early as possible, so that no valuable time is lost;
- Monitoring continuously and supporting accordingly the response actions;
- Activation of reporting procedure and requesting external assistance as necessary.

In case of a small-scale event, an alarm coming to the bridge from one of the various sensors deployed throughout the vessel (e.g., smoke detector) or a relevant report from a crew member, normally no general alarm will be sounded until the Master of the ship acquires a clear picture of the situation. Any alarm will warn only the crew members of the ship. A further investigation is conducted about the status of the event by a dedicated assessment team manned with experienced personnel, and depending on the result, the general alarm throughout the ship will be sounded or not.

Abandoning the ship is always considered the solution of last resort. This has been solidified in SOLAS with the inclusion of the “Safe Return to Port” philosophy that considers a ship to be its own best lifeboat (SOLAS amendments, entered into force for newbuilt ships after 1 July 2010). Passengers and crew should normally be able to evacuate to a safe area on board and stay there. In addition, a ship might be able to proceed to port at a minimum safe speed. But sometimes there are extreme cases, e.g., the ship is sinking, about to drift towards the shore, there is a serious and immediate risk for the passengers and crew coming from a large fire, where abandonment of the ship is unavoidable.

According to International Code for Safety Management (ISM), Shipping Companies[1] are required to provide shoreside support in shipboard emergency situations; the Safety Management System (SMS) should include measures ensuring that organizational structure can respond at any time to hazards, accidents and emergency situations involving its ships. The shore-based emergency response acts as an advisory body to the Master and any on-site company representatives. Its main role is to support and assist the Master and the crew of the ship. It also liaises and provides relevant information to the authorities, the emergency/rescue services, the families of the passengers, the environmental/pollution agencies, the Flag, the P & I Club, the insurance company, the classification society, the local agent, the press, etc.

3.1.2 Evacuation management

When the alarm sounds, the second stage of the evacuation process begins, which is the evacuation management. This stage includes possible actions to mitigate damages and to locate all the passengers. In emergency situations, there is an increased likelihood of passengers panicking. The crew’s training is a key factor for the success of this stage. Crew members should take control, mitigate the panic, act quickly and calmly, keep the passengers in order and help them find their way to the muster stations.

The complexity of this stage gets even harder when considering that most of the passenger ships have rambling layouts, identical corridors and confusing layout diagrams (Stefanidis et al., 2019). The localization of passengers, especially of children, elderly and disabled people

[1] According to the definition provided by ISM, “company means the owner of the ship or any other organization or person such as the manager, or the bareboat charterer, who has assumed the responsibility for operation of the ship from the shipowner and who, on assuming such responsibility, has agreed to take over all the duties and responsibility imposed by the Code”.

is a challenge. When the alarm sounds every passenger must go to the muster stations, so every possible space of the ship must be checked for missing people, especially cabins. This is done by specially-trained crew members and it is a time-consuming process.

3.1.3 Passenger mustering and preparation for disembarkation

The main evacuation process starts with the Master's decision (or his/her substitute, if the Master is incapacitated) to proceed with passengers' assembly to the muster stations. Normally, a dedicated alarm signal (at least 7 short blasts followed by one long on the ship's whistle or siren and additionally on an electrically operated bell or klaxon or other equivalent warning system) will be triggered, along with a verbal announcement from the ship's public address system. The sounding of the alarm does not mean evacuating the ship directly. It means that the crew members must report to their stations, establish communication with the bridge, and prepare for their duties according to the muster list[2]. It also means that all the passengers must immediately proceed to their muster/assembly stations.

During the mustering/assembly stage, a series of crew actions concerning evacuation is executed. The life-saving appliances of the ship (lifeboats, life rafts, marine evacuation systems, etc.) are prepared for launching and deployment according to specific procedures and instructions. The crew members should be aware of the suitable muster station according to the location of the passengers and the safest route to reach it. One of the most challenging difficulties would be to adapt the route to mustering stations if parts of the ship are heavily damaged or dangerous to go through. The internal communication and constant updates from and to the bridge are issues of major importance. The guidance of the crew and from the signs on board must be as simple as possible.

The movement of the passengers towards the muster stations is assisted by dedicated crew members, who are functioning as guides in predefined positions (e.g. stairways, corridors, etc) according to the evacuation plan of the ship. Other crew members are searching the cabins and other public spaces to make sure no passenger is left behind. The sweeping process for the cabins and public spaces is systematic; it follows a specific predefined plan and a special procedure is applied by the crew. In the muster stations, crew members are assigned to counting the passengers, distributing lifejackets to them, assisting them with life-jacket donning, briefing them regarding the situation, etc. Depending on the ship type and procedures, the passengers need to don lifejackets either collected from their cabins or at the muster stations (Pospolicki, 2017). If any passenger is missing and the tally does not add up, the crew will initiate search and rescue actions. The safety of the crew is a priority as well. Thus, search and rescue of any missing crew member will also be performed.

In addition, there are provisions for the rescue of special social groups and crew members should be trained accordingly. Dedicated crew members are assigned to assist disabled people or passengers requiring special assistance (as per list on the bridge) to reach their muster stations. These groups are identified during registration; a special plan is created for them and crew members are assigned with the duty to help them.

3.1.4 Ship abandonment, boarding and launching of survival crafts

After mustering to the assembly stations, crew and passengers are waiting for the abandonment order. The abandonment order is only given by word of mouth from the Master.

[2] In case of emergency, the ship's staff is divided into several interdependent teams, each of which performs a specific function. The function is described in the muster list and the emergency plans/procedures/instructions of the vessel.

If the Master's decision is to abandon the ship, then the next stage of the evacuation process is initiated. In this phase, passengers and crew move to the embarkation stations in a controlled manner (as a group) and await further orders or embark directly into the lifeboats without waiting for the full assembly of all the passengers in each embarkation station (i.e., to save time). After maximum capacity has been reached, the survival crafts are launched from the deck level to the water. According to the SOLAS requirements, the maximum duration of the embarkation and launching stage is 30 minutes (SOLAS, Ch. III, Reg. 21.1.3).

Some factors may delay the progress, such as heavy weather, ship rolling, darkness (if the evacuation takes place at night), boarding of injured, elderly and disabled people, etcetera. According to Pospolicki (2017), albeit, for example, injured people might be granted priority during embarkation, selective embarkation will most probably prolong the process. In addition, accounting of all passengers is crucial because after the survival crafts have been launched it is very difficult to retrieve passengers remaining onboard.

The main engine(s) and propeller(s) will be stopped. Overboard discharges will also be stopped especially in way of craft launch areas. Life-saving appliances will only be launched/deployed upon the order of the Master or his/her substitute. Normally, an announcement from the ship's public address system will be made, and a dedicated alarm signal will be sounded. Only thereafter, embarkation to the survival crafts is performed, life-saving appliances are deployed, and the passengers and crew leave the vessel using various means (by lowering the lifeboat, going down a slide or chute, climbing down a ladder, etc.). The lifeboats will be launched as close as possible to their maximum capacity and as fast as the situation allows, following a specific launch sequence/pattern to avoid accidents, such as lifeboat collision. The sequence of lifeboat launching will be monitored and controlled by the Master and dedicated crew members.

At lifeboat or life raft or Marine Evacuation Systems (MESs) stations, each crew member will complete his/her assigned tasks as per the muster list. Among these tasks is providing the lifeboats with emergency communication, positioning and detection equipment, i.e. handheld VHF radios (walkie-talkies), Emergency Position-Indicating Radio Beacons (EPIRBs), portable Global Maritime Distress Safety System (GMDSS) VHF radios, Search and Rescue Radar Transponders (SARTs), etc. If time permits, additional useful items, i.e. blankets, food, drinks, etc. can be supplied to the lifeboats, and a final headcount will be undertaken before the lifeboat is lowered to the water, and the number of passengers inside the lifeboat will be reported to the Master.

3.1.5 Clearing from the ship and waiting for rescue

The final stage of the evacuation process is the clearing of the ship and waiting for rescue. After launching, lifeboats manoeuvre clear of the ship's side and any floating obstructions, which may damage their hull, by using their engine (or oars if their engine fails to start). Lifeboats should remain in the vicinity of the vessel, marshal other survival crafts (e.g. life rafts) and tow them away from the ship. Once lowered to the water, all Life Saving Appliances (LSAs) should immediately get to a safe distance from the ship and assemble to facilitate the Search and Rescue (SAR) operation or sail towards the nearest safe haven. The area near the ship is considered a dangerous zone due to possible oil spills or the potential capsizing of the ship. As the LSAs assemble, the crew must also search for survivors in the water. According to Pospolicki (2017), this stage of the evacuation process does not follow standardized procedures and the passenger are typically rescued by nearby ships (e.g. other passenger ships, cargo ships etc.), maritime rescue boats and helicopters. It must be noted that rescuing people (sometimes thousands of them) unfamiliar with the sea, crowded into lifeboats and liferafts, presents a unique search-and-rescue challenge.

3.2 Human behaviour in emergency situations

Ship evacuation can be compared with the evacuation processes in buildings as both are closed environments - but with different geometry. However, e.g. flowrates through exits and walking speeds depending on the number of persons per square metre (P/m^2) are simply the same. Further, the process starts in both locations with the response to an alarm, then people are prompted to assemble before exiting. Since the field of ship evacuation is not as well explored as the evacuation ashore, this section makes also use of findings of evacuation ashore and especially of buildings (e.g. in the case of fire).

Behaviour of humans in emergency situations can be erratic and unpredictable and human response may be analysed in the following stages: notification, cognition and activity. Each stage is accompanied by its own complex bundle of behaviour. So, not all individuals will respond to alarms in the same way and furthermore, it is unlikely that one individual would respond two times in the same way.

For the sake of illustration, we summarize some of the findings gathered in the literature among these publications: Brown (2016) cited Ozel's (2001), Brennan's (1997), Proulx's and Fahy's (1997) and Purser's and Bensilum's (2001).

- Females tended to respond more quickly than males.
- People who received emergency training respond sooner than others.
- The education level has no effect on the response time.
- Older persons needed more time for responding and took a long time to prepare to evacuate.
- Nearly one third was asleep and did not wake up for the alarm; some woke up and fought to go back to sleep, despite the alarm.
- Hearing the alarm adequately shortens the response time.
- The type of notification has an impact on how people respond.
- Awake and dressed people can start the evacuation movement sooner.

Notification Phase

In the initial phase, the notification, the response to an alarm depend on awareness, experience and knowledge (what does the alarm means, what behaviour and action is required and how familiar am I with the environment). Additionally, the complexity of behaviour is given by other stimuli. The notification stage ends with a physically and/or mentally disengaging from what they were doing and recognizing that the situation changed into an unusual happening.

Cognition Phase

People begin to interpret and process the information given by the notification and other cues in a row, by other persons nearby and/or instructions given by crew members as they decide how to respond. Galea et al. (2010) described three types of behaviour in this phase:

- Cues are insufficient and situation is not clear. People might ignore them and go on with their current activities until an unambiguous cue reach them. Then, people will react with one of the two following behaviours.
- Cue is acknowledged by people and therefore the reaction is stopping the current activity and starting with the evacuation movement. This marks the end of the response phase and the start of the evacuation movement.
- Individuals perceived a clear cue that is also acknowledged but react with actions like information gathering (and therefore social interaction). With this behaviour the activity phase is started.

Activity Phase

This phase starts after the acknowledgement of an evacuation cue with the setting of reactions. In this phase all information tasks and actions before starting the evacuation movement are completed.

The response time depends on several factors: the clearness and acknowledgement of the evacuation cue, the behaviour of people as reaction, the interaction between the individuals, the environment as well as how quickly they move.

Poole and Springett (1998), cited in Brown (2016), developed the following eight fallacies regarding human behaviour in emergency evacuation:

1. Individuals start to move as soon as they hear an alarm. Passenger response time is an important aspect of evacuation behaviour that must be better understood.
2. Motivation to escape underpins any movements or actions a person may carry out. Passengers will often continue with their pre-alarm activity and not attempt to “help themselves”. This was witnessed numerous times during the sea trials undertaken in the research of Brown (2016) and often passengers were reluctant to do anything unless told to do so by a crew member.
3. Time to evacuate depends only on the time it takes to move to and through an exit.
4. People are likely to move toward the exit to which they are nearest. Often passengers will take a known route to get where they need to go rather than the shortest. This was observed numerous times throughout the trials, carried-out by Brown (2016), in which passengers sometimes moved from one assembly station to a more distant one.
5. People move as individuals without considering others. The presence of a crowd impacts a person’s movement and passengers will often attempt to help other passengers. Furthermore, in dense crowds, people are often forced to move with the crowd rather than chose their own path. Family units tend to move as family units rather than alone.
6. Signage helps ensure people find a route to safety, however, anxiety and narrowed attention often means peripheral cues go unnoticed. One example, provided by Brown (2016), was that passengers wait significant periods of time in congested areas trying to reach an assembly station, rather than simply following the signs to a different assembly area, which was completely uncongested.

7. All people involved are equally able to physically move to an exit. Elderly people observed often required assistance on stairs, people in wheelchairs had to use elevators. Effects of alcohol will impair an individual's motor skills and individuals with less experience on ships will tend to be less stable moving about.
8. People will not necessarily be safe because they will panic. While a powerful concept, the term panic is often used inaccurately in the context of evacuation where people do not necessarily enter a sudden state of uncontrollable anxiety or irrational behaviour.

Human behaviour in Ship Evacuation

Passenger ship evacuation displays unique characteristics that make it quite different than evacuation from other domains, such as airplanes and buildings (Papanikolaou, 2009). Some of these characteristics are listed in Table 1 (Stefanidis et al., 2019; Vassalos et al., 2002).

Table 1: Differences in evacuation among the maritime, aviation, and building domains.

	Maritime	Aviation	Buildings
Geometry	Complex (diverse general arrangements, identical corridors)	Relatively simple	Complex, but relatively steady motions
Evacuation routes and mustering	People must be equipped with lifejackets. Disembark via very unfamiliar methods such as getting into lifeboats, life rafts and possibly evacuation slides or chutes	People must be equipped with lifejackets	Head for the nearest exit point and then to street level
Environment	The passengers move from one high-risk area to another high-risk and unfriendly environment		Evacuation on dry land-based scenarios means escaping to safety

The particularities of maritime evacuation have a major effect on the behaviour of passengers. Geometrical complexities and ship motions lead to disorientation and confusion of passengers and reduces their mobility. In addition, complex evacuation routes and mustering procedures are likely to exacerbate panic and generally unpredictable behaviour. This unpredictability is further magnified due to the awaiting unfriendly sea environment.

Brown (2016) stated that the research on ship evacuation focuses on the assembly and boarding process. The evacuation process can only be successful, if the required evacuation time is shorter than the available evacuation time, that is determined by that point, when it will not be possible no longer to launch survival crafts that have enough time to sail away to a safe distance from the ship (depending on ship stability).

Crew members

Crew members are very important for the success of the evacuation process. They must be well-trained, experienced (to the extent possible) and always alert and ready to face the worst-case scenario. In an evacuation, they should act calmly and quickly, report to the bridge and guide the passengers. They should be in control during all the stages of the process. There are different teams for each kind of incident (e.g., fire team). In case of an incident, each team should report and try to deal with the situation without alarming the passengers, but if the situation seems to get out of control they should be informed immediately.

The group of crew members is usually, like the passengers, multinational and consists of seafarers, on board hotel-staff, restaurant-staff and entertainers, while the non-seafarers crew members are heavily outnumbering the number of qualified seafarers.

Crew members' responsibilities and tasks in an evacuation situation depend on training, experience and rank on board. Incidents in the past have shown the importance of fulfilling the assigned responsibility to avoid unclear and counterproductive instructions and thus an ineffective or incomplete evacuation with a drastically expanded required time of evacuation and chaos (Brown, 2016).

In an emergency case, crew members who are not active seafarers are at least those who are the contact persons and who must deal with passengers one-on-one, since the trained seafarers are busy with technical issues, like operating with technical equipment, firefighting, preparing and launching the live-saving appliances (Poole and Springett, 1998).

One speciality of crew members is that they may need to move along evacuation routes in a direction opposite to the movement of passengers (IMO, 2014) to fulfil their responsibilities. This needs to be reflected in the sense of space requirement, walking speeds and following in ship architecture and design.

Passengers

On ships a huge number of persons need to be evacuated in an emergency case. SOLAS (IMO, 2014) defined "passengers" as "persons on ships by excluding the Master, crew members and persons employed or engaged on the ship (e.g. restaurant employees)".

Unfortunately, passengers on ships are not a homogenous group: passengers are multinational, multicultural and speak diverse languages – even English as global lingua franca will not be spoken and understood by all passengers. Furthermore, the following factors have an effect on the required time in an evacuation process and need to be taken into account: age, gender, current activity, awake/asleep, dressed/undressed, adults with or without children, mobility impairments, cognitive impairments, under the influence of e.g. medication, alcohol, neighbours (interaction and influence), behaviour under stress ("stress resistant").

Usually passengers are inexperienced in the situation of a needed evacuation. Additionally, in most cases their training will be limited to the drills conducted during the current cruise and during cruises done before: for voyages with a duration of 24h and more IMO recommends (since the Costa Concordia-disaster in 2012) to conduct assembly exercises before the ship leaves the port and after each embarkation (Brown, 2016).

Passengers' response to alarm

Several definitions are used; in the FP7-project SAFEGUARD[3] the response time is defined as the time between the sounding of the alarm and the moment when passengers start purposeful movement to an assembly station - even if first cues may be noted before the alarm was given (IMO, 2012).

The response time of passengers play a significant role in how efficiently the assembly process is completed (Brown, 2016, p. 15): an early response would mean that the assembly can be completed (IMO, 2014) earlier, but in the case all passengers react in the same time delays could be occur because of a high person density on the routes. Therefore, the response time distribution has a significant impact on the total evacuation time (Spearpoint, 2004). One of the results of the experiment carried out and described by Brown (2016) is, that the response time in cabin areas differs to response time in public areas. Moreover, it is suggested that different response time distributions should be used for different ship types (ibid.). Besides, it is assumed that the response time depend on the signal and the alarm system. As the response time in evacuation processes in buildings is significant shorter if the alarm is clear, it is recommended to add announcements to the different alarms existing on board (e.g. for fire, man overboard, evacuation). Therefore, also laypersons would be able to classify the heard alarm correctly without any doubts.

Assembly/Mustering

As assembly is the phase after the individual's response known and includes the beginning of the movement to and assemble at the assembly stations, which are predefined as save places on board near lifesaving appliances (including their counting; further instructions given to passengers). On ships – unlike on buildings - the evacuation routes lead them downward and upward and additionally the ship is in motion (rolling, pitching, heaving and combinations of these). In the case the ship is damaged or laying on its side evacuation routes could be cut. It must be taken into account, that all these factors may cause disorientation during the movement phase. Further, several experiments of research indicate that the walking speed decreases for trim angles in the upward as well as the downward direction – these results need to be proven in further research as they were measured when using a mock up (controlled environments do not take the psychologic aspect during an emergency case into account) or conducted the experiment with participants who did not display the group of passengers.

To avoid expanding the required time of assembly ineffectively, the architecture of ships must support flowrates to lead passengers from their initial position to the assembly areas as fast as possible. The other way around, this means for evacuation routes that e.g. bottlenecks must be avoided. In addition, also the interior – especially in the areas where evacuation routes could be - must be taken into account to avoid an expanded assembly time, e.g.: some floor coverings are more slippery than others and furniture should not hinder passengers' and crew members' ways.

[3] https://fseg.gre.ac.uk/fire/safeguard.html

Donning of lifejackets

The research and its results in the field of donning the lifejackets in ship evacuation seems not to be saturated at all. Therefore, mainly educated considerations can be presented in this section.

On board lifejackets are usually deposited in the passengers' cabins as well as in public areas, especially at assembly stations. For children it must be taken into account that special lifejackets must be used and therefore also must be on hand in sufficient quantities.

In an emergency case, two procedures seem to be living practices: on the one hand passengers are obliged to don the lifejackets (or at least take them with them) when starting their movement from their cabins to the assembly station and, on the other hand, it is foreseen that lifejackets are distributed at the assembly stations.

However, the donning of lifejackets was quantified in a research within the project FIRE EXIT (see Section 6.1), cited by Brown (2016). It showed that the required time to don a lifejacket has a lognormal distribution with a mean of 38,5 ± 11,8 s.

Ship abandonment

The aim is getting people off the ship and move clear of the immediate hazard (Brown, 2016) by preparing, boarding, and launching the survival craft. The SOLAS Convention (IMO, 2014) recommends a maximum duration of this process of 30min - with full complement of persons and equipment. As Brown (2016) elaborated, results of the project FIRE EXIT (see Section 6.1) showed that – when using slides and vertical chutes for abandonment - males tend to be faster than female and trained persons are more than twice faster than untrained.

The following points are a summary of the identified challenges relating to human behaviour in a maritime evacuation situation:

- Huge number of untrained persons in need of being evacuated.
- Maybe inclement weather conditions.
- Abandonment of survival craft is an uncertain process.
- "What then" after a successful abandonment (Brown, 2016).

3.3 Onboard evacuation procedures

According to Clause 1 of the IMO ISM Code (IMO, 1993), Shipping Companies should develop, implement and maintain a Safety Management System (SMS), which must include, among other functional elements, emergency preparedness. This forms the reactive pillar of the SMS; since emergencies cannot be entirely controlled, either through design or through normal operational procedures (which is the proactive pillar of SMS). Clause 8 of the IMO ISM Code stipulates that Shipping Companies should identify potential emergency shipboard situations and establish procedures to respond to them. Moreover, they are required to provide shoreside support in shipboard emergency situations. For these procedures and measures to be effective, programs for drills and exercises to prepare for emergency actions should be established.

Shipping companies have contingency plans in place for shipboard emergencies. The objective of these plans is to ensure that the Master, the officers and the crew of the ship can respond to emergency situations efficiently and effectively. These plans should provide clear and unambiguous instructions and guidance, to manage the emergency, gain control over the situation, and avoid or minimize the risk to human life, marine environment, and property.

Moreover, the duties and responsibilities of the crew members are described in the muster list of the vessel. Plans and procedures for ship abandonment are included in these contingency plans.

It should be emphasized that, according to Clause 5.2 of the ISM Code, the Master of the ship has the overriding authority and the responsibility to make and exercise decisions with respect to safety at sea, prevention of human injury or loss of life, and avoidance of damage to the environment, and to property. Thus, in an emergency, he/she has the responsibility to act promptly according to his professional judgment of the overall circumstances. It is also his responsibility to activate the shore emergency response whenever required.

Evacuation plan

Ship specific and flag/classification society approved evacuation/escape plan/drawing/routes is developed during the design phase of the ship to ensure the safest and most efficient evacuation of passengers and crew. Flags/Classes stipulate specific requirements for these plans. A passenger ship evacuation plan can be based on the ship's general arrangement plan. The plan includes generally the compartments and their functions, muster stations, embarkation stations, main evacuation routes, alternative evacuation routes, doors including opening directions, stairs, ladders, lifesaving appliances, etc.

It should be noted that the passenger assembly areas can be directly adjacent to the point where the passengers will embark on a lifeboat or enter an escape slide or chute of a Mass Evacuation System (MES). In this case, the muster stations are also functioning as embarkation stations, but adequate deck space is required. Frequently, muster stations are not close to the evacuation system; it is more convenient to muster passengers or crew in a large, protected space.

Normally, the evacuation plan(s) must be accompanied by a study describing the evacuation analysis performed to produce and optimize the plan. SOLAS and the flags/classification societies provide specific requirements for the analysis (see Section 3.2).

Life-jackets distribution

Different procedures are followed for the distribution of life jackets to the passengers. For example, in some cases, the lifejackets are distributed to passengers solely in the muster or embarkation stations. In other cases, passengers who are already in their cabins, collect the lifejackets from there and evacuate. The rest of the passengers (i.e., passengers without cabins, or passengers who are not in their cabins when the alarm sounds) will be handed a lifejacket in the muster or embarkation stations by the crew. To avoid congestion problems (from passengers moving towards the opposite direction than the evacuation route), passengers who are not in their cabins when the alarm sounds, are instructed to proceed directly to their muster stations. Notably, the second strategy requires that there will be enough lifejackets stored in the muster stations. One measure to increase the availability of lifejackets in the muster stations is the collection of unused lifejackets from the cabins by the searching crew teams and their transferring to the muster stations. Nevertheless, the following points regarding lifejackets must be noted:

- SOLAS as well as flag State regulations, provide minimum requirements for the specification, type, number, position and distribution of lifejackets for the passengers and the crew.

- Cruise Lines International Association (CLIA), the world's largest cruise industry association, has adopted a policy of carrying additional adult lifejackets onboard each cruise ship in excess of the number required by SOLAS[4]. 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. Some smaller oceangoing cruise ships may be constructed with only one main vertical fire zone that is utilized for accommodation spaces. For these vessels, CLIA's policy is that the maximum number of excess lifejackets provided need not exceed fifty percent of the total number of persons carried by the vessel. Extra lifejackets for children in excess of legal requirements, in a number equal to 10% of the number of passengers berthed within the most populated main vertical zone, must also be carried on international voyages under this policy.
- Life-jacket distribution is a time-consuming activity in a process with sometimes severe time constraints imposed.

3.4 Specialized safety and emergency training of crew members on passenger ships

Onboard passenger ships, the human element plays a vital role in ensuring passenger safety and the success of the evacuation process. IMO regulations in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) require seafarers and other personnel working on passenger ships to have specific safety and emergency training, as per MSC.416(97) and MSC.417(97). The STCW Code stipulates mandatory minimum requirements for the training and qualification of Masters, officers, ratings and other personnel on passenger ships engaged on international voyages. These requirements can be extended to personnel serving on passenger ships by the Administrations.

Before being assigned to shipboard duties, personnel providing direct service to passengers in passenger spaces must receive additional safety training as required by the respective regulation of STCW. This training must ensure the attainment of abilities such as:

- the ability to communicate with passengers during an emergency,
- the ability to demonstrate to passengers the use of personal life-saving appliances,
- the ability to embark and disembark passengers, with special attention to disabled persons and persons needing assistance.

Furthermore, Masters, officers, ratings, and personnel designated on the muster list must have successfully completed crowd management training before being assigned to shipboard duties. The training must ensure that the personnel involved will be competent to contribute to the implementation of the shipboard emergency plans and procedures to muster and evacuate passengers.

Additionally, any person designated on the muster list as having responsibility for the safety of passengers in emergency situations must have successfully completed an approved crisis management and human behaviour training. The training must ensure the acquiring by the participants of the following competencies as a minimum:

- the ability to organize shipboard emergency procedures,
- the ability to optimize the use of resources,

[4] https://cruising.org/about-the-industry/policy-priorities/clia-oceangoing-cruise-line-policies/operational-safety

- the ability to control response to emergencies,
- the ability to control passengers and other personnel during emergency situations,
- the ability to establish and maintain effective communication.

Onboard emergency training and drills

According to the ISM Code, Shipping Companies should establish programmes for drills and exercises to prepare for emergency actions. As IMO suggests in Resolution A.1072(28) (IMO, 2013), any system of contingency planning for shipboard emergencies should provide for emergency training and education of shipboard personnel, to develop general awareness and understanding of actions to be taken in the event of an emergency. For the emergency preparedness system to be effective, all crew members must know in advance what their duties and responsibilities are and to whom they are to report under the plans.

The system of emergency training and education of shipboard personnel should include procedures, programmes or activities developed to:

- familiarize shipboard personnel with the provisions of the system and plans.
- provide training for shipboard personnel about the system and plans, especially for personnel transferred to new assignments.
- schedule regular drills and exercises to prepare shipboard personnel to deal with potential shipboard emergency situations.
- coordinate the shipboard personnel and the shipping company's actions effectively and include and take note of the aid which could be provided by external emergency coordinating authorities.
- prepare a workable feedback system. Feedback is essential for refining emergency response plans and emergency preparedness based on the lessons learned from previous exercises, accident investigations or real emergencies.

SOLAS stipulates requirements regarding emergency training in Chapter III, Part B, Regulation 19. Specific requirements for passenger ships are also specified in Regulation 30. The key points of these requirements are the following:

- An abandon ship drill must take place weekly. The weekly drill does not need to involve the entire crew, but each crew member must participate in an abandon ship drill each month. Passengers must be strongly encouraged to attend these drills. The drills of the crew must take place within 24 h of the ship leaving a port if more than 25% of the crew have not participated in abandon ship and fire drills on board that particular ship in the previous month. When a ship enters service for the first time, after modification of a major character or when a new crew is engaged, these drills shall be held before sailing. The Administration may accept other arrangements that are at least equivalent for those classes of ships for which this is impracticable.
- Drills shall, as far as practicable, be conducted as if there were an actual emergency.
- Every crew member with assigned emergency duties shall be familiar with these duties before the voyage begins.
- On a ship engaged on a voyage where passengers are scheduled to be on board for more than 24 h, musters of newly embarked passengers shall take place prior to or immediately upon departure. Passengers shall be instructed in the use of the lifejackets and the action to take in an emergency.

Whenever new passengers embark, a passenger safety briefing must be given immediately before departure, or immediately after departure. The objective of this briefing is to inform the passengers of their muster station, the essential actions they must take in an emergency, and the method of donning lifejackets. The safety briefing must be made by means of an announcement, in one or more languages likely to be understood by the passengers. The announcement must be made on the ship's public address system, or by other equivalent means likely to be heard at least by the passengers who have not yet heard it during the voyage. The briefing may be included in the muster of newly embarked passengers prior to or immediately upon departure. Information cards or posters or video programmes displayed on ships video displays may be used to supplement the briefing but may not be used to replace the announcement.

Each abandon ship drill shall include:

- summoning of passengers and crew to muster stations with the alarm required by regulation followed by drill announcement on the public address or other communication system and ensuring that they are made aware of the order to abandon ship.
- reporting to stations and preparing for the duties described in the muster list.
- checking that passengers and crew are suitably dressed.
- checking that lifejackets are correctly donned.
- lowering of at least one lifeboat after any necessary preparation for launching.
- starting and operating the lifeboat engine.
- operation of davits used for launching liferafts.
- a mock search and rescue of passengers trapped in their staterooms.
- instruction in the use of radio life-saving appliances.

Different lifeboats must, as far as practicable, be lowered at successive drills. Each lifeboat shall be launched, and maneuvered in the water by its assigned operating crew, at least once every three months during an abandon ship drill. Exceptions to this requirement are provided for free-fall lifeboats and for ships operating on short international voyages. As far as is reasonable and practicable, rescue boats other than lifeboats which are also rescue boats, shall be launched each month with their assigned crew aboard and maneuvered in the water. In all cases, this requirement shall be complied with at least once every three months.

If a ship is fitted with MESs, drills shall include exercising of the procedures required for the deployment of such a system up to the point immediately preceding actual deployment of the system. This aspect of drills should be augmented by regular instruction using the on-board training aids. Additionally, every system party member shall, as far as practicable, be further trained by participation in a full deployment of a similar system into water, either onboard a ship or ashore, at intervals of no longer than two years, but in no case longer than three years. This training can be associated with the rotational deployments, in addition to or in conjunction with the servicing intervals.

Virtual Reality (VR) and Augmented Reality (AR) training initiatives

Recent events in the maritime industry have prompted shipping companies to become more proactive towards staff safety training, therefore effective means to develop and implement comprehensive training requires close to reality simulation. If, though simulators are not always available or cost effective and only cover a narrow spectrum of scenarios, VR and AR training contributes significantly to the resolution of key maritime changes (SAFETY4SEA, 2018). “With VR the training becomes visual: the learning process mimics real-life experiences by visualizing the tasks. It is also a safe place to practice complex situations. The cost of education becomes cheaper based on learning groups, the education frequency and the education place.” (Markopoulos et al., 2019). Clearly the augmented and virtual technologies have their own advantages but can also bring some challenges to a project that involves training and learning. The following Table 2 and Table 3 show a SWOT analysis that aim to identify the benefits but also some of the challenges of using such technologies for training purposes.

Table 2: SWOT Analysis of VR technologies for Staff Training.

Strengths	**Opportunities**
• Highly accurate depiction of complex realistic scenarios (Ginnis et al., 2010) • Immersive and interactive learning environment where the training becomes visual (Markopoulos et al., 2019) • Improves knowledge retention • Reduce dependency on field visits • Safe training environment of dangerous scenarios • Cost effectiveness	• It can improve students' learning interest • It does encourage active learning • VR Training technologies are becoming more mature and affordable • Training scenarios content could be updated and maintained relatively easily • Transfer of findings from other domains and industries • Increase in graphical fidelity
Weaknesses	**Threats**
• VR training modules and scenarios can take large amount of resources • Technology barrier • Lack of mature multi-user fidelity	• Incremental costs especially for updating and maintaining the content (Azhar et al., 2018) • Uncertain skill transfer without additional testing platforms • Potential adverse effects with implications on the overall learning effect and experience

Table 3: SWOT Analysis of AR technologies for Staff Training.

Strengths	**Opportunities**
• Just-In-Time (JIT) information delivery for training purposes • Not as immersive as VR, thus less fatigue or adverse effects • Data recording and analysis of training • Easy to integrate real time communication between trainer and trainee (Butkiewicz and Stevens, 2020) • Better coordination of senses, for the training purpose • Intuitive to use • Efficiency and effectiveness of training with blended or traditional learning (Cowling et al., 2016) • Contextual information (Lee, 2012)	• It can improve students' interest in exploring various scenarios • It does encourage active learning • Mature technology with good prospects • Real time students feedback and training improvement (Vasiljević et al., 2011) • Training scenarios content could be relatively easy updated; maintained or enriched • It covers a wide array of types of learning (collaborative, experimental, sensory) • Increase in graphical fidelity • Industry 4.0 data elements can be integrated (Fraga-Lamas et al., 2018) • Real-time training applications
Weaknesses	**Threats**
• For maximum efficiency, AR requires field visits or high-fidelity mock-ups • Cost can increase for some high-end features or optional • Connectivity issues can affect the experience	• Incremental costs especially for updating and maintaining the content • Possible technological errors (GPS and location, overlapping realities accuracy, etc)

3.5 Evacuation analysis and planning methodologies

Passenger ship evacuation is a very complex process. Consequently, modelling of passenger ship evacuation is significantly more complex than modelling of airplane or building evacuation. Although there are common elements in the simulation of passenger evacuation equally applicable to ships, airplanes or buildings, there are procedural, human behaviour and environmental factors that constitute conventional evacuation software, developed for other industries, unsuitable for marine emergency evacuation. The following points regarding the modelling of passenger ship evacuation are worthy of note (Stefanidis et al., 2019; Vassalos et al., 2002):

- Evacuation at sea often involves a very large number of people as in the case of Ro-Ro passenger ships or ultra-large cruise ships. This presents a modelling problem in terms of macroscopic and microscopic movement of people, processing capacity and information handling.
- There is a multitude of evacuation scenarios that need to be considered due to e.g. the range of possible incidents (fire, collision, flooding, cargo shift, etc.).
- It would be sub-optimal to model the evacuation stages (mustering, embarkation, launching of life saving appliances, etc.) separately or sequentially. A holistic approach is necessary to understand the evacuation process in ships and to properly model and analyse it for design, operational and regulatory purposes.

3.5.1 Evacuation analysis as an IMO requirement

In the wake of tragic accidents such as the sinking of the Herald of Free Enterprise and Estonia, the International Maritime Organization (IMO) introduced in 1995[5], as a mandatory provision of SOLAS, the evacuation analysis of Ro-Ro passenger ships constructed on or after 1 July 1999 at an early stage of design. This requirement has been extended to other passenger ships with Resolution MSC.404(96), which was adopted on 19 May 2016 by the Maritime Safety Committee (MSC) of IMO as an amendment to SOLAS. According to this amendment, escape routes of passenger ships (other than Ro-Ro passenger ships) constructed on or after 1 January 2020 carrying more than 36 passengers, shall also be evaluated by an evacuation analysis early in the design process (SOLAS Part II-2, Regulation 13, Paragraph 3.2.7.1).

The objective of the evacuation analysis is provided by SOLAS in Part II-2, Regulation 13, Paragraph 3.2.7.2.:

"The analysis shall be used to identify and eliminate, as far as practicable, congestion which may develop during an abandonment, due to normal movement of passengers and crew along escape routes, including the possibility that crew may need to move along these routes in a direction opposite to the movement of passengers. In addition, the analysis shall be used to demonstrate that escape arrangements are sufficiently flexible to provide for the possibility that certain escape routes, assembly stations, embarkation stations or survival craft may not be available as a result of a casualty."

[5] Resolution 1 of the 1995 Conference of Contracting Governments to the International Convention for the Safety Of Life At Sea, 1974.

3.5.2 IMO evacuation analysis framework (MSC.1/Circ.1533)

The framework for the evacuation analysis is provided by IMO. MSC, at its ninety-sixth session, in May 2016, approved the MSC.1/Circ.1533 - "Revised guidelines on evacuation analyses for new and existing passenger ships", as a guide for the implementation of amendments to SOLAS Regulation II-2/13.3.2.7.

Some key elements of these guidelines are the following:

- The guidelines offer the possibility of using two distinct methods: a simplified evacuation analysis, and/or an advanced evacuation analysis.
- The aim of the analysis, as stipulated by the circular itself, is to assess the performance of the ship with regard to the benchmark scenarios and relevant data specified in the guidelines, rather than simulating an actual emergency.
- Although the approach presented in the guidelines is sufficiently developed to deal with realistic simulations of evacuation on board ships, there is still a shortfall in the amount of verification data and practical experience on its application.
- Almost all the data and parameters provided in the guidelines are based on well-documented data coming from civil building experience. Nevertheless, as the guideline emphasizes, the simulation of these benchmark scenarios is expected to improve ship design by identifying inadequate escape arrangements, congestion points and optimizing evacuation arrangements.
- It is also to be noted that the acceptable evacuation durations in these guidelines are based on an analysis of fire risk.

The analysis methods presented in the guidelines are based on the following assumptions:

- passengers and crew will evacuate via the main escape route towards their assigned assembly station, as referred to in SOLAS Regulation II-2/13.
- passenger load and initial distribution are based on Chapter 13 of the International Code for Fire Safety Systems (FSS Code).
- full availability of escape arrangements is considered, unless otherwise stated.
- assisting crew will immediately be at the evacuation duty locations ready to assist the passengers.
- smoke, heat and toxic fire products are not considered to impact passenger/crew performance.
- family group behaviour is not considered.
- ship motion, heel, and trim are not considered.

Performance standards

The guidelines require specific performance standards for the evacuation system. These standards, as illustrated in Figure 2, are related to the calculated total evacuation duration and should be as follows:

$$1.25\,(R+T) + 2/3\,(E+L) \leq n \qquad (1)$$

$$(E+L) \leq 30 \text{ min} \qquad (2)$$

Where:

- Response duration (R) is the duration it takes for people to react to the situation. This duration begins upon initial notification (e.g. alarm) of an emergency and ends when the passenger has accepted the situation and begins to move towards an assembly station.

- Total travel duration (T) is the duration it takes for all persons on board to move from where they are upon notification to the assembly stations.
- Embarkation and launching duration (E+L) represent the overall duration required to provide for abandonment by the total number of persons on board, starting from the time the abandon ship signal is given after all persons have been assembled, with lifejackets donned.
- The total evacuation duration (n) depends on the type of ship. For ro-ro passenger ships, n = 60 min; and for passenger ships other than ro-ro passenger ships, n = 60 min if the ship has no more than three main vertical zones; and 80 min, if the ship has more than three main vertical zones.

Performance standard (2) complies with SOLAS regulation III/21.1.3, which specifies that "all survival craft required to provide for abandonment by the total number of persons on board 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 after all persons have been assembled, with lifejackets donned".

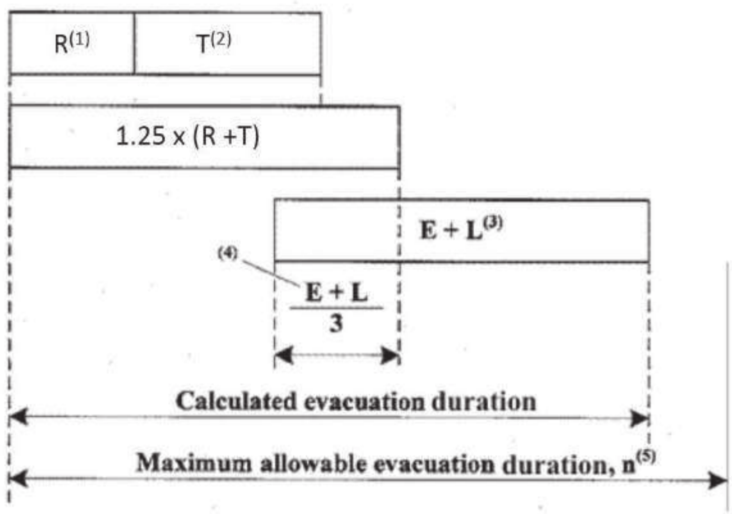

Figure 2: Evacuation performance standards as provided by MSC.1/Circ.1533.

Embarkation and launching duration E+L should be calculated separately based upon:

- results of full-scale trials on similar ships and evacuation systems.
- results of a simulation-based embarkation analysis.
- data provided by the manufacturers. However, in this case, the method of calculation should be documented, including the value of correction factor used.

The embarkation and launching duration E+L should be clearly documented to be available in case of change of LSA. For cases where neither of the three above methods can be used, E+L should be assumed equal to 30 min.

Evacuation scenarios under consideration

MSC.1/Circ.1533 specifies a minimum of four evacuation scenarios to be analysed as follows:

- **Case 1 (primary evacuation case, night, in accordance with Ch. 13 of the FSS Code)**: passengers in cabins with maximum berthing capacity fully occupied; members of the crew in cabins occupied to 2/3 of maximum berthing capacity; and service spaces occupied by 1/3 of the crew.
- **Case 2 (primary evacuation case, day, in accordance with Ch. 13 of the FSS Code)**: Passengers in public spaces occupied to 3/4 of maximum capacity, 1/3 of the crew distributed in public spaces; service spaces occupied by 1/3 of the crew; and crew accommodation occupied by 1/3 of the crew.
- **Case 3 (secondary evacuation case, night) and Case 4 (secondary evacuation cases, day)**. In these cases, only the main vertical zone, which generates the longest individual assembly duration, is further investigated. These cases utilize the same population demographics as the primary evacuation cases.

The guidelines provide the following two alternative scenarios that should be considered for both Cases 3 and 4:

- **Alternative 1 (preferred option for ro-ro passenger ships)**: one complete run of the stairways having largest capacity previously used within the identified main vertical zone is considered unavailable for the simulation; or
- **Alternative 2**: 50% of the persons in one of the main vertical zones neighbouring the identified main vertical zone are forced to move into the zone and to proceed to the relevant assembly station. The neighbouring zone with the largest population should be selected.

The guidelines also provide additional scenarios to be considered as appropriate:

- **Case 5**, if an open deck is outfitted for use by passengers, and
- **Case 6**, if separate embarkation and assembly stations are employed. In this case, an analysis of travel duration from the assembly station to the entry point of LSA should be taken into account in the process of determining embarkation and launching duration.

Simplified evacuation analysis

The simplified evacuation analysis models the problem as a hydraulic network, with the corridors and staircases being the pipes, the doors being treated as valves and the public spaces acting as tanks (Stefanidis et al., 2019). The simplified method is presented in detail in Appendix 1 of Annex 2 of the guidelines

This method of estimating evacuation duration is based on the following assumptions:

- all passengers and crew will begin evacuation at the same time and will not hinder each other.
- initial walking speed depends on the density of persons, assuming that the flow is only in the direction of the escape route and that there is no overtaking.
- people can move unhindered
- counterflow is accounted for by a counterflow correction factor.

- simplifications are accounted for in a correction factor and a safety factor.

The assumptions of the simplified method are limiting by their nature. As the complexity of the ships increases, these assumptions become less realistic. In such cases, as the guidelines recommend, the use of the advanced analysis method is preferable. Still, in the early design phase of the ship, the simplified method has merit due to its relative ease of use and its ability to provide an approximation to expected evacuation performance.

Advanced evacuation analysis

The second method described in MSC.1/Circ.1533 is a more advanced method that should be based on computer simulations. In this method, the following assumptions are made:

- the passengers and crew are represented as unique individuals with specified individual abilities and response durations.
- a safety factor is introduced in the calculation to take account of model omissions, assumptions, and the limited number and nature of the benchmark scenarios considered.

The model to be utilized for the analysis should have the following characteristics:

- Each person is represented in the model individually.
- The abilities of each person are determined by a set of parameters, some of which are probabilistic.
- The movement of each person is recorded.
- The parameters should vary among the individuals of the population.
- The basic rules for personal decisions and movements are the same for everyone, described by a universal algorithm.
- The time difference between the actions of any two persons in the simulation should be not more than one second of simulated time, e.g. all persons proceed with their action in one second (a parallel update is necessary).

The advanced modelling should include the following categories of parameters:

- **Geometrical**: layout of escape routes, their obstruction and partial unavailability, initial passenger and crew distribution conditions (based upon the cases defined in Ch. 13 of the FSS Code).
- **Population**: ranges of parameters of persons and population demographics. The guidelines provide passenger sex and age distribution, crew sex distribution, response duration distribution, walking speeds on flat terrain and on stairs.
- **Environmental**: static and dynamic conditions of the ship. However, due to the lack of relevant data to assess the effect, ship conditions are currently not considered.
- **Procedural**: crew members available to assist in an emergency. Currently there is no need to model the crew's assistance, however crew's distribution shall be considered.

MSC.1/Circ.1533 provides detailed specifications of four evacuation scenarios to be considered for conducting advanced evacuation analysis. The initial distributions of passengers and crew are derived from Ch. 13 of the FSS Code, as presented above in paragraph 3.3.3.3, with additional indications only relevant for the advanced evacuation analysis. Specifically:

- **Cases 1 and 3 (night)**: Passengers in cabins with maximum berthing capacity fully occupied; 2/3 of crew members in their cabins; of the remaining 1/3 of crew members:

  - 50% should be initially located in service spaces.
  - 25% should be located at their emergency stations and should not be explicitly modelled.
  - 25% should be initially located at the assembly stations and should proceed towards the most distant passenger cabin assigned to that assembly station in counterflow with evacuees; once this passenger cabin is reached, these crew are no longer considered in the simulation. The ratio between the passenger and counterflow crew should be the same in each main vertical zone.
- **Cases 2 and 4 (day)**: Public spaces, as defined by SOLAS Regulation II-2/3.39, will be occupied to 75% of maximum capacity of the spaces by passengers. Crew will be distributed as follows: 1/3 of the crew will be initially distributed in the crew accommodation spaces (cabins and crew day spaces); 1/3 of the crew will be initially distributed in the public spaces; the remaining 1/3 should be distributed as above (for cases 1 and 3).

The advanced evacuation analysis method is presented in Annex 3 of the guidelines. Appendix 1 of Annex 3 provides details on the method to determine the travel duration by simulation tools, while Appendix 2 provides guidance on validation/verification of evacuation simulation tool.

3.5.3 Evacuation analysis software

Several evacuation simulation researches are in progress or have been completed so far. As a result, several sophisticated models for performing advanced evacuation analysis of passenger ships are available, with some of them being offered commercially. According to Stefanidis et al. (2019), the most prominent ship evacuation modelling software are EVI[6], maritimeExodus[7], IMEX (see Section 3.5.3.4), AENEAS[8], and VELOS (see Section 3.5.3.5). Each of these tools has been developed to evaluate the time to evacuate using different modelling methods, taking into consideration different factors and different assumptions. A brief presentation of these models is provided below.

3.5.3.1 EVI

EVI was originally developed at the Ship Stability Research Centre (SSRC) of the Universities of Glasgow and Strathclyde; the software was further refined and is now marketed by Brookes Bell. It is a ship and port terminal evacuation analysis tool in use since the first interim guidelines were published by the IMO in 2002. EVI conforms to the definition of advanced evacuation analysis in accordance with the IMO Guidelines for passenger ships (MSC/Circ.1533) and the provisions of SOLAS Ch. II-2, Reg. 13, Par. 7.4 (evacuation analysis). It is advertised that the software has been used on over 40 vessel designs to demonstrate compliance with IMO requirements, in support of design iterations and fire risk assessment of internal ship layouts and to validate passenger ships' turnaround time in newly developed terminal buildings.

EVI is a multi-agent evacuation model, where each passenger or crew is modelled by an individual "agent". As Azzi et al. (2011) state, these agents are governed by rules at macro and micro levels. At the macrolevel, there is the planning and development of routing

[6] http://www.brookesbell.com/service/software/evi-escape-evacuation-analysis
[7] https://fseg.gre.ac.uk/exodus/
[8] https://www.dnvgl.com/services/aeneas-the-standard-in-passenger-evacuation-analysis-48508

information which will guide an agent through the environment topology. At the microlevel, the agent is required to travel between the entrance and exits of the geometry, and to avoid the walls, obstacles and other agents moving the surrounding environment (Papanikolaou, 2009). Because of this combination of macro- and microscopic behaviour, EVI is regarded to be a mesoscopic model. EVI treats space as a continuum – unlike other models that treat the ship area as a mosaic of square grids – and the process of an agent moving from one point of reference to another becomes a process of pursuing a static target. The continuous space modelling allows any ship accommodation layout to be accepted. The choice of the direction of movement in the presence of other agents and/or obstacles is approached by combining grid-based techniques and social forces model (hybrid approach) thus utilizing both the effectiveness of grid-based techniques and the flexibility of social force methods. To simplify calculations, a range of discrete decisions is established around the agent with the objective of identifying the one that will allow the agent to travel as fast as possible (given its nominal speed) towards the local target. Also, a continuous local (social/personal) space is established around each agent which other agents will aim to avoid. This space is used to prevent deadlock situations when the number of agents in an area becomes too high (density increases). The agents decide against the best use of personal space to resolve any conflicts that may arise. As a result, this approach allows the evacuation process to be modelled in sufficient detail and still runs “fast” for applications even with the largest cruise ships. EVI's continuous space, discrete decision pedestrian motion model can flexibly adapt to the complexities of any ship's geometry and topology. Agents are considered as vehicular transport systems capable of carrying information, interacting with other agents and autonomously travelling around the ship environment. Another feature of EVI is the ability to assign certain tasks to both passengers and crew. By programming individual agents with the use of elements called Objectives and Messages, it is possible to reproduce any evacuation procedure (or egress scenario, not necessarily associated with an emergency). These elements make EVI an interactive and flexible simulation tool (Vassalos et al., 2004). EVI offers real-time simulation and a 3-D interactive graphical user interface that allows for play-back and analysis of different scenarios. EVI can be linked with fire and flooding simulation software to undertake direct assessment of the impact of smoke and flooding on escape/evacuation performance.

3.5.3.2 maritimeEXODUS

maritimeEXODUS software was developed by the Fire Safety Engineering Group (FSEG) at the University of Greenwich. The maritime industry has recognized the capabilities of the software and the research undertaken to develop it by several awards. The UK Ministry of Defense has also endorsed maritimeEXODUS.

maritimeEXODUS is a multi-agent model that can simulate people-people, people-fire, and people-structure interactions. The software is written in C++ and uses rule-based software technology to control the simulation. For additional flexibility, these rules have been categorised into five interacting sub models known as the Passenger, Movement, Behaviour, Toxicity and Hazard models. The geometry of the vessel structure is represented in space by a fine-mesh (microscopic) model (Glen et al., 2001). Specifically, the geometry is mapped in a two-dimensional spatial grid made up of nodes and arcs. Each node represents a small region in space (generally about 0.5m by 0.5m) typically occupied by a single person. Individuals travel form node to node along a system of arcs that links the nodes. The model tracks the path of each passenger as they gather at their assigned assembly point and await the order to abandon the vessel. If the passengers are subjected to the effects of fire hazards, maritimeEXODUS takes this into account and predicts whether passengers are likely to survive the effects of fire hazards such as heat, smoke and toxic gases. maritimeEXODUS also takes into account the impact of heel and trim on travel speeds and can simulate the abandonment phase. The motion of each occupant is determined by a set of rules of which many are stochastic based. In the case of a fire accident, the software can simulate the fire and smoke propagation together with the passenger evacuation using velocity-based fine network mode. maritimeEXODUS makes use of data generated from experiments performed with volunteers in the Ship Evacuation Behaviour Assessment (SHEBA) facility[9] (Glen et al., 2003).

3.5.3.3 AENEAS

According to DNVGL, the AENEAS software performs evacuation analyses for RoPAX Ferries, Cruise Ships and High-Speed Crafts in compliance with IMO MSC.1/Circ. 1238[10]. The software was jointly developed by TraffGo-HT and GL and is certified by the German Flag administration BG-Verkehr. In addition to the standard IMO scenarios, AENEAS offers the assessment of additional high complex scenarios. These scenarios may address among other topics ship motion including static and dynamic heel and trim as well as group behaviour for the embarkation of LSA.

AENEAS is a multi-agent software that uses a 3D interface (Bucci et al., 2016). The persons (agents) are represented as individuals with independent attitudes, abilities, and goals. The software has the unique feature of discretizing the plans of the ship in a grid of squared cells. Each cell can be free or occupied by a person or an obstacle. The cell side is 0.4 m long and each agent can occupy only one cell at each time step. The following types of cell can be used, which allow very fast simulations even for large populations:

- Free cells, which can be occupied by agents during the evacuation.
- Wall cells, which represent obstacles (i.e., walls, furniture, etc.) along the escape routes.
- Goal cells, which represent the objective to be achieved by each agent. The objective may be either an assembly station or a cabin.
- Door cells, which represent doors. They affect the evacuating flow by reducing the agent walking speed.
- Step cells, which represent stairways (both up- and down-stairs) affecting the evacuating flow.

During each time step of the simulation, agents move from cell to cell, using the neighbouring free, door or step cells to reach its assigned goal cell. The agents follow escape routes, which may be specified either by the user or assigned by default as the way towards the closest goal cell. For orientation, agents make use of the values of a potential associated with each cell. For each route, the potential of a cell assumes a value that increases proportionally with the distance from the goal cell. The agent finds its way by comparing the potential of the cell where it is standing on with the potentials of the neighbouring cells. There are 8 adjacent cells to take into consideration. The software is composed of 3 modules:

- **AENEASed**, the editor module by which a CAD drawing can be imported and converted into the relevant cellular grid.

[9] SHEBA facility is a mockup of a ship’s space, equipped with a muster room, an 11m long corridor, stairs, vertical ladder, watertight door, and watertight hatch. The entire rig is mounted on hydraulic rams that can heel the facility to 22°.
[10] MSC.1/Circ. 1238 is now superseded by MSC.1/Circ. 1533.

- **AENEASsim**, the module that runs the simulations and analyses the results. To take into account the random nature of a real evacuation, for each scenario a number (at least 500) of simulations are automatically generated and carried out. The demographic parameters of passengers and crew may be fixed either by default based on the MSC.1/Circ.1238 or properly established by the user according to the actual population present on board. The results of each scenario are synthesized by the probability density function of the evacuation time associated with each simulation, and through sketches of the decks with the congestion points corresponding to the significant evacuation time (defined as the 95-percentile) to be analysed.
- **AENEASview**, the module that permits visualization and analysis of the evacuation process and simulation results in a three-dimensional environment.

3.5.3.4 IMEX

Intelligent Model for EXtrication simulation (IMEX) model is an evacuation analysis tool that has the following capabilities (Park et al., 2004):

- It includes general features of evacuation models.
- It reflects physical interactions between evacuees.
- It provides a direct mechanism to evaluate evacuation procedures.

IMEX has two core sub-components, a force-based pedestrian dynamics model and an intelligent human behaviour model. The pedestrian dynamics model, called “Pynamics”, is based on a numerical simulation scheme known as the Discrete Element Method (DEM). It is a force-based model that uses strict Newtonian equations to describe the physical and psychological factors of local human movement behaviour. It integrates all the forces acting on the evacuee, including the evacuee’s self-propulsive force and all the external forces generated by interactions with evacuees and motions of the ship. For human behaviour model, intelligent human agent is implemented based on the Physical Conditions, Emotional State, Cognitive Capabilities and Social Status (PECS) model (Schmidt, 2000). Physical, emotional, cognitive, and social state variables are added and combined properly on decision making in IMEX.

3.5.3.5 VELOS

As Ginnis et al (2010) describe, Virtual Environment for Life On Ships (VELOS) is a multi-user Virtual Reality (VR) system that enables designers to assess early in the design process passenger and crew activities on a ship for both normal and emergency conditions and to improve the ship design accordingly. The functionalities of VELOS include: Geometric and VR modelling; crowd microscopic modelling (through a library of nearly 20 steering behaviours); interface to simulation packages (e.g. sea-keeping software for improving the environment realism and taking into account the ship-motion effect on passengers' movements); and networking support.

VELOS evacuation-specific functionality is greatly enhanced by the VR nature and client-server architecture provided by the VR system, namely, the participation and real-time interaction of remote multiple users in the form of avatars. For example, avatars in the evacuation simulation may act as crew members, family-group leaders or just passengers. These VR system-inherited features entail a very distinctive approach to evacuation analysis in VELOS, when compared to other evacuation tools. In particular, the capability of multiple users’ immersion and active participation in the evacuation process, the real-time interactivity and capability for making on-the-fly alterations of environment events and crowd-behaviour parameters, and the detachment from the need for discretized spaces by allowing agents and avatars to move continuously on decks, enrich VELOS with novel and useful properties and features.

The evacuation-specific functionalities of VELOS are summarized in the following point:

- It provides an integrated framework for both the simplified and the advanced method of evacuation analysis recommended by IMO. Especially for the advanced method, the IMO's approach is enhanced by addressing important model simplifications (e.g., ship motion, fire) and restrictive assumptions (e.g., simplistic crowd behaviours, full availability of escape arrangements).
- It enables the enrichment of the geometrical model of the ship with topological information to improve path-planning procedures.
- It provides efficient communication through several interfaces that enable dynamic specification and handling of the required input data. These data comprise passenger/crew demographics and allocation, behavioural parameters, environmental conditions (fire, flooding) as well as ship motions.
- It enables the post-processing of the fundamental output (agent trajectories) for extracting evacuation-specific information, e.g., travel-time distribution, cumulative arrival time, passenger density at specified areas.

3.5.3.6 EVDEMON (EVacuation DEmonstration & MOdeliNg)

"EVDEMON" is a method for simulating the evacuation procedure from the scope of passengers on ships. The project is based on the analysis of motions of large number of passengers during emergency situations. The simulation consisted from route-choice, queuing and movement models trying to describe as realistic as possible the time and space behaviour of individual people. The results of the model can be used as evidence for the approval of evacuation plans by relevant authorities.

3.5.4 Evacuation optimization approaches

Some of the basic approaches for Decision Support Systems (DSS) are briefly described below. These approaches have as their primary target to optimize the evacuation plan.

1) Hardcoding IF-ELSE rules based on information in a specific scenario and give a specific evacuation plan (Yudin and Karpov, 2017). The problem with this approach is that the rules might be very complicated due to the large number of parameters that must be considered in a maritime evacuation context.
2) Heuristic algorithms are used for optimization problems and could be used for developing an optimal evacuation plan. There are a lot of different Heuristic algorithms and a combination can be used in several optimizing problems for fast and secure evacuation (Martí and Reinelt, 2011). These algorithms are used in many cases efficiently.
3) Advanced evacuation analysis of passenger ships is a stochastic process in which the total evacuation time is calculated via computer-based simulations, by considering each passenger's characteristics (e.g., age, gender, etc.) and the detailed layout of the ship (Yudin and Karpov, 2017). This approach has been tested successfully in several cases.
4) A study by Cho, Ha and Park (2016) presents a velocity-based egress model, which takes into account different aspects of human behaviour in an emergency situation, for the evacuation analysis on passenger ships. It was assumed that the egress model consists of three behaviours: individual, crowd, and emergency behaviour. The

individual behaviour was represented by the body shape, walking speed, walking direction, and rotation of each passenger. The basic walking direction of each passenger was obtained as a solution to the shortest distance route to a destination using a visibility graph.

5) Goodwin et al. (2013) have suggested an ant colony optimization approach for planning safe escape routes. The authors addressed automatically finding the safest escape route in emergency situations in large buildings or ships with imperfect knowledge of the hazards. This solution can be used for a personal smartphone and might be very useful for PALAEMON project.
6) Emergency Evacuation Decision Support suggested by Rødseth (2006). This electronic DSS can aid in evacuation and rescue operation at sea. The main components of this DSS are: 1) Situation assessment, 2) Survivability prognosis tool, 3) Controllable directional evacuation, 4) Evacuation analysis and congestion measurements, 5) Smoke control strategies, 6) Passenger identification, 7) Tracking of lifeboats, 8) Communication with Search and Rescue, 9) Communication in search area.
7) Eleye-Datubo et al. (2006) developed a Bayesian Network (BN) model. In this approach the equation $P(t) = 1 - e^{-\lambda t}$ used to identify the evacuation probability.
8) Kana and Droste (2019) suggested an early-stage design model that estimates personnel locations on board a vessel during times of evacuation. In this case, principal eigenvector analysis is used. This approach has the following weaknesses. This model doesn't fit the most representative vessel layouts and better predictions for the estimated personnel locations is needed.
9) Another approach has been suggested by Vanem and Ellis (2010). This solution presents an evaluation of the cost-effectiveness of a novel passenger monitoring system based on Radio Frequency Identification (RFID) technology for implementation onboard passenger ships for improved safety and security. This improved safety will come at a certain cost. In this solution, the cost-effectiveness of the system involving a thorough risk analysis has been examined.

3.5.5 The future of ship evacuation modelling

Stefanidis et al. (2019) provide the following suggestions for the improvement of the evacuation analysis tools:

- Real time data, from the various sensors monitoring both the type and propagation of damage and human physiological factors, should be incorporated in an evacuation analysis model that can evaluate different route alternatives for individuals while taking the human behaviour under consideration.
- Evacuation models can also be improved with regards to their accuracy in embodying the differences in walking speed as a function of the individuals' specific psychological and physical characteristics. This implies including family and panic behaviour as well as the effect of disabled people in the evacuation flow.
- Security threat should be added in the list of subjects to be investigated with respect to evacuation.
- Evacuation models should include calculation of the actual time for lifeboat embarkation. Most of the models calculate explicitly only the time to evacuate up until the assembly station and are not able to do the same for the lifeboat boarding stage due mainly to the lack of operational or experimental data that would allow verification.

- Existing models could be refined by taking into account recent studies (Kim et al., 2019) on the effect of heeling angles on the walking speed.
- The continuous, non-static, effect of ship motions in walking speeds has also to be linked with real time flooding simulations so that the time-to-evacuate can be associated with the time-to-capsize.

3.5.6 Evacuation Strategies in relation to human movement

In an evacuation situation every minute counts, which makes evacuation strategies as guidelines for emergency situations very important. As the evacuation is a complex process and additionally passengers are a heterogeneous group – as well as crew members – several basic issues need to be considered. Thus, in this section space requirements and the density of people regarding walking speeds as well as gait disorders and its causes as aspects that affect the evacuation process and the required time are described.

Space Requirement and Density of People

For human adults it holds true that the body proportions depend on the ratio of body height and leg length, the torso is the widest part of the human body. The body height on average of persons living in central Europe and of both sexes is 172.3 cm. The body width on average amounts for both, men and women, 27% of the body height – without clothes. Further, the body depth amounts 13% of the body height (Weidmann, 1993).

The ellipse, that is the area of the human body projected on the floor, the body width and body depth as main axes, displays the minimum space requirement of a person – in Figure 3 the width is 0.5m and the depth 0.3m, which are the presumed dimensions of an average central European (Weidmann, 1993). However, this space requirement does not include clothes or eventually carried luggage or life jackets taken with the passengers or already donned on their way to the assembly stations. This additional space requirement is calculated with 0.085m².

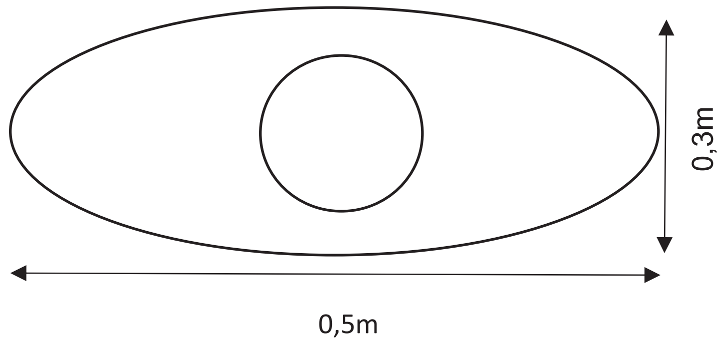

Figure 3: Body proportions.

The density of persons (ρ) or the density of the persons' flow can be defined by the number of persons N and by the reference area A in square metres (Winkens, 2007):

$$\rho = \frac{N_{persons}}{A}\,[1/m^2]$$

By a conversion to the maximum density of people per square metre, the theoretical value of 11.8 Persons/m² results. By calculating this value, the spaces between the persons that can't be used are not included. Thus, these spaces must be deducted: the needed area is calculated as square. Anyway, the needed space per person is then 0.11m² and a theoretical density of people of 9.3 P/m². If additionally, clothes and feet are taken into account, the space requirement of a person results in 0.15m² and the maximum density of persons 6.6 P/m². As the space requirement of bigger and heavier persons is more, the density of persons is reduced. Further, via the body height on average the calculation of the space requirement according to nationality is feasible (Knopp, 2010).

Walking Speeds

A moving crowd needs more space than a standing crowd (Still, 2017). The influence of increasing the maximal walking speed is investigated by increasing the interaction range beyond nearest neighbour interactions. The variation of the maximal walking speed has a strong influence on the shape of the flow–density relation (Kirchner et al., 2004).

- At a density of persons of 0.3–0.45 P/m² a personal freedom of movement is restricted.

- At a density of persons of 0.75–1 P/m² the free choice of the personal walking speed is greatly limited and at the density of 1–1.5 P/m² the free choice of a personal walking speed doesn't exist anymore. Further, at a density of 1.5–2 P/m² a crowd occurs and following, persons are forced to change their walking directions frequently. If the density of persons increases further, a movement of persons can only be intermittently performed. At this range it is not possible anymore to pass. At least, at a density of more than 5 P/m² the mass stands still (Weidmann, 1993).

However, the walking speeds doesn't decrease linearly. Until a density of approx. 3 P/m² the walking speed decreases quickly, at a density of more than 3 P/m² the deceleration is slowed down until a complete standstill happens (Knopp, 2010).

However, human gait is a highly complex activity. An ingenious interaction between the nervous system, musculoskeletal and cardiorespiratory system is needed to perform a physiological and healthy gait. Gait disturbances is often expected to be more present among older adults.

Jahn et al. (2010) described in their work: Gait Disturbances in Old Age a reduction of walking speed about 1% per year from age 60 onward. This assertion relies on a spontaneous walking speed, even greater differences could be seen at a maximum walking speed. Therefore, people in their thirties show a walking speed about 1.5 m/sec whereas the age group over 80 years walked the same distance in about 1 m/sec. At the maximum speed test, the 30-40 years group walked at a speed between 2-2.5 m/sec, the over 80 years old, however only about 1.5 m/sec. or slower.

Gait Disorders

Epidemiological data on gait disorders in elderly is still insufficient, nevertheless existing data gives a good overview about this health condition among elderly. Even though more research on prevalence is needed, potential causes and risk factors associated with gait and balance disorders are well known.

Mahlknecht et al. (2013) pointed out a prevalence of gait disorders about 10.7% in 60-69 year olds increasing up to 61.7% for the age group of 80-97 years for both men and women. At the age group of 70-79 years old 37.4% shows signs of gait disorder. After gender splitting, the prevalence among women is slightly higher than among men. Data were collected in the context of a cohort study in Bruneck (northern Italy) on cardiovascular and neurological diseases. For this specific cross-sectional investigation 488 community-residing elderly underwent a neurological assessment including standardized gait evaluation. According to this study two third of causes is attributable on neurological origin.

A research team at the Albert Einstein College of Medicine at the Bronx, New York (Verghese et al., 2006) got very similar findings on their community-based cohort study. Recruitment took place among home dwelling adults, aged 70 to 99 between 1999 and 2001, during entry and annual visits at the Hospital over a time period of 5 years. Eventually 488 adults participated within the study. Prevalence of abnormal gait was 35.0%. The causes of gait disorders among this cohort has been shown about 15.7% attributable to neurological causes (including causes in combination with neurological diseases) and 20.8% on other (non-neurological) causes. In contrast to the European cohort study 2013, the authors could not find any difference on gender according to prevalence.

Below is an illustration of causes for Gait Disturbance (Salzman, 2010).

Medical conditions and Risk Factors for gait disturbance: **Neurologic disorders** e.g. stroke; Parkinson disease, vestibular disorders, normal-pressure hydrocephalus **Musculoskeletal disorders** e.g. muscle weakness or atrophy, osteoporosis, lumbar spinal stenosis **Mental/Psychiatric disorders** e.g. depression, anxiety, sleep disorders, substance abuse **Cardiovascular diseases** e.g. peripheral arterial disease, coronary artery disease, arrhythmias **Metabolic diseases** e.g. Diabetes mellitus, hyper-and hypothyroidism, obesity **Sensory abnormalities** e.g. hearing impairment, visual impairment **Other** e.g. recent surgery, recent hospitalization

The knowledge about possible risk factors and causes of gait disturbance also enables a different approach to the prevalence on Gait disorders in older people. Tools like Years Lost due to Disability (YLD) and Disability- Adjusted Life Years (DALYs) can give an impression of disease burden. Those measurements are commonly used by the World Health Organisation (WHO) particularly because of the Global Burden of Disease Study (GBD).

DALYs established for the GBD, described as following (WHO, n.d.):

One DALY can be thought as one lost year of “healthy” life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability.

DALYs were calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the YLD for people living with the health condition or its consequences.

$$DALY = YLL + YLD$$

However, YLD gives information about the lifespan lived with disability. Calculation is done as followed:

$$YLD = I \cdot DW \cdot L$$ [11]

The number of incident cases in that period is multiplied by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (death) (WHO, n.d.).

Examples of DALYs – in Western Europe Countries and at both sexes based on the previous named risk factors of gait disturbance (IHME, n.d.) are given in Table 4.

[11] I…Incident
DW… Disability Weight
L… Average Duration of the Case until Remission or Death

Table 4: Examples of DALYs based on gait disturbance risk factors.

Health condition	Age group 50-69		Age group >70	
	DALYs	YLD	DALYs	YLD
Neurologic disorders				
Stroke	2.99%	1.80%	6.99%	4.34%
Parkinson disease	0.26%	0.17%	1.32%	0.69%
Musculoskeletal disorders				
Back pain	7.02%	14.42%	3.22%	9.51%
Other musculoskeletal disorders	1.83%	3.55%	0,50%	1.01%
Mental/Psychiatric disorder				
…Depression	2.32%	4.76%	1.00%	2.95%
Anxiety	1.61%	3.31%	0.57%	1.67%
…Schizophrenia	0.76%	1.57%	0.15%	0.44%
Bipolar disorder	0.6%	1.24%	0.15%	0.45%
Other mental disorders	0.64%	1.32%	0.26%	0.76%
Cardiovascular diseases				
Ischemic heart disease	6.68%	0.89%	11.38%	1.88%
Metabolic diseases				
Diabetes	3.8%	5.99%	3.86%	7.26%
Sensory abnormalities				
Hearing impairments	1.81%	3.72%	3.19%	9.40%
Blindness and vision impairments	0.83%	1.71%	1.22%	3.59%
Falls	2.48%	4.04%	2.91%	5.68%

Despite of good understanding of risk factors, epidemiological data on gait disturbance is still insufficient. Physical activities like gait are very complex activities with a number on influencing factors (e.g. health condition). Existing data can give an idea on the complexity as well as influencing factors and prevalence. Based on the known risk factors possible diseases can be identified. Health data like the Global Burden of Disease Study with its measurements of DALYs and YLD gives an impression of the prevalence of this specific health conditions. Percentage of People with health condition, relevant for gait disturbance, increase and change over lifespan. Mental disorders for example, plays a bigger role in younger population (50-69) whereas health condition like stroke or ischemic heart diseases are more common in older population (>70). Furthermore, multi-morbidity must be always kept in mind. On interpretation of the data could be that health condition decrease dramatically at the age around 70yrs. However, the composition of the population must be considered in the corresponding context.

As a conclusion, PALAEMON will need to consider the effect of the variability of human movement, as well as the factors that contribute to it, on the effectiveness of the evacuation procedure.

4 Evacuation systems and technologies

This section provides an overview of the systems and technologies (ICT-related) that are currently employed to support the maritime evacuation process. The main types of equipment are identified, and their characteristics are briefly described. The systems and technologies have been selected according to their relevance to the components of the PALAEMON system.

The main objective of this section is to provide input to the design requirements and specifications of the PALAEMON components. The PALAEMON system will need to co-operate and/or build upon existing/legacy systems and technologies and therefore this section will provide important information regarding the technical specifications of the required interfaces.

4.1 Maritime evacuation systems

The evacuation systems used in the maritime domain are lifeboats, liferafts, Marine Evacuation Systems (MESs), and mega-lifeboats. The requirements for these systems, such as the minimum number of lifeboats and liferafts, their passenger capacity, and the required onboard equipment are defined by SOLAS and the LSA Code (see Section 7).

Lifeboats

Lifeboats are the most important lifesaving appliances of the ship. They are used in emergency situations for abandoning ships. Lifeboats are small vessels, secured on the ship on a system that usually allows it to be launched by only using its own weight and it can be used from passengers and crew members. Lifeboats are made from reflective or fluorescent materials in order to be highly visible. Also, lifeboats must have first aid equipment, food and water supplies and signalling means. Some of them are additionally equipped with radios, propulsive means, navigational equipment and other appliances that facilitate the SAR operations. Besides the lifeboats, a ship must carry one boat for rescuing purposes, called rescue boat. If the ship has more than two lifeboats, one of them can be assigned as rescue boat.

There are three types of lifeboats used in merchant ships:

- **Open lifeboats***:* Open lifeboats tend to disappear from the maritime domain, as safety requirements are getting stricter, but they can be found in older ships (Figure 4). They are roofless lifeboats usually powered by hand propelled ores, but a compression ignition engine may also be provided.
- **Enclosed lifeboats***:* Closed lifeboats in contrast with open lifeboats offer better protection to the passengers from seawater, wind, rain and sun (Figure 7). They are considered safer as they have higher watertight integrity and they are divided into two categories, partially and fully enclosed. They are usually equipped with propulsive installation.
- **Freefall lifeboat***:* Free fall lifeboats are similar to enclosed lifeboats, but they are different regarding their design and in the way they are launched (Figure 5 - Figure 6). They have an aerodynamical shape so when they fall and touch the water, they can penetrate it easily. Usually they are positioned in the aft of the ship and stowed in downward slipways. They are heavier as they are strongly constructed to survive the impact with the water. One of their main advantages is that they are launched quickly. Freefall lifeboats are exclusively used in merchant cargo ships (e.g., tankers,

containerships, bulk carriers etc.) and are intended to be operated by specially trained crew members.

Besides free fall mechanism there are two more launching mechanisms, the onload and the offload mechanism, which are briefly described below (Wankhede, 2019):

- **Offload mechanism**: The offload mechanism releases the lifeboat boat after it touches the seawater surface. There is a hydrostatic piston unit provided at the bottom which is connected to the operating lever via a link. As the lifeboat touches the seawater surface, the water pressure will move a hydrostatic piston up and operate a hook arrangement in order to release the fall wire. In case of a system failure due to rough seas or any other malfunction the operator can perform an on-load release.
- **On load mechanism**: The use of an on-load mechanism allows the operator to release the lifeboat from the wire when it is full of passengers and above the water level. The on-load release is operated when the lifeboat is about to touch the sea water surface in order to make the fall as gentle as possible, so that the passengers are not harmed and the lifeboat not damaged. The mechanism can be operated from a lever provided inside the lifeboat.

Table 5 provides some basic technical characteristics of indicative existing lifeboats.

Table 5: Information for different types of lifeboats (Source: www.survitecgroup.com).

Product	Capacity (persons)	Material	Hull type	Extra information
Twin Fall Davit Launched Lifeboat	21 - 126	Corrosion-resistant materials, minimal maintenance	Monohull	Offshore and merchant applications (tankers, dry cargo vessels etc.)
Freefall Lifeboat	15 - 95	Corrosion-resistant materials, minimal maintenance	Monohull	Offshore and merchant applications (tankers, dry cargo vessels etc.)
VIKING NORSAFE JYN-57 TOTALLY ENCLOSED LIFEBOAT	Max 26	Fire-retardant glass-fibre reinforced polyester (GRP)	Monohull	Totally enclosed-Positive stability up to 180 degrees
VIKING NORSAFE GES-30 MKII FREE-FALL LIFEBOAT	Max 40		Monohull	Free fall lifeboat
BJ75II	Max 43		Monohull	Open type lifeboat, ZX2105J Inboard Diesel Engine
NM85F	Max 85	Fireproof material	Monohull	Totally enclosed lifeboat, 380J-3 Inboard Diesel Engine

Figure 4: BJ75II Open type lifeboat (Source: www.ningbonewmarine.com).

Figure 5: Twin Fall Davit Launched Lifeboat (Source: www.survitecgroup.com).

Figure 6: Freefall Lifeboat (Source: www.survitecgroup.com).

Figure 7: NM85F totally enclosed lifeboat (Source: www.ningbonewmarine.com).

Liferafts

Liferafts usually play an assistive role as lifesaving appliances (Figure 8, Figure 9). They are launched in a much easier way and usually are auto-inflatable. Usually, they are located on the muster stations and in the aft of the ship. Table 6 provides some basic technical characteristics of indicative existing liferafts.

Table 6: Information for different types of liferafts (Source: www.survitecgroup.com).

Product	Capacity (Persons)	Material	Ship types
SurvitecZodiac Open Reversible Liferaft	50 to 151	Durable polyurethane	Small passenger vessels, high speed crafts, fishing vessels
RFD Ferryman	25, 30, 37, 50, 65, 100, 130	Durable polyurethane-coated, nylon material	Passenger vessels operating in coastal and inland waterways, and high-speed crafts

Product	Capacity (Persons)	Material	Ship types
Elliot IBA Liferafts	4, 6, 10, 20, 30, 50, 100, 151	Specially formulated polyurethane (PU), proofed nylon fabric	Passenger and/ or commercial fishing vessels operating in protected or inshore waters
SurvitecZodiac Means Of Rescue (MOR)	Suitable for 10 stretcher borne persons	Durable polyurethane-coated fabric	Roll-on/roll-off (Ro/Ro) passenger ships

Figure 8: SurvitecZodiac Open Reversible Liferaft (Source: www.survitecgroup.com).

Figure 9: RFD Ferryman (Source: www.survitecgroup.com).

Marine Evacuation Systems (MES)

An MES consists of an inflatable slide or escape chute that connects the ship with specially designed, high capacity liferafts. Its main advantage compared to traditional lifeboats is that embarkation of large numbers of passengers may be accomplished in less time. There are several types of MES, such as Chute (Figure 10) and Dual Chute Systems (Figure 11), Mini Chute Systems (Figure 12), Slide Systems, Mini Slide Systems and direct boarding liferafts. Table 7 provides some basic technical characteristics of indicative existing MESs.

Table 7: Information for different types of Marine Evacuation Systems(MESs) (Source: www.survitecgroup.com).

Product	Evacuation Capacity (persons, time)	Ship types	Embarkation height	Extra information
VIKING EVACUATION DUAL CHUTE	908 / 30 min.	Largest passenger vessels	From 8.9 to 16.8 meters	Integrated with 153-person liferafts

Product	Evacuation Capacity (persons, time)	Ship types	Embarkation height	Extra information
VIKING EVACUATION MINICHUTE	582 / 30 min. or 326 / 17 min.	Small and medium vessels	From 5 to 20 meters	Requires few crew members
Offshore Mass Evacuation System	150 / 10 min.	Roll-on/roll-off (Ro/Ro) passenger ships	Up to 46 meters	The system can be configured for use with 50, 70, 75, 100 or 150-person liferafts

Figure 10: Offshore Mass Evacuation System (Source: www.survitecgroup.com).

Figure 11: VIKING EVACUATION DUAL CHUTE (Source: www.survitecgroup.com).

Figure 12: VIKING EVACUATION MINICHUTE (Source: www.survitecgroup.com).

Mega-Lifeboats

A recent development in lifeboat design are systems with capacities that exceed the prescriptive SOLAS requirement of maximum 150 persons (LSA Code, see also Section

7.1.3). These novel designs exploit the regulatory provisions for providing an equivalent level of safety compared to the traditional designs. In addition, mega-lifeboats address the issue of the large number of traditional lifeboats that need to be fitted on high-capacity passenger and cruise ships. Schat-Harding has developed a 370-person lifeboat (CRV55, Figure 13) that works with the LS45 a davit system (Figure 14)[12]. Innovative features of the CRV55 is the double deck design that allows faster boarding times and the davit system that allows lowering without outswing. Another interesting design is Palfinger Marine's MPC49 (Figure 15), which has a maximum capacity of 450 persons, spanning two decks and including comfortable seating arrangement. Table 8 provides some basic technical characteristics of existing mega-lifeboats.

Table 8: Information for different types of mega-lifeboats (Sources: www.motorship.com, www.palfingermarine.com).

Product	Capacity (persons)	Dimensions (m) and Weight (t)	Material	Hull type	Extra information
Schat-Harding CRV55	370	Length: 16.7 m Width: 5.6 m Stowed: 16 t Fully loaded:44 t	Fibreglass reinforced polyester (FRP)	Catamaran	2x 70hp diesel engines, speed 6 kn, twin rudders
Palfinger Marine MPC49	Max. 450	Length: 15 m Width: 5.52 m Fully loaded: 53t	Fibreglass reinforced polyester (FRP)	Monohull	Double deck design, comfortable seating

Figure 13: The CRV55 mega-lifeboat that is fitted on Royal Carribean's Genesis class ships (Source: www.maritimejournal.com).

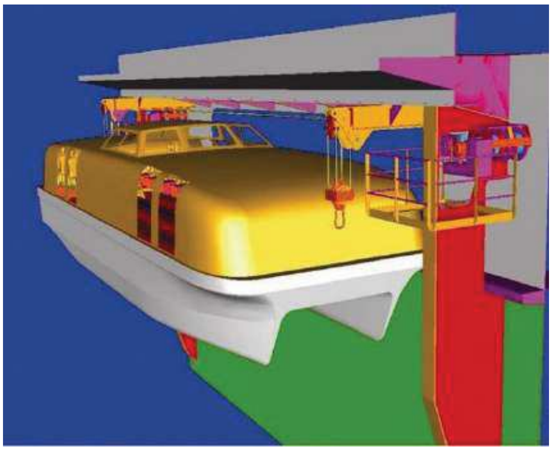

Figure 14: LS45 davit system (Source: www.motorship.com).

[12] https://www.motorship.com/news101/ships-equipment/design-for-safety-approach-encompasses-mega-lifeboats

Figure 15: Palfinger Marine MPC49 lifeboat (Source: www.palfingermarine.com).

4.2 ICT Technologies that support the evacuation process

4.2.1 Ship condition monitoring

Modern merchant ships are complex structures and their structural integrity is imposed to large strains when sailing in different sea states and simultaneously having to deal with corrosive environments and varying ship building and repair quality and practices.

In this framework, all parties involved in shipping, are called upon to ensure compliance with the regulations and work of the IMO concerning common rules and standards regarding ship inspection and survey. Albeit the regulatory framework is in place, it is complex and due to its international nature, enforcement can be weak (Knapp and Franses, 2009). Inspection is also dependent on the surveyor- inspector and his skills, experience and expertise. While this fact is not necessarily a fault in the existing inspection regulations it adds one more unknown and immeasurable variable to the problem. With respect to inspection regulations, these are well in place but there are reports (Bloor et al., 2006; Eliopoulou et al., 2012; Knudsen and Hassler, 2011; Papanikolaou et al., 2007, 2006) that show that vessels continue to sail with grave irregularities and defects even after recent inspections. For example, in the case of Double Hull Tankers, Non Accidental Structural Failures (NASF) appear frequent, in ships from 0-5 years old and not accounting for significant under reporting of relevant non-serious accidents

(Hamann et al., 2011; IACS, 2010). This fact can be attributed to poor build quality and substandard maintenance and repairs.

These problems concerning ship structural integrity and inspection can be mitigated by using real time condition monitoring of the structural integrity of the ship. Through condition monitoring, many of the failures and/or damages can be detected in real time or better yet avoided. In addition, rectification actions can be planned and executed using real time data.

Global condition monitoring of ship's structure and stability

Hull monitoring is at its infancy in the maritime industry and performed only with strain gauges on the ship's hull for various types of ships, such as Tankers, Container ships, and Bulk Carriers (Figure 16, Figure 17). Optional requirements for hull monitoring exist in several notations from classification societies (Sagvolden et al., 2010), using the same technology (strain gauges) as described above. This system can be used in ship but also in offshore structures. It is accomplished with strain gages and several other functionalities that measure ship's rigid body motion, local and global strain measurements.

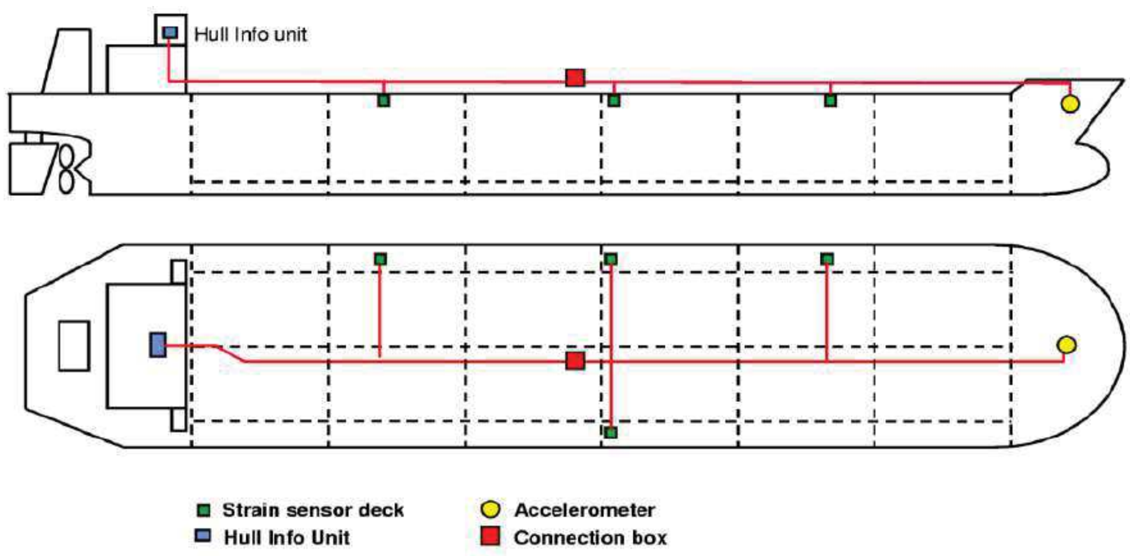

Figure 16: Condition monitoring of a ship employing Strain gauges and accelerometers.

Figure 17: Long base strain gauge on deck of Bulk Carrier.

These strain gauge systems are cumbersome, have an initial procurement of approximately 100k each and because local deformations (in the area of the strain gauge) are translated to global deformations, a damaged plate and/or compartment can offer misleading information.

Regarding emergency situations, the condition assessment of damaged vessels due to critical events has more recently focused on the issue of residual structural strength. Traditionally, collisions and groundings have been related to damage stability or cargo spill. A critical event may also be the consequence of cracking, a common damage in marine structures. Ships damaged by cracks will have a lower ultimate strength and repair may be difficult to carry out during the ship voyage, living aside the issue of cost.

Over the past two decades, the structural design engineers have applied limit state and risk assessment methodologies which aim to take into account, during the design stage, the consequences of structural damage on the structural integrity of a vessel. The ABS ‘‘Guide for assessing hull girder residual strength’’ (ABS, 1995) provides such guidelines to facilitate the assessment of structural redundancy and hull girder residual strength. Following a critical event, however, the key requirement in carrying out a structural assessment is the response time coupled with sufficient knowledge of the incurred damage. Assuming that the latter may be speedily communicated to emergency response personnel, evaluating the possibility of hull girder breakage after a critical event is usually carried out using simplified methods. Such analytical or semi-analytical methods are based either on obtaining a reduced section modulus of the hull section or the ultimate bending moment. The latter can, for example, be estimated using the incremental-iterative approach of Smith, incorporated in the IACS Common Structural Rules (CSR)[13] for intact ships, although this requires modification and/or further simplifying assumptions, since the cross-section of the damaged vessel is not symmetric. No defect assessment procedure has been put to place by any relevant party, especially including the capabilities of the FE method.

Local SHM

Local damages on a ship are quite frequent, either by fatigue, sudden impact loads, combination of corrosion and high stress or cyclic load. Although most of the times these

[13] http://www.iacs.org.uk/publications/common-structural-rules/

damages do not have an adverse effect on the global structural integrity of the ship, these need to be addressed. CS rules dictate that small cracks and defects need to be rectified but most importantly excess damage can be prevented with repairs. Although not widespread, Ship Hull Monitoring (SHM) for local damages has been proposed (Sagvolden et al., 2010). These local SHM techniques are based on small local strain gauges which are placed in selected places, identified as vulnerable to excessive loads, such as the following:

- Side shell fatigue monitoring.
- Stiffeners and stringers in specific places.
- Slamming and ice response monitoring (bow included).
- Sloshing load monitoring on tank walls.
- Design-specific sensors on innovative vessels.

The second means is optic fire brag rating strain sensors which are also placed in selected places for same reason. The main drawbacks of these methods are:

- The identification of a damage or defect can be done only if the damage is at within the area of the strain gage sensor of fibre.
- The identification of a defect is at the order of mm.

4.2.2 Communications infrastructure

4.2.2.1 Internal Communications

For the correct operation of the systems onboard a ship and the comfort of its passengers, some communication systems must be fitted inside the ship. Upon failure of other means of communication, crew members serving as messengers will be utilized to maintain the communication lines. PALAEMON will be able to use some of these systems to interact with the passengers and crew in order to manage a smooth and safe rescue in case of accident. This section contains a list of all the internal communication devices currently available on ships, as well as candidate technologies that may be exploited in the context of PALAEMON.

- Announcements in the public-address system of the ship and handheld VHF radios are the main forms of communication between the command team under the Master of the ship and the emergency teams. Other means of communication are also used for communication in emergencies. For example, communication between the command team and the engine room team can also be made by telephone.

- In order to communicate devices wirelessly within a local network, WiFi is a widely used technology. It works by deploying a series of hotspots to which the devices connect and exchange information, such as Internet service. By analysing the network traffic sent by the devices in the network, the location of the passengers and/or the number of people on each area of the ship may be estimated. Also, WiFi hotspots can send notifications or messages to the devices connected to them, with the aim of helping passengers find the correct path in an evacuation situation or guide the crew to find straggling passengers.

- As an additional form of wireless communications, 4G antennas can be deployed on a ship that may contribute to a more accurate representation of the location of the passengers.

- Another technology that can be used for passenger localization is BLE. BLE provides an inexpensive way of deploying Bluetooth beacons either on the ship or on the survival crafts during the evacuation. BLE beacons can also send information to devices they are connected to, showing notifications or directions in case of evacuation.

- In passenger ships, it can also be possible to find RFID payment systems, where the passengers are provided with smart bracelets linked to their profile that allow them to identify themselves across the ship. These bracelets may also be used to identify the location of a passenger or notify them if necessary.

4.2.2.2 External Communications

Automatic Identification System (AIS)

AIS is a worldwide automatic positioning system that was first introduced by the IMO in 2002 and involves fitting small, continuously transmitting transponders to vessels. This alerts other vessels and shore stations with AIS receivers to the presence of that vessel. The AIS signals can then be received by any vessel, land station or satellite fitted with an AIS receiver, and is then typically displayed on a screen using interactive chart-plotting software (BigOceanData, 2016).

AIS was developed as a short range, high intensity system with a line-of-sight range of 10-20 Nautical Miles (NM) (initially, now it becomes 40 NM) between the transponders and terrestrial (shore and vessel based) receivers. Its primary purpose is to allow vessels to see who else is operating in their immediate vicinity to prevent collisions. What is less well known is that AIS signals can also be received by low orbit satellites. This has transformed the capability of AIS, giving it a truly global reach and allowing users of AIS services to locate and track vessels anywhere on the face of the earth from their desk or bridge.

The AIS format uses Time Division Multiplex Access (TDMA) radio access that allows for just 4,500 time slots per minute. One time slot equates to a single vessel transmission. Each AIS slot is 26.67 ms long, so that 60 s/26.67 ms takes to 2250 slots, in two frequency channels, which amounts to 4500 slots. Each AIS burst conveys 168 information bits.

AIS types of information

Class A (Ships and Ferries)

Static Information such as:

- MMSI (Maritime Mobile Service Identity).
- Call sign and name of vessel.
- IMO Number.
- Length and beam.
- Type of ship.
- Location of position-fixing antenna.

Dynamic Information such as:

- Ship position with accuracy indication and integrity status.
- Position Time stamp in UTC.
- Course over ground (COG).
- Speed over ground (SOG).
- Heading.
- Navigational status (e.g. underway by engines, at anchor, engaged in fishing etc).
- Rate of turn (ROT).

Voyage-related information such as:

- Ship's draught.
- Hazardous cargo (type) (e.g. DG (Dangerous goods), HS (Harmful substances) or MP (Marine pollutants).
- Destination and ETA.
- Route plan (waypoints) (at the discretion of the Master).

Class B (Small Vessels)
Static Information:

- MMSI (Maritime Mobile Service Identity).
- Call sign and name of vessel.
- Length and beam.
- Type of vessel.

AIS has been successfully used in maritime and inland navigation for applications that include collision avoidance, Vessel Traffic Service (VTS) tool, aid to navigation, tool to support search and rescue operations and for detecting ships via satellite (Bober, 2015). However, considering the increasing need for larger volumes of data exchange, AIS may soon reach its designed capacity.

AIS is an important framework for safety of navigation and it is a carriage requirement defined by SOLAS for large vessels (e.g., 300 tons and upwards). Because of its effective and useful technology, the use of AIS is often extended to vessels that do not comply with the carriage requirement (i.e., AIS Class-B) and allows other applications such as Aids to Navigation (AtoN), Application Specific Messages (ASM), Search and Rescue Transmitter (SART), Man Over-Board unit (MOB) and Emergency Position - Indicating Radio Beacon (EPIRB-AIS). This extended use of AIS technology has caused significant increase in VHF Data Link (VDL) load, which has become an active concern in IMO and International Telecommunication Union (ITU).

According to Luglio et al. (2018): "E-navigation aims at increasing safety and efficiency of navigation, defining reliable data exchange formats and communication channels between either ship to ship or ship to shore. New technological advancements start from the consolidation of AIS, which is mandatory in some classes of ships for the notification of the position and to send distress signals. In pair with AIS baseline services, additional services are gaining momentum and are available in state-of-the-art equipment, including the handling of sending and receiving Application-Specific Messages (ASMs)."

Because of increasing general demand of radio spectrum for digital communication (mobile phones and data), ITU issued recommendation ITU-R M.1842 (ITU, 2009) to define characteristics of an enhanced VHF radio systems for maritime mobile services. In addition, ITU defined techniques for efficient and standardized maritime communications at higher data rates (up to 32-fold) providing the core element of the upcoming VHF Data Exchange System (VDES), which has been standardized in the 2015 with the recommendation ITU-R M.2092-0 (ITU, 2015).

VHF Data Exchange System (VDES)

International organizations like the International Telecommunication Union (ITU), the International Maritime Organization (IMO) and the International Association of Maritime Aids to Navigation and Lighthouse Authorities (IALA) have recognized the growing use of AIS as well as the increasing need for data communication. Therefore, they have started the development of the next generation of AIS – the VDES.

According to Bober (2015): “VDES will include the original function of AIS; it will provide extra channels for Application Specific Messages as well as additional functions of higher data exchange capability considering requirements for data communication like data protection or the assurance of data delivery. The VDES will provide terrestrial data communication as well as satellite components using VHF radio channels.”

VDES, the next generation of AIS will take into consideration the requirements for more data exchange capabilities. Thereby, the AIS radio channels (VHF Data Link - VDL) will be protected from overload as AIS populations increase. First signs of AIS channel overload were seen in some busy areas like big seaports or areas with a large number of recreational vessels using AIS.

Besides, the VHF Data Exchange System (VDES) standard is meant to improve on both messaging capabilities and system flexibility (standardizing the use of satellite channels) as well as to allow higher bitrates for application messages regarding AIS and ASM.

VDES aims at first complementing / extending and in the next future (tentatively by year 2019-2022), replacing current AIS, by providing a vast gamut of data exchange channels and methods. Thereby, the AIS radio channels will be resilient to overload as AIS populations increase, and new services will be enabled by the progressive introduction of alternative VDES channels.

VDES supports terrestrial data communication as well as a satellite component, leveraging VHF radio channels. The traditional SAT-AIS[14] was provided as an added option to exploit the advantage of global satellite coverages for AIS broadcasting beyond the coastal areas, without increasing the actual terminal capabilities. On the contrary, the combined use of terrestrial and satellite channels is defined in the early stages of the VDES standards, as a design requirement. This represents an opportunity to offer worldwide coverage and facilitate the implementation of interoperable e-navigation and modernization of the Global Maritime communications.

According to Bober (2015): “VDES aims for protecting the original functions of AIS while providing additional capacity for a wide range of applications in maritime safety communication. VDES is intended to be a globally available digital data exchange system dedicated to maritime safety, security, efficiency and the protection of the environment. VDES has the potential to support maritime data communication, e-Navigation, River Information Services and possibly the modernization of GMDSS (Global Maritime Distress and Safety System).”

VDES is a technological concept utilizing terrestrial and satellite radio communication links in the VHF maritime mobile band to facilitate globally interoperable digital data exchange between ships, between ships and shore, between shore and ships and between ship and satellite.

The concept of VDES comprises the functions of the existing AIS, an additional communication link for the exchange of Application Specific Messages (ASM) and an additional communication link enabling higher capacity VHF digital data exchange (VDE). The

[14] https://www.esa.int/Applications/Telecommunications_Integrated_Applications/SAT-AIS_for_maritime

concept includes terrestrial radio communication links as well as the satellite radio communication links in the VHF maritime mobile band.

Recently the frequency allocation definition stepped forward, but it is still in progress. In fact, the World Radiocommunication Conference (WRC-19) held at Sharm el-Sheikh, Egypt (28 October – 22 November 2019) stated in the Provisional Final Act, that:

“The frequency bands 157.1875-157.3375 MHz and 161.7875-161.9375 MHz (corresponding to channels: 24, 84, 25, 85, 26, 86, 1024, 1084, 1025, 1085, 1026, 1086, 2024, 2084, 2025, 2085, 2026 and 2086) are identified for the utilization of the VHF Data Exchange System (VDES).

The VDES terrestrial and satellite components are described in the most recent version of Recommendation ITU-R M.2092. These channels shall not be used for feeder links. The channels may be merged using multiple 25 kHz contiguous channels to form channel bandwidths of 50, 100 or 150 kHz. The channel usage is shown below:

- The channels 1024, 1084, 1025 and 1085 are identified for ship-to-shore, shore-to-ship and ship-to-ship communications, but ship-to-satellite and satellite-to-ship communications may be possible without imposing constraints on ship-to-shore, shore-to-ship and ship-to-ship communications.
- The channels 2024, 2084, 2025 and 2085 are identified for shore-to-ship and ship-to-ship communications, but ship-to-satellite and satellite-to-ship communications may be possible without imposing constraints on shore-to-ship and ship-to-ship communications.
- The channels 1026, 1086, 2026 and 2086 are identified for ship-to-satellite and satellite-to-ship.
- Communications and are not used by the terrestrial component of VDES.
- The channels 24, 84, 25 and 85 are identified for ship-to-shore and shore-to-ship communications.
- The Earth-to-space component of the VDES shall not cause harmful interference to, nor claim protection from, nor restrict future development of, terrestrial systems operating in the same frequency bands.
- Until 1 January 2030, the channels 24, 84, 25, 85, 26 and 86 may also be used for analogue modulation described in the most recent version of Recommendation ITU-R M.1084 by an administration that wishes to do so, subject to not causing harmful interference to, or claiming protection from other stations in the maritime mobile service using digitally modulated emissions and subject to coordination with affected administrations.”

The allocation of frequencies for the satellite link is a very important step and it is easy to forecast a huge interest for the VDES system and its development in the future. The use of this system is important because of its future spread and the development it is going to meet (Figure 18).

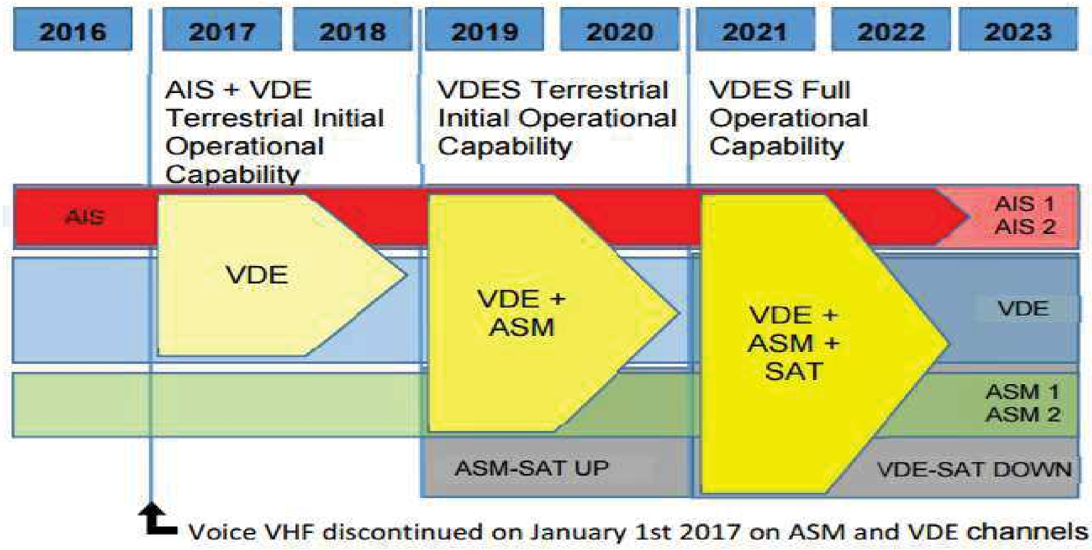

Figure 18: From IALA Guidelines, Dec. 2016.

VDES brief description

The following is a brief description of VDES, as provided by Bober (2015).

The functions of the VDES can be summarized as follows. The existing Automatic Identification System (AIS) as defined by IMO and ITU (Figure 19) will be kept unchanged in its original purpose to provide identification and navigation data to support ship to ship collision avoidance, VTS, tracking of ship and locating in search and rescue. AIS position reports and ship data reports, AIS AtoN message and AIS SART messages will stay on channels AIS 1 and 2. For long range tracking of AIS channels 75 and 76 are used. The existing ASM on the AIS channels will be gradually moved towards the new ASM channels to ease the channel load for the original AIS functions.

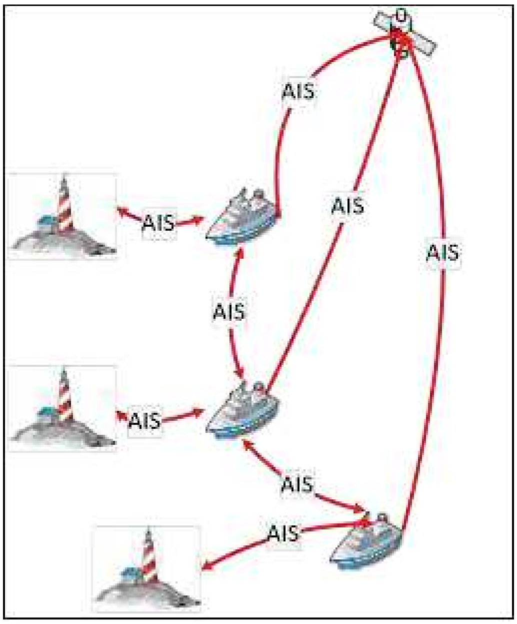

Figure 19: Functionality of existing AIS system.

The function of Application Specific Messages (ASM) is known from the existing AIS. ASM provides a kind of container for data which are supplied by external applications (Figure 20). The data structure and its interpretation must be known by the recipient to be able to decode and understand the content of the ASM.

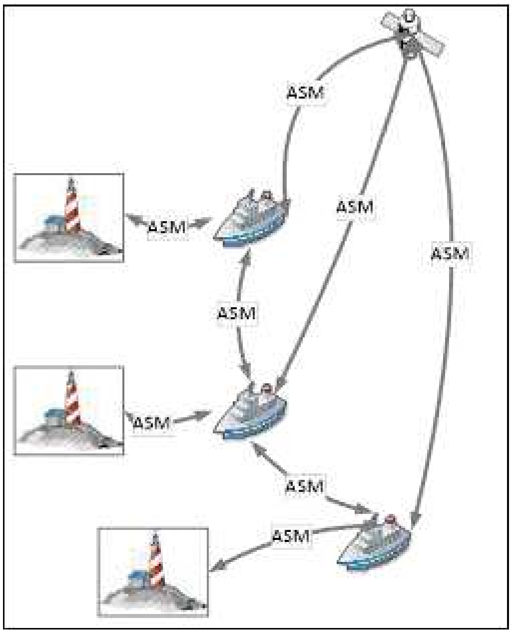

Figure 20: Functionality of ASM.

IMO has defined several international Application Specific Messages like meteorological and hydrographical data, area notice or route information. In addition, regional defined ASM are used, e.g. in St. Lorenz Sea Way and in inland navigation. The use of ASM is slowly growing. With the introduction of e-Navigation and the increasing use of River Information Services the use of ASM is expected to rapidly increase due to the expanding need for digital data exchange.

VDES will provide ASM channels that might have higher capacity than AIS; however, the data structure of the messages shall remain as defined in AIS. This will allow for gradual transfer of existing ASM from the AIS channels to the new VDES ASM channels.

The need to keep track of all existing Application Specific Messages (ASM) in order to facilitate data exchange has been established (IALA Recommendation e-NAV 144). IALA has taken the responsibility to collect these, and now maintains this online IALA ASM Collection (Table 9). Stakeholders should endeavour to use the ASM´s in this Collection before developing new ASM's. If, and when, new ASM´s are developed, these should be reported to the IALA Secretariat as soon as possible, so that the IALA ASM Collection can be updated.

Table 9: Application Specific Messages (ASM) according to IALA.

Title	Msg	DAC	FI	Version	#slots (max)	State	Registrant	Permitted as from	Not to be used after
Buoy position monitoring	6	235	20		1	In force	Trinity House	01/04/2019	
Monitoring aids to navigation	6	0	0		1	In force	Zeni Lite Buoy Co., Ltd	01/03/2002	
Text telegram using 6-bit ASCII	6	1	0		5	Replaced	ITU-R.M.1371-1	01/01/1998	31/05/2007
Text using 6-bit ASCII	6	1	0		5	In force	ITU-R.M.1371-3	01/06/2007	
Application acknowledgement	6	1	1		1	Replaced	ITU-R.M.1371-1	01/01/1998	01/04/2010
Interrogation for specified FMs within the IAI branch	6	1	2		1	In force	ITU-R.M.1371-1	01/01/1998	
Capability interrogation	6	1	3		1	In force	ITU-R.M.1371-1	01/01/1998	
Capability reply	6	1	4		1	In force	ITU-R.M.1371-1	01/01/1998	
Application acknowledgement to an addressed binary message	6	1	5		1	Deprecated	ITU.R-M.1371-4	01/04/2010	
Dangerous cargo indication	6	1	12		2	Deprecated	IMO Circ. 236	01/05/2004	01/01/2013
Tidal window	6	1	14		3	Deprecated	IMO Circ. 236	01/05/2004	01/01/2013
Number of persons on board	6	1	16		1	Deprecated	IMO Circ. 236	17/05/2004	01/01/2013
Number of persons on board	6	1	16		1	In force	IMO Circ. 289	01/06/2010	

Utilizing the higher capacity of the ASM channel may allow acknowledging the reception of ASM and thus enabling an automatic delivery assurance of the ASM. All new ASM and gradually all existing ASM should be transmitted on the VDES ASM channels.

VHF Data Exchange terrestrial

The VHF Data Exchange terrestrial (VDE terrestrial) will facilitate a seamless data exchange to enhance digital radio communication beyond the capabilities of ASM (Figure 21).

VDE terrestrial will enable a two-way terrestrial data exchange between ships and between ships and shore in coastal coverage areas. The VDE may provide up to 32 times higher capacity than AIS.

This will allow for data exchange which is not bound to the message structure of ASM. It will enable a whole range of new applications which may require data exchange of higher volume.

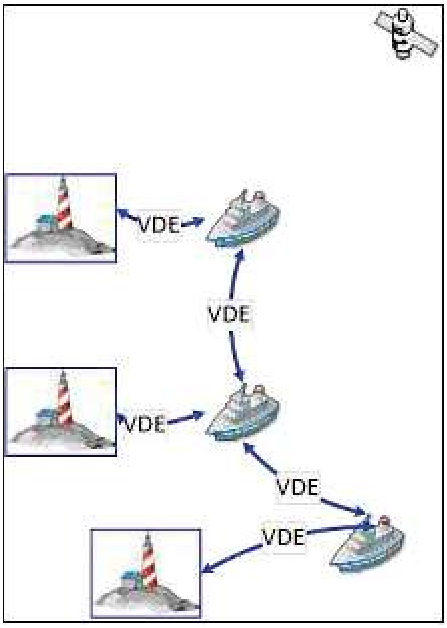

Figure 21: Functionality of the VDE terrestrial.

VHF Data Exchange by satellite

The VHF Data Exchange by satellite (VDE SAT) will provide data exchange between ships and shore via satellite. This will enable a global coverage of the VHF data exchange. VDE SAT should complement the VDES terrestrial outside the coast station coverage area. This will extend the VDES coverage to high sea, to Polar Regions and to remote areas, where no shore infrastructure is available.

VHF Data Exchange satellite reception (satellite uplink)

Like the satellite reception of AIS today, satellites which are equipped with the appropriate VDES receivers can receive data exchange transmissions from the ships (Figure 22).

For AIS and ASM this will be most likely the reception of the regular terrestrial transition. For satellite reception of VDE transmissions an optimized protocol for satellite reception might be used to ensure a robust data exchange from ship to satellite.

VDE transmission received by satellite (satellite uplink) will be forwarded from the satellite to a ground station on earth and from there further to the shore-based user.

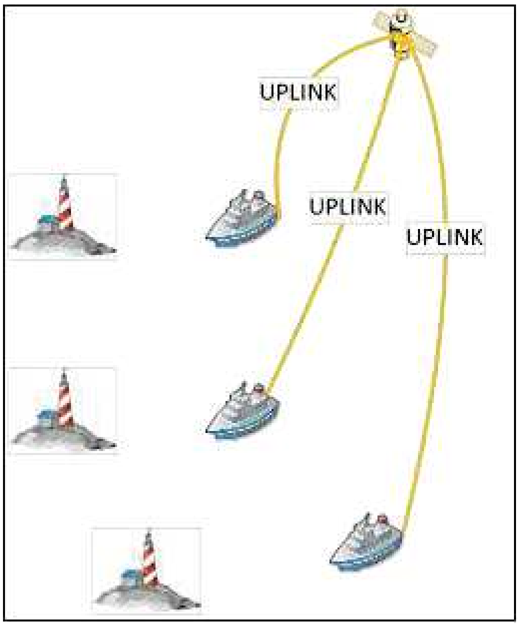

Figure 22: Functionality of the VDE satellite uplink.

VHF Data Exchange satellite transmission (satellite downlink)

VDES will provide the capability for data transmission from satellite to one or more ships (Figure 23). VDES satellite transmission will allow sending data to ships at high sea, in remote areas or in the polar region.

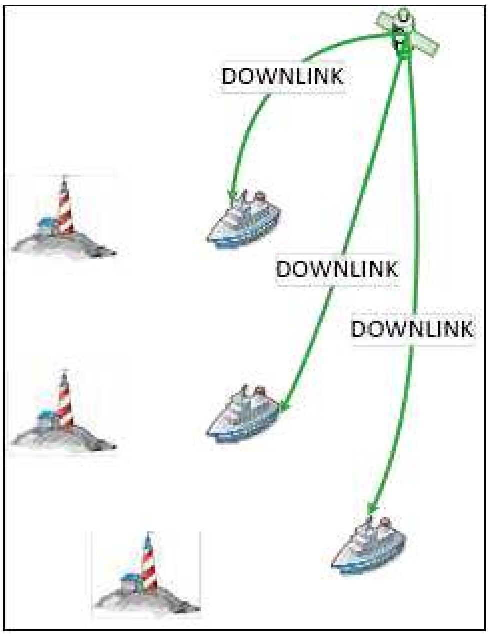

Figure 23: Functionality of the VDE satellite downlink.

4.2.3 ICT Infrastructure onboard ships

Maritime operations are strongly supported by ICT systems. These operations are characterized by complexity and consisting of specific elements which could vary from port management to ship communication. The extensive use of ICT and increased automation are strongly promoted by the European Commission in order to reach increased levels of safety, improved technological efficiency along with reduced environmental impact. Furthermore, new services will be created due to the development in communication and digitalization technologies and maritime industry will start reconsidering information and data management since, along to ports and shore-based support centres, most ship systems will be connected to the Internet. Such environment enables and pushes data streams from several sources on board. The emerging ICT technologies that will have dominant role in maritime transportation are:

- **Wireless communications**: since smart devices and computer power are increasing exponentially, people (crew or passengers) on board are allowed to be connected at any time.
- **Big data analytics**: high-volume data created on board are being processed using advanced analytics.
- **Cloud computing**: the possibility of offloading tasks (e.g., storage, heavy operation) to cloud-based instances is something extremely time-consuming. However, it is also true that the maritime realm presents certain conditions (lack of “ultra-wideband” connectivity at some points) that might hinder the full utilization of this paradigm.
- **Internet of Things (IoT)**: systems, devices and streams of data are connected; technical systems on board are also supported by IoT offering increased automation.
- **Automation**: automated systems are often used to transfer data from sensors (smart) and global networks; such contribution will enhance the efforts of or replace human operators.
- **Cybersecurity**: critical infrastructures on board are becoming more and more interconnected raising the issues of safety and resilience and pointing their importance.

In maritime transport a connected passenger ship may use advanced ICTs for several core applications, such as Route Management, including issues of planning and optimization, decision support, real time tracking, cost and quality control; Safety and Security Management including surveillance, access control, command and control, save and rescue; Passengers and Crew Welfare focusing mainly on the personal information management and Internet access. ICT infrastructures on board (private or public) establish a framework built on a tri-layer approach of Connectivity Management, Device Management and Service and Information Management. This framework for a ship that facilitates compliance with SOLAS, consists of several components in four main categories:

1. **Communication installations** such Very High Frequency (VHF) or Medium Wave (MF) Transceivers, High Frequency (HF) Transmitters, Emergency Position Indicating Radio Beacon (EPIRB), Search and Rescue Radar Transponder (SART), Navtex, Satcom C (Immarsat) via Enhanced Group Calling (EGC).
2. **Automatic identification systems (AIS)** with dedicated displays, radar displays and Electronic Chart Display and Information System (ECDIS) which identifies each vessel via ship’s name, position, speed, heading, persons on board, estimation of arrival time to next port and International Maritime Organization (IMO) number after call sign.
3. **Voyage Data Recording (VDR)** system due to IMO regulations since July 2002 for all passenger ships and other ships above 3000 gross tonnage.
4. **Vessel Traffic Service (VTS)**, which is like air-traffic control in the aviation domain.

Overall, the utilization of ICT solutions on the naval realm comes to complement the legacy systems that have accompanied traditional vessels for decades. Nowadays, sensor-based deployments can be straightforwardly installed on board and span a wide range of applications/functionalities; e.g., traffic management, predictive maintenance, automatic lookout sensing or for remote networks; systems for predictive maintenance, automatic mode detection, autonomous navigation or autonomous engine control facilitating optimal efficiency along with failure prediction, and a long etcetera. Besides, it goes without saying that the impact of new and more efficient radio access technologies (e.g., WiFi, Bluetooth, etc.) facilitates (and cheapens) the integration of this kind of solutions, since there is a number of alternatives to the traditional (and expensive) wiring.

4.2.4 Indoor positioning technology for people localization onboard passengers' ship

Problem definition

Large passenger ships like cruise liners or RoPax ferries are ships with a high guest capacity (up to several thousand people), numerous cabins, restaurants, pools and leisure facilities spread over several decks. Orientation in a place like this is not easy for most passengers, given the relative short time a passenger has to get familiar with such a complex geometry. Finding one's way is not only a problem when passengers embark but also later during the cruise, and especially during an emergency situation. On such big ships, parents often struggle not to lose sight of their children. Navigating on board can also take much longer than expected, the deck plans are usually not sufficient for stress-free wayfinding. In the case of an emergency, operators need to make sure that nobody of the crew and passengers is still in an area of risk. In addition, they need to know if and how many of the crew and passengers have moved to their assigned muster station.

Indoor positioning

Indoor Positioning Systems (IPS) enables the accurate positioning of objects or people within buildings or indoor spaces. GPS does not offer a trustworthy performance in indoor scenarios, since its levels of precision drastically drop when there is a surface (even worse if it is metallic) between a device and the satellites. Furthermore, with satellites it is not possible to determine the floor level a device is located on, that is why an IPS must rely on other localization methods. Indoor positioning is based on a transmitter/receiver model where there are two possibilities to determine the current location of an asset or person indoors, client and server-based approaches.

Client-based technology is used to keep track of individuals that might require back channel for further information exchange (i.e., visualization of own position on a map, location-based alerts, task management, etc) and for navigation purposes. A smart device (i.e., smartphone) with a specific application is handling the indoor positioning based on external signallers such as WiFi and BLE in combination with the device inertial sensors. The position is determined on the smart device but can also be transferred continuously to a backend to provide supervisors with the device/user's location. Hence, the device requires network connection.

Server-based technology is used to keep track of assets and persons and typically comes with a one-way communication towards the receiver. Nonetheless a return communication to the asset tag is also possible (e.g., in the form of an LED activation, e-ink display). The receiver hardware is installed within the premise to capture the signals of the transmitters/senders and to transfer data to the backend engine.

Technology overview

There are several potential sensor technologies available to meet the requirements of a specific tracking/localization scenario with regard to the accuracy requested.

- **WiFi** – WiFi is a good alternative to indoor GPS. In most cases it is easy to install a WiFi positioning system since existing WiFi infrastructure can be used (access points, hotspots, etc), User does not necessarily have to connect with the WiFi, it is sufficient to have it enabled. For positioning the so-called fingerprinting method is used, Received Signal Strength Indication (RSSI) and the Media Access Control (MAC) address are significant. It requires a dedicated app installed in the smartphone which calculates the current position based on this data. If a server-based solution if more suitable for the scenario of interest, additional beacons can be used avoiding the need of the app, all WiFi capable devices are detected, and asset tracking is possible. Accuracy depends on multiple factors such as the number of available access points, reflections in corridors, and shielding through walls, ceilings and other elements. Sensor fusion can improve accuracy in client-based applications.
- **Bluetooth Low Energy (BLE) beacons** - Beacons are small radio transmitters that broadcast signals using BLE in a radius of up to 70 meters. These signals are detected by a mobile device (e.g., smartphone) in a client-based approach or by a specific hardware (locator nodes) in a server-based approach. The underlying technology is using RSSI measurement to determine beacon's position. BLE beacons are cost effective and energy-efficient components that can run on button cells up to five years and more.
- **Ultra-wideband (UWB)** – UWB is a short-range radio technology that is mainly used in industrial environments with high precision needs. With less than 30 cm the accuracy is considerably better than when working with WiFi or beacons, also height differences can be measured accurately, low latency time (position updates up to 100 times/s) is another advantage. The position is determined by a transit time method (Time of Flight, ToF) instead of RSSI, this method measure the time of light between an object and several receivers.
- **Radio-Frequency Identification (RFID)** – RFID describes a system that use radio waves to identify objects or persons. In passive RFID systems there is a transponder (tag) on whose microchip data (serial number) are stored, which can be forwarded wirelessly to a reader. The reading unit generates the energy to activate the tag. Distance between reader and transponder must be less than one meter
- **Closed-Circuit TeleVision (CCTV)** - Technologies for indoor positioning can be augmented with an imaging system, such as dome cameras. Especially in logistics and the security sector, the connection of an external camera system and thus the establishment of a correlation between camera image and position data can provide significant advantages. Not only does it enable to locate mobile devices, objects and persons, but also to allocate optical features (e.g., clothes, colours, or numbers as identification criteria). Furthermore, a corresponding recognition of difference in images offers benefits when supplementing positioning technologies such as BLE that do not provide sufficient accuracy on their own.
- **Sub-Gigahertz wireless technology** - This technology uses several RF bands below 1GHz, for example the 433MHz ISM band, or the 868/916MHz bands. As is the case with BLE, sub-GHz systems use active tags. Moreover, the frequency bands used

have lower bandwidth, and face different restrictions of use in different parts of the world. Their main advantage is that they are not highly populated by other systems, but are rather dedicated to IoT applications, as the one considered in this work. LoRaWAN is a media access control (MAC) protocol for wide area networks. It is designed to allow low-powered devices to communicate with internet connected applications over long-range wireless connections. It operates in the 868Mhz frequency band. Depending on the amount of data and the spreading factor transmission is only possible with higher latencies (30s-5min) which makes this technology unsuitable for live tracking systems.

5 Marine Casualty Analysis

This section presents an analysis of selected major marine casualties and incidents involving lifeboats on passenger ships. The main objective is to identify challenges related to maritime evacuation and main contributing factors. This information will be used as input for the component requirements of the PALAEMON system and provide a basis for defining the conditions that the PALAEMON system will be expected to operate (i.e., basis for developing PALAEMON use cases).

Enhancing the safety of passenger ships can be achieved by modifying the contributing factors found in accident investigation reports, through appropriate measures that adopt a risk-based assessment approach and taking in to account new approaches such as those provided in the PALAEMON project.

Marine accidents can be considered an important safety indicator, and their number shows that there is much more to be done to improve it. According to the annual overview of marine accidents and incidents by EMSA (2019), there is still a large number of ships involved in marine casualties and incidents, despite the extension of the regulatory framework, the continuous improvement of the operational procedures and the ship's equipment. In a statistic regarding ships' accidents in the last eight years, by category, passenger ships are on the second place with a yearly percentage almost unchanged (23.7%) in the last five (Figure 24).

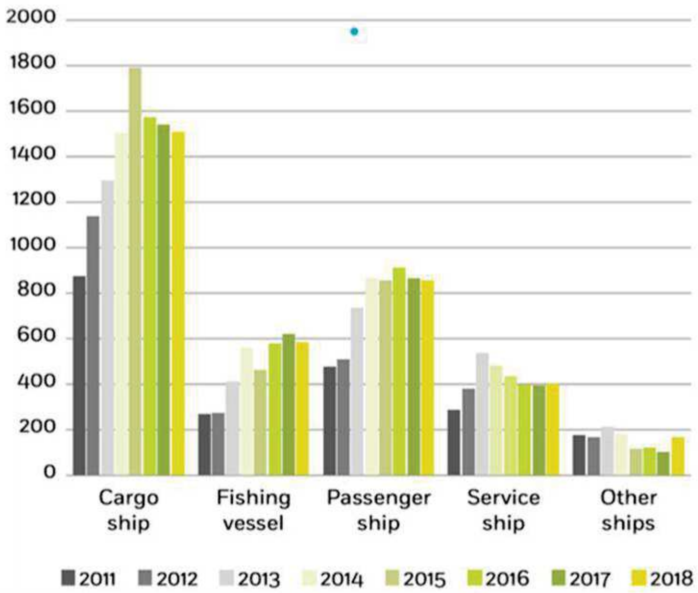

Figure 24: Distribution of ships involved in accidents by main category (Source: www.emsa.europa.eu).

In maritime accidents the root causes and contributing factors are the most important issues revealed by the investigations. Various statistics are done regarding these issues depending on the scope for the interpretation and the measures that will be taken in the future. EMSA is deeply involved in accident investigations because the link between cause, contributing factors, accident, consequences, response and measures to be taken is methodologically studied.

Regarding the same period, it is interesting to see how some of the contributing factors in maritime accidents are distributed. The contributing factor related to "Shipboard operations" represented a percentage of 65% of the total, with 2003 cases related to the accident event "Human action", as shown in Figure 25.

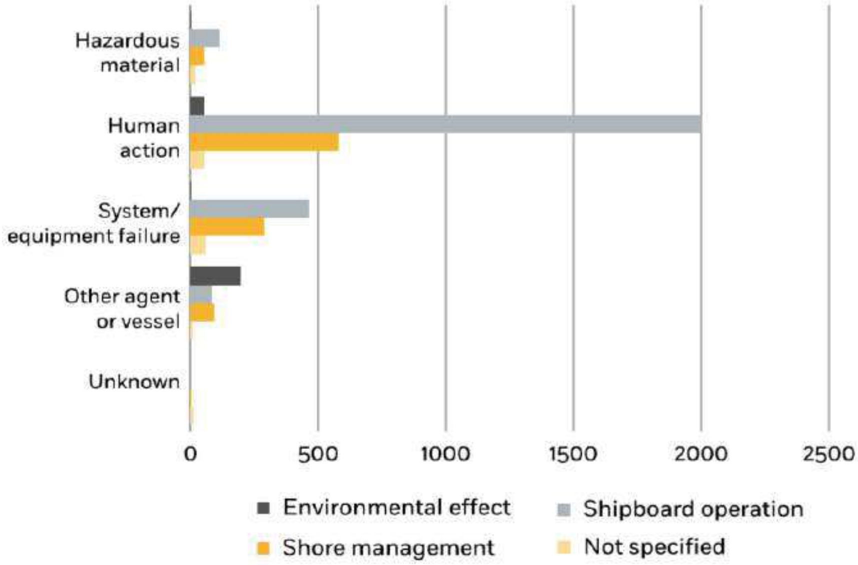

Figure 25: Relationship between accident events and the main contributing factors for 2011 – 2018 (Source: www.emsa.europa.eu).

Some very interesting facts are showed in Figure 26, representing the contributing factors of the maritime accidents of passenger ships. The figure illustrates the 6 most reported contributing factors related to 'Human action'. Personnel and manning - Inadequate work methods (43), Crew resource management - Planning & coordination (26), Social environment - Safety awareness (21) represent the highest figures.

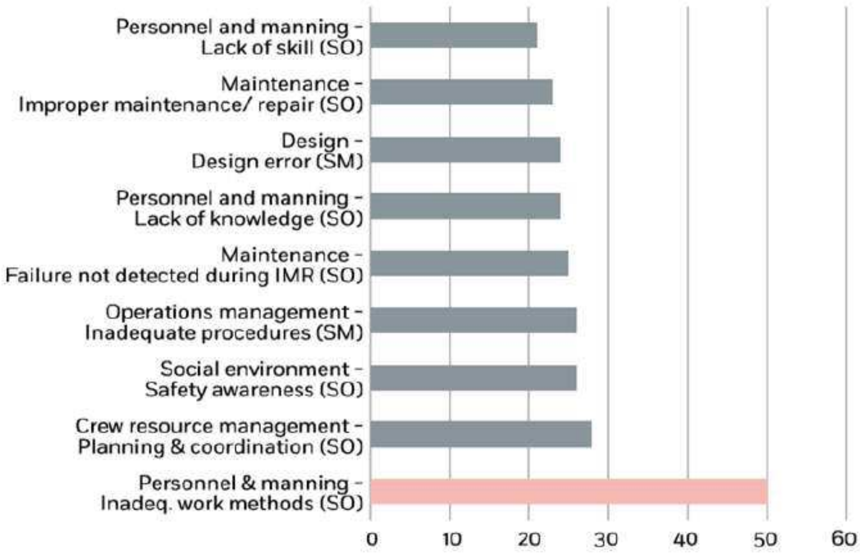

Figure 26: Contributing factors related to 'Human action' for passenger ships in the period 2011-2018 (Source: www.emsa.europa.eu).

These figures point out the fact that passenger ships are subject to various risks related to maritime accidents and the large number of people on board give the safety measures a paramount importance. The measures are directly related to the above contributing factors in order to minimize the possibility of accidents occurring and to mitigate the consequences as much as possible.

Usually, the evacuation process consists of two stages: *assembly* and *abandonment*. After the general alarm sound passengers are asked to *assemble* to their muster station and put on the lifejackets. They are guided by the crew who search for all the people, guide them through corridors staircases and decks and this is a time-consuming activity due to a large number of passengers, some of them in different conditions (elderly, people with disabilities, children etc) but also the dimensions of the ship. The abandonment phase begins after the Master's order "abandon ship" and SOLAS provides 30 minutes to prepare and launch the lifeboats and life rafts. Both phases of the evacuation process can be improved to increase the efficiency of operations that take place in the relatively limited time. The decisions to be made must be based on the most accurate information and best practices, and the introduction of new technologies can contribute to the success of a safe evacuation in the event of a ship is abandoned.

5.1 Major marine accidents with evacuation issues

5.1.1 Cruise Ship Costa Concordia (2012)

"On 13 January 2012, the Costa Concordia was in navigation in the Mediterranean Sea (Italian coastline), directed to Savona, with 4229 persons on board (3206 passengers and 1023 crew members), facing rough sea conditions (wind speed: 17 knots). The ship was sailing too close to the coastline under the Master's command and collided with the "Scole Rocks" at the Giglio Island. After the collision the ship violently heeled, the speed immediately decreased, the vessel lost propulsion and was consequently affected by a black-out. The Emergency Generator Power switched on, but worked in a discontinuous way, so it was not able to supply the utilities to handle the emergency. The ship turned starboard by herself and finally grounded at the Giglio Island heeled". (MCIB, 2012)

The last decade was marked by the accident of the cruise ship Costa Concordia in 2012, whose grounding was followed by the abandonment of the ship and the evacuation of all passengers and crew members. During evacuation 32 people died and 157 injured and represents the largest maritime evacuation in history. In the conclusions of the investigation report (MCIB, 2012) it is mentioned that *"the human element is the root cause in the Costa Concordia casualty, both for the first phase of it, which means the unconventional action which caused the contact with the rocks, and for the general emergency management."*

It is also necessary to consider that the ship was fully compliant with the applicable SOLAS regulations. The case of Costa Concordia is a very good example for studying the picture of a maritime passenger ship accident followed by an evacuation.

From the results it is well understood that opportunities to abandon ship before it started listing were wasted and that crew members were not properly trained in evacuation procedures. The Master didn't warn the SAR Authority on his own initiative, as the warning was received by a person calling from shore. When he decided to do so valuable time was already lost. He also didn't activate the Muster List, so some inconsistencies emerged in the assignment of duties to crew members. The abandon ship signal was given too late and it was not preceded by an effective general emergency alarm. Several passengers testified that they did not hear those signal-voice announcements. In addition, the Master and most of the officers abandoned the ship before her evacuation was completed. Also, the fact that the ship was heeled made the movement of the passengers even harder.

Conditions	**Contributing factors**
• Weather and sea conditions: Rough sea conditions (wind speed: 17 knots). • The ship was affected by heel, loss of propulsion and black-out.	• The Emergency Generator didn't work properly. • Crew members were not properly trained. • Opportunities to abandon ship early, before it started listing, were wasted. • Heel made the movement of passengers difficult. • The Master delayed warning the SAR Authority. • No activation of Muster List. • Delay of abandon ship signal which was not heard from the passengers. • Master and most of the officers abandoned the ship before her evacuation was completed.

5.1.2 Passenger Ferry SEWOL (2014)

The MV Sewol Ferry accident took place on 16 April 2014 and only 172 of a total 476 people were rescued. Subsequent accident investigations found that the Sewol was carrying 124 cars, 56 trucks, and 1157 tons of cargo, which was more than twice the legal limit and that they were improperly secured. There is a possibility that the accident was a result of cargo displacement following a sharp turn, after which, the ferry listed 20 degrees, cargo fell in the sea from the one side causing loss of stability and allowed to take on water. The anti-heeling pumps could return the ferry to its upright position, but they were not working.

A passenger (high school student) aboard the ferry made the first emergency call and reported that the Sewol was capsizing. A communication officer, at the Guest Services Desk, instructed the passengers to stay put using the ferry's PA system. This action was based on the officer's own judgment as the bridge was not responding. The announcements of "passengers to stay put" continued until water began flooding passenger compartments and cabins. Passengers were also told to put on personal floatation devices, lifejackets and more clothing. The bridge personnel didn't know how to properly use the announcement equipment and they thought that all broadcasting systems on the bridge were out of order. As a result, all communication between crew members and the Guest Services Desk were made only with hand-held two-way radio transceivers. There were other ways to announce the evacuation in order to inform the passengers but the crew on the bridge didn't use them, so until that moment the passengers thought that the best option was to stay put in their cabins. Meanwhile, crew members went to starboard side in order to drop life rafts, without receiving any orders from the Master, but the effort to reach them was unsuccessful due to the list of the ship. Finally, the Master ordered the second mate to announce evacuation. Although, survivors testified at the court that the ferry's PA system repeatedly ordered passengers not to move (Kwon, 2016).

Nearby ships dropped lifeboats in order to assist the evacuation. After rescuing the crew members, a member of the Patrol Vessel-123, went up to the ferry and dropped two life rafts and returned to the boat without letting passengers know about the evacuation. At that time, crew members tried unsuccessfully to reach life rafts on the port side. About 150 to 160 passengers jumped into the water in the last 20 minutes (Kwon, 2016).

It is well understood that the evacuation failed because the life rafts could not be used due to the tilt and the crew members didn't react as they ought to. Some people were rescued by helicopters. Finally, one of the most crucial parameters to this tragic incident was that the Master and crew members abandoned the ship before the passengers. After that it was very difficult for them to handle the situation without any guidance. An early diving rescue operation failed and finally the coast guard didn't even enter the boat to help the passengers (Song, n.d.).

Conditions	Contributing factors
• The ship capsized after flooding.	• Anti-heeling pumps were not working. • Insufficient communication and information flow between bridge-crew members and crew members-passengers as well. • Lifesaving appliances could not be reached due to the list of the ship. • Master and crew members abandoned the ship before the passengers.

5.1.3 M/V Norman Atlantic (2014)

"In the night between the 27th and 28th December 2014, during the navigation between Igoumenitsa and Ancona, a fire broke out on the ship M/V NORMAN ATLANTIC, carrying on board 417 passengers, 55 crew members and at least 3 ascertained illegal immigrants. The ship was facing very rough sea conditions, storm wind and discrete visibility. Overall 452 people were rescued and the bodies of 11 victims were recovered, while 16 passengers and presumably 6 illegal immigrants are still missing. People were rescued between the 28th and the 29th of December, 88 of whom by ships which arrived on the area, through lifeboats and life rafts. The remaining people were rescued by helicopters and patrol vessels". (MIT, 2014)

The fire was detected by the alarm system in the ship's open garage. The Distress signal was given after a few minutes and MRCC PIRAEUS coordinated the first stages of the SAR operations and they reported difficulties in establishing contact. When the fire alarm was activated, the crew didn't verify the situation. The Master, after seeing the flames, ordered to transmit the fire alarm and to issue the "crew call". A few minutes after that, the chief mate informed the Master that the situation could not be dealt with and the electric system on board was severely damaged by fire, causing the first black-out.

People could be gathered only on two upper decks, as the rescue boat on the starboard side was destroyed by the fire as well as the mini chute on the starboard side. The lifeboat on the portside was instead lowered to the embarkation deck by the crew, and without any specific order by the Master, 88 persons got on board and were lowered to the sea. Also, the life rafts placed on the portside of the ship were launched without the Master's authorization and the control of the crew members. Except for a small number of passengers who could embark on the lifeboat on the portside, evacuation was possible only through air rescue means (MIT, 2014).

Although the organization on board was compliant with regulations, there were several issues. The presence of smoke and the time of the day made the situation harder to be dealt with and valuable time was lost because the fire was not identified immediately. In addition, the cooperation of crew members was improper. The passengers were not able to identify the crew members, because they did not wear any special equipment/clothes and as they reported they provided minor help only in the area of the rescue means. Finally, it was crucial that there was no audible alarm or a public announcement in the area of passenger cabins neither any announcement via the public address system on a later stage.

Conditions	**Contributing factors**
• Weather and sea conditions: very rough sea conditions, storm wind and low visibility. • The ship was affected by black-out.	• Delayed verification of the fire. • Evacuation means on starboard side were destroyed by the fire. • Smoke and darkness made the situation even harder to handle. • Bad cooperation between crew members and passengers. • No audible alarm or public announcement was activated in the area of passenger cabins.

5.1.4 Sorrento (2015)

“On 28/04/2015, at 11:45 (UTC), about 20 miles off West of Palma de Mallorca island (Spain), a fire occurred on board the Ro-Ro-Pax SORRENTO. The ship was sailing on the route Valencia - Palma de Mallorca. As a consequence of the casualty, the ship was lost. No injuries and fatalities were registered”. (MIT, 2015)

The ship departed from the port Palma de Mallorca and was sailing to Valencia facing very rough sea conditions, wind and moderate visibility. There were 110 passengers on board and 46 crew members. There were no fatalities and only 14 people got intoxicated by smoke, but the ship was lost (no pollution was reported).

For reasons yet to be ascertained, while the M/V SORRENTO was sailing, a fire broke out on deck number 4. Despite the activation of the fixed extinguishing system and the intervention of fire teams, it became quickly uncontrollable. The Master did not initially consider an evacuation to be required, but after having launched a distress signal he ordered abandon ship through the starboard side, because the intensity of fire was greater on the port side. Two Italian ferries that were sailing nearby assisted the operations shortly after a helicopter, a patrol boat of the Spanish Coast Guard and a tugboat had arrived on the scene. Some people didn’t manage to reach the survival crafts or the rescue boats because of the fire and were evacuated by helicopter (MIT, 2015).

Conditions	**Contributing factors**
• Weather and sea conditions: very rough sea conditions, wind and moderate visibility.	• It was not initially considered that an evacuation will be required. • The fire made the evacuation possible only from starboard side.

5.1.5 Viking Sky (2019)

"On the afternoon of 23 March 2019, the cruise vessel Viking Sky experienced a black-out and loss of propulsion facing storm weather (wind: 9-10 Beaufort or 22-25 m/s from the southwest) and rough sea conditions (total significant wave height over deep water of 9-10 meters from west) in the Hustadvika area of the Norwegian Coast. The Master immediately sent out a mayday". Viking Sky was manned by 458 crew members and was carrying 915 passengers. (AIBN, 2019)

Notwithstanding that the sailing course was modified because the weather forecast had warned the Master for dangerous sea conditions, the Master had instructed the crew to prepare the vessel for the deteriorating weather conditions. Black out and loss of propulsion was caused due to loss of lubricating oil pressure. The Master assessed the situation, broadcasted a mayday and instructed the crew to drop both anchors but they did not hold, and the ship continued to drift. After that, the General Alarm was activated, and the mustering of the passengers and crew began. Shortly after the blackout, the emergency diesel generator started and powered the emergency switchboard and later the propulsion motors were restarted and provided sufficient propulsive power. When the first helicopter arrived, the crew maneuvered the vessel to give the helicopters the best possible working conditions in order to start the evacuation. The Master had considered evacuating passengers and crew using the lifeboats but given the environmental conditions, this was considered to be too dangerous. The evacuation operations through helicopters continued until the next morning. When the first tugboat arrived, the weather conditions didn't allow to secure a towline. Only in the next morning the weather conditions had improved enough to enable the ship to be tugged, although the vessel maintained its own propulsion. After that, the Master decided that the vessel was out of danger and stopped the evacuation process (AIBN, 2019).

Conditions	Contributing factors
• Weather and sea conditions: storm weather (wind: 9-10 Beaufort or 22-25 m/s) and rough sea conditions (total significant wave height over deep water of 9-10 meters) • The ship was affected by black-out and loss of propulsion due to loss of lubricating oil pressure.	• The weather conditions were too dangerous to use the lifeboats. • Passengers could evacuate the ship only through helicopters.

5.2 Accidents and incidents involving lifeboats on board passenger ships

Most of the accidents and incidents related to lifeboats occurred during the lifeboat drills. Lifeboat drills, also known as abandoning drills, are the training activities carried out by a ship's crew before the ship leaving the port (see Section 3.3). The purpose of the exercise is to prepare and effectively show the crew and passengers how the ship can be evacuated in case of abandonment. The *muster drills* are carried out mainly for passengers, to inform them and the crew also, about escape routes and evacuations procedure. The lifeboat drills consist in steps of emergency procedures and train the ship's crew how to load the lifeboats, lower into the water (move a distance from the ship) and recover the lifeboats on board.

If the ship is not in port, the drills must be done within at least 24 hours after the vessel leaves the port and the frequency of drills is stated in SOLAS Ch. III/19.3 Drills: 3.2, "*Every crew member shall participate in at least one abandon ship drill and one fire drill every month*".

Even if the lifeboats drills have the scope to assure the safety of people, they are very dangerous considering the number of the accidents that have occurred. Despite the lack of comprehensive statistics on lifeboats accidents, there are a significant number of reports in the media about injuries related accidents during abandonment exercises aboard ships. Most of the injuries during lifeboats drills are caused by the faulty design of the lifeboats and the equipment, inadequate or insufficient training of crew that usually leads to human error, and improper maintenance (e.g., corrosion/wear of the equipment etc.).

The following examples may outline a picture of the accidents on board passenger ships related to lifeboats during evacuation drills in the last years in order to draw conclusions as to their causes and the contributing factors and the measures that can be taken.

5.2.1 Facts

According to CruiseMapper's statistics[15], on December 29, 2018, while navigating in the Gulf of Mexico, en-route from Mexico back to New Orleans, the passenger ship *Carnival Dream* lost one of its lifeboats. Reportedly, the boat (unit number 28) *broke loose from its davit and fell into the sea*. As the ship was unable to retrieve the heavily damaged lifeboat (left-down photo), it was abandoned after salvaging all its equipment and supplies.

In Port NOLA, the lifeboat was replaced with a new one. Fortunately, no injuries or ship damages were reported. A similar accident occurred in January 2017, onboard passenger ship *Grandeur of the Seas*, when a lifeboat had fallen from the ship and capsized in the water (Figure 27) due to a weakened cable which eventually broke.

Figure 27: Lifeboat accident onboard passenger ship Grandeur of the Seas in 2017.

According to the opinion of ex-crew members[16], lifeboats are the second most dangerous working places onboard cruise ships (after watertight doors) and the numerous cases of accidents during the boat drills, which involve the lowering of the lifeboats, confirm it. Five people were hurt (one seriously) onboard of passenger ship *P&O Arcadia*, on January 2018, during a routine lifeboat drill, when the ship was berthed in Ponta Delgada, Azores. The lifeboat broke from cables during rescue drills and fell into the sea.

In February 2017, onboard of cruise ship *Emerald Princess* one fitter died during the checking of the pressure into the nitrogen cylinder *used to launch lifeboats; the cylinder exploded* and the blast throw out the other cylinder on the pier, where luckily no one was harmed.

[15] https://www.cruisemapper.com/accidents
[16] http://crew-center.com/most-dangerous-areas-cruise-ship-crew

In September 2016, one crew member died, and four others were injured onboard cruise ship *Harmony of the Seas*, when a lifeboat became detached from the fifth deck and fell 10 m, during a drill. Due to the force of the impact, one crew member was fatally injured (BMA, 2017). When lifeboat 14 was ready to be lowered with five men on board, the operator in position released the lowering winch brake. The lifeboat was then suddenly destabilized and fell into the sea causing injuries to four crew members and killing one. According to the investigation report (BMA, 2017), the fall of the lifeboat was caused by the release of the forward and aft long links, disruptive event without action by the crew. According to Pospolicki (2017), the cause of this failure was the combination of internal corrosion within the wire holding the lifeboat and a failure of the personnel to identify the technical failure. Among the factors which contributed to the accident, two are technical/design factors but other two are human related:

- Unclear division of roles in the mind of the preparation team sailors.
- Absence of a cross-check step allowing to identify an omission.

It is worth mentioning that a similar accident occurred in April 2015 on board CMC CGM Christophe Colomb, when a lifeboat with three men onboard (two casualties, one seriously injured) *fell during a drill*. The incident was caused by a hardware failure that originated to the shipyard that built the vessel.

On July 2016, onboard cruise ship Norwegian Breakaway, four crew members were injured when one of the rescue boats broke from its tethering (left hanging from one wire) and fell into water, during a routine safety drill in port of Kings Wharf.

In 2013, on the cruise ship *Thomson Majesty,* eight crew members were in a lifeboat during a drill, when the lifeboat plunged 18 meters into water, upside down. Five of the crew members were killed and three were injured. The accident occurred immediately after the Cruise Line International Organisation (CLIA), following the Costa Concordia disaster, announced some safety proposals applicable to all cruise lines (Walker, 2013). One proposal was that the loading of lifeboats for training purposes is to be performed only while the boat is waterborne and the boat should be lowered and raised with only the lifeboat crew on board (MSC 91/7/1). Transport Malta investigation report (TM, 2014) concluded that the wire rope had been inspected at appropriate intervals however, the wire rope was a lower grade than required and had inferior strength. The accident "was a result of a parted wire rope fall that cause severe internal corrosion at the break point".

Figure 28: Tender boat malfunction onboard Cruise Ship Balmoral in 2016.

Many other accidents with lifeboats onboard passenger ships have occurred in the last years, fortunately without any casualty. An indicative example is a tender boat malfunction during a drill on cruise ship *Balmoral*, in January 2016 or *cable broke* during a lowering of the lifeboat on *Costa Mediteraneea* in August 2015 (Figure 28).

5.2.2 Main contributing factors in lifeboat-related accidents

The dangers involved in operating lifeboats are confirmed by the number of accidents in which the lifeboats were involved. Most of the accidents occurred during maintenance and routine drills and the main causes are related to design failure, lack of maintenance and lack of training. There are only a few examples of accidents in recent years that confirm the saying that “lifeboats kill or injure more people than save lives”.

As Lemmis (2017) reported: “This can be attributed to a number of factors including poor or inadequate maintenance, lack of crew training, lack of familiarization in handling lifeboat equipment, ineffective (or the avoidance of) drills and safety devices being overridden”. The main causes of lifeboat accidents can be separated into two categories, design and management. Management encompasses both maintenance and training although, safe management and lifeboat design are strongly interconnected (Ross, 2006). Some key areas and aspects that need attention are: Lifeboat Release and Retrieval System (LRRS) failures, wire rope failures, limit switch failures, winch crank handle injuries, bowsing and tricing bad practice, lifeboat engine failures. In addition, Wankhede (2019) reported some additional issues to pay attention in order to prevent lifesaving appliances accidents such as the use of on-load mechanisms, the communication between crew members and the design faults.

Summarizing the opinions of the experts (Acejo et al., 2018), the factors that contribute to the occurrence of maritime accidents related to lifeboats can be classified in the following categories:

- Failure of on-load release mechanism
- Design flaws other than on on-load release mechanisms
- Unintended operation of on-load release mechanism
- Insufficient maintenance of lifeboats, davits, and launching equipment
- Communications failures
- Unfamiliarity with lifeboats, davits, equipment, and their controls
- Unsafe procedures during lifeboat drills and inspections

The first three factors refer to technical aspects and the last three to the human factor contribution, one of them being common for both aspects, technical and operational.

On-load release mechanism and design flaws other than on on-load release mechanisms

The failure of the release mechanism is often related to design rather than operational problems. Of course, the failure appears in the operating time in most of the accidents but is the best example of the link between the design and usage. More often the hook is used incorrectly than a spontaneous yielding of the material takes place (hooks are now manufactured from noncorrosive material). Therefore, the operating instructions must be very well prepared. The production of some simple, intuitive and easy to inspect accessories for the operation of the LSA is the goal of the designers. Some possible solutions proposed for the future are to use the remote wire control for the lifeboats launching and recover the boats or telescoping system instead of gravity davits at least for drills until SOLAS requirements allow for such a measure. The IMO, as a response to the growing number of lifeboats accidents, released new Regulation III/1.5 and the amendments of LSA Code Ch IV concerning the on-load mechanism fitted to new and existing cargo and passenger vessels.

New aspects should be considered in the design phase of the life savings equipment, an aspect not at all minor being the one related to the average weight of a person. According to 2005 Centres for Disease Control (CDC) study cited by RINA, the average adult male now weighs 190 pounds (86.6 kilograms), while the average weight for adult women is 164 pounds (74.5 kilograms)[17].

Maintenance of lifeboats, davits, and launching equipment

Maintenance issues are mainly related to the wire ropes (cables) of the launching equipment. In most accidents broken cables were found to be caused by loss of strength due to rust, which can occur due to the atmospheric conditions of the sea (i.e. high salinity). Poor maintenance can be attributed both to bad management on the ship but also to design problems, such as obstructing the access to cables or other mechanisms that require maintenance.

Some possible solutions include carrying out the right maintenance by well trained and skilled -engineers and better interaction between equipment manufacturers, suppliers and ship's crew.

Life raft securing strap

An incident, analysed by the IMCA (2020) and made public through Safety Flash, pointed out that the securing strap used to retain the life raft in place was broken (parted in the buckle – the weakest point) and the life raft was deployed into the sea (later, recovered on deck). The analysis shows that the contributing factor are related to degradation of the sling's material due the high temperature and high UV levels, even though it was installed on board one year before.

The recommendations were referred to manufacturer's instructions regarding service life of the securing straps and inspections routines for life rafts and its lashings should consider the environmental conditions.

Marine Evacuation System slides

A UK MAIB (2018) analysis highlighted that mass evacuation of passengers wearing normal clothes is very different from the case of wearing an immersion suit, due the different friction coefficient. The presence of water on the slides walls and floor affect the speed of descent and possible injuries can occur. In an exercise based on the analysis, one person was injured due the descending speed combined with the hit of the MES raft inflating cylinder. The MES design concept must consider the various coefficients of friction of clothing and the angle of descending on the slides (provided by SOLAS to 30 – 35 degrees).

[17] https://www.maritimeinjuryguide.org/maritime-accidents-injuries/vessel-injuries/lifeboat-drill-injuries/

Lifeboats drill

A report by the Seafarers International Research Centre (Sampson et al., 2016) showed that tight vessel schedule often do not allow enough time for drills, resulting a lack of training of the crew and a questionnaire involving 2500 seafarers found that some of them are retained in participating in drills due to fear of the equipment involved. Despite a considerable amount of fear among seafarers related to both davit-launched and freefall lifeboats drills, they are preferred by the most of them rather than the life rafts, in an emergency.

According to training specialists, the drills muster must never be rushed, the crew has to be briefed and debriefed and the use of the checklist is recommended because the majority of drills accidents happen when the drills are too few and the crew is unfamiliar with the equipment.

Human factor

One way the human factor can be improved is by correctly applying the codes regarding the training of the seafarers. In this regard, the most important rules is stipulated in the STCW Code, Reg V/1, V/3 (Mandatory minimum requirements for the training and qualifications of the Masters, officers, ratings and other personnel on ro-ro passenger ships and passenger ships other than ro-ro) and requires that the personnel on board the passenger ships be trained for the following aspects:

- Crowd management, including awareness of life saving appliance and control plans; the ability to assist passengers en-route to muster and embarkation stations; mustering procedures.
- Familiarization, including: Design and operational limitations; Stability and stress requirements and limitations; Emergency procedures.
- Safety training for personnel providing direct service to passenger in passenger spaces.
- Communications.
- Life-saving appliances.
- Passenger safety, cargo safety and hull integrity.
- Loading and embarkation procedures.
- Stability, trim and stress calculations.
- Crisis management and human behaviour.

The observance of the provisions of the STCW code by the crew of the passenger ships can improve safety by mitigating the risk of human error in the operations of evacuation of the passenger ship. In a published study, the IMO Maritime Safety Committee stated that the above causes of lifeboat accidents are easily preventable and asked Member Governments to bring the Circular 1206/2009 to the attention of any and all relevant parties, such as industry organisations and seafarers. The said circular contains:

- Measures to prevent accidents with lifeboats.
- Guidelines for periodic servicing and maintenance of lifeboats, launching appliances and on-load release gear.
- Specific procedures for maintenance and servicing.
- Guidelines on safety during abandon ship drills using lifeboats.
- Guidelines for simulated launching of free-fall lifeboats.

6 Projects related to maritime evacuation

This section includes brief descriptions of concluded and on-going research projects that relate to improving the maritime evacuation process. The projects are presented in a chronological order.

The main objective of this section is to identify other research initiatives that could be potentially exploited by PALAEMON in the development of its innovative components.

6.1 FIRE EXIT

Full Title	Formulation of immediate response and evacuation strategies through intelligent simulation assessment and large-scale testing
Project website	N/A
Funding Framework	FP5-GROWTH
Duration	2002 - 2005

This project developed a Ship Evacuation Simulator, maritimeEXODUS (see also Section 3.5.3.2), for assessing issues of mustering, ship motions, fire and evacuation. The project built on existing software, such as SMARTFIRE and SHEBA and enhanced their capabilities. The project covered fire emergency aspects, such as specification of how equivalence of fire safety can be achieved, prediction of the spread of fire with CFD software, creation of a module to derive from there the pattern of smoke spreading during the evacuation and its impact on abandonment, simulation of ship's motions and smoke spreading in real-time. FIRE EXIT also aimed to achieve establishment of performance data for Life Saving Appliances to trace back failures to their sources.

6.2 SAFECRAFTS

Full Title	Safe abandoning of ships, Improvement of current Life Saving Appliances Systems
Project website	N/A
Funding Framework	FP6-SUSTDEV
Duration	2004 - 2009

The objective of this project was to develop an assessment method for evaluating the performance of life saving appliances and develop two viable novel concepts for passenger ships. To evaluate the LSA performance, volunteers were put through tests using LSAs in different conditions and situations and use the Human Health Status (HSS) as a criterion. Subsequently, the two most promising novel concepts for ship evacuation were generated and further examined. The project also included building prototypes for both concepts to assess their feasibility. The benefits of these novel concepts include improved safety, wider acceptance of rescue systems by the maritime industry, more efficient investments on rescue systems, and reductions in space needed onboard for LSAs.

6.3 Project EGO

Full Title	-
Project website	https://fseg.gre.ac.uk/fire/EGO.html
Funding Framework	EPSRC funded project
Duration	2005 - 2007

The main objective of this project was to merge the innovative technologies of Escape Simulation and Ship Configurational Design. This will lead to changes from the scope of design, regulation, construction and operation of ships which will try to improve the personnel movement on board.

This project was mainly focused on fire evacuation modelling and ship architecture design. Some other issues analysed were the crew manning numbers, function and movement, the identification of key performance measures for the crew, extension of the ship evacuation software maritimeEXODUS and a demonstration of a methodology for ship design that integrates ship configuration design with modelling of a range of crewing issues through PARAMINE-SURFCON.

6.4 SAFEGUARD

Full Title	Ship Evacuation Data and Scenarios
Project website	https://fseg.gre.ac.uk/fire/safeguard.html
Funding Framework	FP7-TRANSPORT
Duration	2009 - 2012

This project addressed the assumptions regarding passenger response time used in a ship evacuation analysis, which is a key parameter specified in the IMO evacuation analysis protocol. The main objective of the project was to collect human performance data, representing passenger response times and calculate the time needed for a ship evacuation. Data was collected for three types of ships, a ferry with cabins, a ferry without cabins and a cruise ship. The data was used for calibration and validation of the evacuation models used in each ship. The project also suggested additional benchmark scenarios for certification analysis, analysed past accidents and reported the results to IMO for possible incorporation into future regulatory amendments.

6.5 FIREPROOF

Full Title	Probabilistic Framework for Onboard Fire-Safety
Project website	N/A
Funding Framework	FP7-TRANSPORT
Duration	2009 – 2012

This project developed a risk-based regulatory framework that employed probabilistic and numerical models of ignition, growth and impact of fires that were developed for maritime fire safety. One of the main objectives of the project was to present the framework to IMO and the Maritime Safety Committee for future enforcement.

The applied methodology included a mathematical model for generating probabilistic fire scenarios and their consequences. From a large number of scenarios, appropriate risk metrics were used to assess the effectiveness of a specific design towards minimizing fire risk. The models developed in this project were based on the code from the software SMARTFIRE and maritimeEXODUS.

6.6 eVACUATE

Full Title	A holistic, scenario-independent, situation-awareness and guidance system for sustaining the Active Evacuation Route for large crowds
Project website	http://www.evacuate.eu/
Funding Framework	FP7-SECURITY
Duration	2013 - 2017

The main objective of this project was to satisfy the safety needs of people during evacuation situations by creating a holistic system. This system will increase the possibilities for a successful evacuation at any type of venue or infrastructure by adapting various plans according to the current evolving conditions through a dynamically surveying the process. The system will analyse the circumstances and identify the best possible evacuation route (Active Evacuation Route, AER). This will be helpful for the civil protection authorities as well.

6.7 FIRESAFE I and II

Full Title	-
Project website	http://www.emsa.europa.eu/implementation-tasks/ship-safety-standards/item/3424-firesafeii.html
Funding Framework	EMSA Studies
Duration	2016, 2017

The main objective of these studies was to improve the fire safety of ro-ro passenger ships by suggesting economically sound measures for the reduction of risk of fire on ro-ro spaces, with the ultimate goal to propose specific rule modifications. The first phase of the project, in 2016, was mainly focused on electrical fire as an ignition source and fire extinguishing failures. On the second stage, in 2017 (FIRESAFE II), the analysis was based on investigating risk control options in relation to detection and decision making, as well as containment and evacuation. In addition, two full scale tests were performed, one focused on alternative fixed fire extinguishing systems and the other on detection systems in open ro-ro and weather decks.

6.8 SafePass

Full Title	Next generation of life Saving appliances and systems for saFE and swift evacuation operations on high capacity PASSenger ships in extreme scenarios and conditions
Project website	http://www.safepass-project.eu/
Funding Framework	H2020-EU.3.4
Duration	2019 - 2022

This project aims to improve the evacuation process by assisting both the crew members and the passengers. SafePass will redefine the evacuation process, systems, equipment and regulations by developing an integrated system that will monitor information from the ship and give the suitable instructions, such as the quickest evacuation routes and information on how to use LSAs properly. In this way the evacuation will be completed faster and safer. The project will also develop advanced, intuitive and easy to use LSAs.

6.9 Projects related to ICT technologies used in maritime evacuation

6.9.1 LYNCEUS and LYNCEUS2MARKET

Full Title	People Localization for save ship evacuation during emergency
Project website	http://www.lynceus-project.eu/
Funding Framework	FP7-SME
Duration	2012 - 2015

The objective of these projects was to improve the existing or launch new devices and actions to minimize the danger and losses in an evacuation scenario. It mainly focused on developing an innovative and low-cost system that consists of wireless devices that will provide people's localization, decision support, activity and disaster escalation monitoring. The innovations include lifejackets that provide real-time passengers location, smart smoke detectors, fire and flood escalating detectors, localizable bracelets providing activity data, automatic handheld devices for counting and identifying passengers during the evacuation and smart localizable key cabins.

The innovative wireless devices were developed to be easily integrated in new and existing passenger ship infrastructure providing a low-cost and robust safe evacuation system. In addition, an adaptive Decision Support System (DSS) which takes into account the information given by the innovative devices was created, as well as an innovative shore or ship-launched Unmanned Aerial Vehicle (UAV) for localizing people and low-cost rescue-boat mounted radars as well. The objective of the DSS was to minimize the risk of incomplete evacuation and assist the difficult assessment of the prediction of ship's motion and sudden changes of the weather, which affect the behaviour of the passengers.

6.9.2 BIGDATAOCEAN

Full Title	Exploiting Ocean's of Data for Maritime Applications
Project website	http://www.bigdataocean.eu/site/
Funding Framework	H2020-EU.2.1.1
Duration	2017 - 2019

The main objective of this project was using modern technological innovations in order to change how maritime-related industries work. As the seafaring sector is very conservative, it could be greatly benefited with the use of emerging technologies, such as data-driven economy, interrelated data streams from diverse sectors and languages, and cross-technology innovations that deliver data in several different formats. These technological changes will enforce an improvement in these industries' workflow, allowing them to improve their performance

Novel services and applications that allow maritime-related industries, organisations and stakeholders, in general, to generate more (a) factual and evidence-based analytics, (b) decision support models, and (c) new business services focused on real-time collaboration, knowledge sharing amongst the key stakeholders, based on both (i) real-time data streams taking into consideration the data and temporal granularity aspects, and (ii) on batch processed data to extract analytics and intelligence to influence strategic mid-term and long-term operations planning. BDO aims to constitute the central node of a dynamic and expanding network.

6.9.3 CONCORDE

Full Title	Development of Coordination Mechanisms During Different Kinds of Emergencies
Project website	https://www.konnektable.net/concorde.html
Funding Framework	FP7-SECURITY
Duration	2014 - 2017

CONCORDE is a web-based platform that supports and enhances the existing coordination and decision processes during small or large-scale medical emergencies, at local, regional and cross-border level. The emergency management system that was developed as a DSS in this project will also be used as a basis in PALAEMON.

6.9.4 I-BiDaas

Full Title	Industrial-Driven Big Data as a Self-Service Solution
Project website	https://www.ibidaas.eu/
Funding Framework	H2020-EU.2.1.1
Duration	2018 - 2020

I-BiDaas aims to empower users to easily utilize and interact with big data technologies. This is an interesting project to be considered in PALAEMON, which will also involve the development of big data structures.

7 Regulatory framework

This section provides an overview of the framework that regulates maritime evacuation and sets requirements for ship design, operational procedures, LSAs, and crew training. In the following paragraphs, international and European regulation with respect to evacuation and safety of passenger ships are summarized, as well as, cybersecurity and data privacy regulations are presented.

The main objective of this section is to identify the main constraints (i.e., minimum requirements) relating to marine evacuation and provide input to the development of the requirements for the PALAEMON components.

7.1 International regulations on evacuation

Passenger ships must comply with all relevant IMO standards, including safety regulations and requirements for the prevention of pollution from ships. The 1912 Titanic disaster resulted in the first SOLAS treaty being adopted and since then many revisions to regulations have been applied, both in response to major incidents and as a result of a pro-active approach to keeping the regulations up to date. The SOLAS treaty applies to passenger ships carrying more than 12 passengers on international voyages, as well as large cruise ships with a capacity of thousands of passengers and thus the treaty is broadly formulated (Brown, 2016). However, IMO has also been working with countries to address the safety of so-called non-SOLAS ships, including developing model legislation and guidance.

After the year 2000, when the size of passenger ships started to increase significantly, regulations placed more emphasis on two pillars; namely the prevention of casualties and the improved survivability of the ship, so that in the case of casualty, persons can remain safely on-board until the ship returns to port. Recent amendments, which are in force since 2010 (IMO, n.d.), also provide regulatory flexibility so that future design may adapt to new challenges. The most important ones are the redundancy of systems, for safe return to port, on-board safety centres from where the safety systems can be operated unhinderedly, fixed fire detection and alarm systems, fire prevention enhancing the fire safety of atriums, the means of escape and ventilation systems, time requirements for orderly evacuation and last but not least, requirements for the essential safety systems which must remain operational in case any of the main vertical zones is unserviceable due to fire.

A major concern for large passenger-ship safety is the difficulty in safely transferring some specific groups of passengers, such as the elderly and injured, from lifeboats to rescue vessels, even if the evacuation process is successful. Thousands of people, unfamiliar with ships and the sea, crowded into lifeboats and life rafts, present a unique search-and-rescue challenge.

Innovative technologies that will be developed during the PALAEMON project should comply with the SOLAS regulation or offer equivalent safety with the current measures. PALAEMON will mainly interact with Ch. III of SOLAS, also referred to as Life Saving Appliances (LSA) Code. There also several references for safety requirements in Chapter II-1 (Construction – Structure, Subdivision and Stability, Machinery and Electrical Installation) and Chapter II-2 (Construction – Fire Protection, Fire Detection and Fire Extinction) of SOLAS, as protection against fire may interact and pose constraints on the design of evacuation systems.

From the most relevant SOLAS chapters to PALAEMON, regulations are summarized, mainly relating to life-saving appliances (lifeboats etc.), fire safety and evacuation procedures.

7.1.1 SOLAS 2017 - Chapter II-1 (Construction – Structure, Subdivision and Stability, Machinery and Electrical Installation)

Regulation 42: Describes the requirements for the emergency source of electrical power and. Additionally, according to this regulation, the available electrical power shall be sufficient all this services that are essential for safety in an emergency, due regard being paid to such services as may have to be operated simultaneously. The emergency source of electrical power shall be capable of supplying simultaneously a list of services (loads) for different periods of time (36 hours is the case for most emergency services). Therefore, the PALAEMON digital ecosystem should be included as one of the loads that will rely on the emergency power system, in case of an incident. Re-evaluation of the existing emergency power system may be necessary, if the sizing is not adequate.

Regulation 22-1: Flooding detection systems for passenger ships carrying 36 or more persons. According to this regulation, a flooding detection system for watertight spaces below the bulkhead deck shall be provided based on the guidelines developed by the Organization (MSC.1/Circ.1291). This detection system may be integrated in the overall PALAEMON system and be one of the parameters that will contribute in the final decision support tool and the guidance during evacuation.

Regulation 19 - Damage control information. According to this regulation plans showing clearly each deck and the boundaries of each watertight compartment, the openings and the means of closure and location of the controls and the arrangement of any corrective actions in case of list due to flooding. In PALAEMON, these plans should be available in electronic format within the platform that will be installed in the navigation bridge panel and they may be dynamically updated based on the input being constantly received and processed from the installed PALAEMON components.

7.1.2 SOLAS 2017 - Chapter II-2 (Construction – Fire Protection, Fire Detection and Fire Extinction)

Regulation 12 – Notification of crew and passengers. This regulation included the most generic requirement of a general emergency alarm system and a public address system, the purpose of which is to notify crew and passengers of a fire for safe evacuation. Additionally, in passenger ships a public address system, or other means of communication complying with the regulation III/6.5 shall be available throughout the accommodation and service spaces and control stations and open decks. In PALAEMON, the general alarm system and the public address system shall not be replaced by another component, but they should be integrated in the ICT infrastructure that will be developed, which will act over and above this regulation's minimum requirement. However, it should be clarified if these systems will still be triggered manually by the crew or they will also be handled by the PALAEMON smart system. The PALAEMON ICT infrastructure will be designed and implemented to not interfere or hinder, under any circumstances (operation or failure), the required functionality, by this regulation, of the general alarm and public alarm systems.

Regulation 13 - Means of escape: Provides the means of escape so that persons onboard can safely and swiftly escape to the lifeboat and liferaft embarkation deck. The enlisted requirements of the means of escape will be critical of the new ship design that will be proposed in PALAEMON, accommodating the innovative Mass Evacuation Vessels (MEVs).

One of the most important constraints, as identified by DNV GL team, was the existence of a fire safety zone at the embarkation decks before the MEVs, which will pose an interesting challenge in the proposed MEV-II concept, where MEVs will be an inherent part of the vessel. Paragraph 3.2.4.1 of the same regulation describes the following requirement:

“At least one of the means of escape required by paragraphs 3.2.1.1 and 3.2.2 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 decks, or to the uppermost weather deck if the embarkation deck does not extend to the main vertical zone being considered. In the latter case, direct access to the embarkation deck by way of external open stairways and passageways shall be provided and shall have emergency lighting in accordance with regulation III/11.5 and slip-free surfaces underfoot. Boundaries facing external open stairways and passageways forming part of an escape route and boundaries in such a position that their failure during a fire would impede escape to the embarkation deck shall have fire integrity, including insulation values, in accordance with tables 9.1 to 9.4, as appropriate.”

The same regulation includes requirements for the marking of escape routes, which should be considered during the design of the visualizations of the PALAEMON digital tools (i.e. signs that will appear in the AR glasses).

Regulation 22 - Design criteria for systems to remain operational after a fire casualty: This regulation describes the design criteria for systems required to remain operational for supporting the orderly evacuation and abandonment of a ship after a certain casualty. In case any one of the main vertical zones is unserviceable due to fire, the following systems shall be so arranged and segregated as to remain operational:

1. Fire main,
2. internal communications (in support of firefighting as required for passenger and crew notification and evacuation),
3. means of external communications,
4. bilge systems for removal of fire-fighting water,
5. lighting along escape routes, at assembly stations and at embarkation stations of life-saving appliances; and
6. guidance systems for evacuation shall be available

The above systems shall be capable of operation for at least 3 hours based on the assumption of no damage outside the unserviceable main vertical zone. These systems are not required to remain operational within the unserviceable main vertical zones.

Cabling and piping within a trunk constructed to an "A-60" standard shall be deemed to remain intact and serviceable while passing through the unserviceable main vertical zone for the purposes of paragraph 3.1. An equivalent degree of protection for cabling and piping may be approved by the Administration.

Applying the above regulation in the PALAEMON system, we should make sure that the PALAEMON system shall comply with this regulation, as it will be considered as one of the main emergency systems of the ship, as well as the cabling that will include should be of the prescribed type in order to remain undamaged through the damaged zone.

Regulation 23 - Safety centre on passenger ships: Passenger ships shall have on board a safety centre complying with the requirements of this regulation. The purpose of this regulation is to provide a space to assist with the management of emergency situations. The same regulation lists the suggested locations for this centre, the means of communication and the control and monitoring of safety systems. Therefore, installing the PALAEMON central server in this space would be a practical decision.

7.1.3 SOLAS 2017 - Chapter III (LSA – Life Saving Appliances)

Regulation 7 - Personal Life Saving Appliances: This regulation describes where and how many personal life saving appliances must be on the ship. These include specifications of amount, location and accessibility of lifebuoys, lifejackets and immersion, anti-exposure suits (for the crew), and liferafts. Special emphasis is given on the amount of life jackets for infants and children, calculated as a percentage of the total amount of passengers, depending on the duration of the ship voyages. Special requirements also exist for liferafts, which should contain adequate equipment to be as self-sufficient once detached from the ship (i.e. battery power lamps that must be recharged by the ship's main and emergency power source). Additional requirements for passenger ships are included in Regulation 22.

The above requirements can be taken into consideration and scaled up for the new Mass Evacuation Vessels (MEVs) that will be designed in PALAEMON, for them to be adequately equipped with the required personal life saving appliances.

Regulation 8 - Muster list and emergency instructions: The most important aspect here is that, for passenger ships, instructions and signs shall be drawn up in the language or languages required by the ship's flag State and in the English language. This should be considered when designing the advanced PALAEMON digital infrastructure, as the language of the messages shown on screens/glasses and other components, should comply with this regulation.

Regulation 16 - Survival craft launching and recovery arrangements: This regulation should be studied and followed by the PALAEMON new Mass Evacuation Vessels (MEVs) designs, as it provides critical details of the methods, dimensions and tolerances of the launching of evacuation vessels. The launching of MEV has been identified as one of the most challenging engineering problems that must be solved in the project, which should also comply with this regulation.

Regulation 21 - Survival craft and rescue boats: This is the most important regulation that will have a direct impact on the design of the PALAEMON Mass Evacuation Vessels (MEVs). It defines the passenger coverage of lifeboats and/or liferafts, depending on if the ship engages on long or short international voyages. The time period of 30 minutes between the launching of lifeboats and abandon ship signal and after all persons have been assembled, with lifejackets donned, must be preserved independently of the new evacuation means and strategies that will be proposed in PALAEMON.

Most importantly, for new evacuation designs, paragraph 1.5 mentions: “A marine evacuation system or systems complying with section 6.2 of the Code may be substituted for the equivalent capacity of liferafts and launching appliances required by paragraph 1.1.1 or 1.2.1.”. Section 6.2 of Chapter VI (Launching and Embarkation Appliances) of LSA Code outlines the requirements of design and construction of marine evacuation systems. Consequently, any new design that will be developed within the PALAEMON context must comply with the requirements of this Section.

Regulation 24 - Stowage of survival craft: This regulation outlines additional requirements for passenger ships, regarding the dimensions of the stowage and launching mechanism of survival crafts. The general requirements of all ships are found in Regulations 13, 14 and 15. These regulations can contribute in the design of the mechanism that will support, stow and launch the MEVs.

Regulation 11 - Survival craft muster and embarkation arrangements: This regulation is also supplemented by Regulation 25, which includes additional requirements for mustering stations of passenger vessels. The PALAEMON ecosystem that we be developed must fulfil these requirements or further enhance them.

Regulation 27 - Information of passengers: This regulation outlines the information that shall be kept on-board and/or ashore, giving emphasis on people in need of special care. This is the minimum basis where on-top each company may request more information, in order to offer additional and more personalized services to passengers, always abiding the new GDPR regulation. Similarly, PALAEMON system will ensure to cover the requirements of this regulation and further expand from this point to gather and process more data to build the evacuation ecosystem and propose the most fitting evacuation strategies.

Regulation 29 - Decision support system of Masters of passenger ships: This regulation describes the minimum requirement, which is the existence of printed emergency plans, covering all the foreseeable emergency situations, and combinations of them. These plans are adequate for passenger ships engaged in non-international or short voyages, as we noticed on-board the El. Venizelos ship of ANEK, during the 2nd day of the WP2 workshop (25-26/11/2019). However, for larger ships (cruise) engaged in long international voyages, these emergency plans tend to be replaced by more advanced decision support tools/software, which is also exactly what the PALAEMON digital infrastructure will attempt to further enhance.

Regulation 35 - Survival craft muster and embarkation arrangements: This regulation indicates that a detailed training manual shall exist in every location the crew is accommodated, illustrating the life-saving appliances and the best methods of survival. Any part of such information can also be provided in audio and/or video format. PALAEMON digital ecosystem can also include this information in a relevant help menu.

Regulation 37 - Muster list and emergency instructions: This regulation includes the crew requirements and duties during an emergency case. In PALAEMON, the guidelines of this regulation can be followed to decide what information will be available at each crew member, depending on his/her rank and duties.

Regulation 38 – Alternative design and arrangements: This regulation provides a methodology for alternative design and arrangements for life-saving appliances and arrangements. The concept of this regulation is that life-saving appliances and arrangements may deviate from the requirements of the existing regulations, provided that they meet the intent of these requirements and provide an equivalent level of safety. Regarding PALAEMON, any new systems that are going to be developed having also the intent to replace any existing life-saving systems, shall prove that they offer the equivalent level of safety with the existing systems that are going to be substituted. To this end, an engineering analysis is required, along with evaluation and approval of it. The minimum contents of this engineering analysis are included in this regulation and they can act as a guidance during the development of the innovative PALAEMON systems:

1. determination of the ship type and the life-saving appliance and arrangements concerned;
2. identification of the prescriptive requirement(s) with which the life-saving appliance and arrangements will not comply;
3. identification of the reason the proposed design will not meet the prescriptive requirements supported by compliance with other recognized engineering or industry standards;
4. determination of the performance criteria for the ship and the life-saving appliance and arrangements concerned addressed by the relevant prescriptive requirement(s):
    a. performance criteria shall provide a level of safety not inferior to the relevant prescriptive requirements contained in part B; and
    b. performance criteria shall be quantifiable and measurable.
5. detailed description of the alternative design and arrangements, including a list of the assumptions used in the design and any proposed operational restrictions or conditions;
6. technical justification demonstrating that the alternative design and arrangements meet the safety performance criteria; and
7. risk assessment based on identification of the potential faults and hazards associated with the proposal.

This regulation also includes an evaluation and approval part, which is subject to the Flag Administration. PALAEMON is an R&D project, meaning that the evaluation and approval of any new systems that are going to be developed is outside the scope of the project, as no documents are going to be submitted to any Flag authority, since there is no operational modification to any specific ship. However, a critical review will be performed by DNV GL, which will not be binding to any evaluation or decision made by any Flag Administration and it will serve as guidance.

7.1.4 Regulatory agenda for 2020

It is worth mentioning that in 2020, some provisions of IMO, which complements the SOLAS Convention, came into force on issues related to rescue equipment and arrangements. According to MSC.421(98), starting from 1 January 2020, the drills for passenger ships must involve crew members who have damage control responsibilities. Listed are some instructions regarding the content of the damage control drill, which must be followed for various scenarios, such as:

- use of the damage control information and the onboard damage stability computer;
- demonstrating proficiency in the use of the flooding detection system; and
- instruction in damage survey and use of the ship's damage control systems;

In 2020 requirement will come into force regarding lifeboats and rescue boats, launching appliances and release gear, clarifying the requirements for the qualification, authorization and the certification of service suppliers and maintenance and testing procedures.

7.2 European regulations on evacuation

The EU legislation on passenger ships was borne, as most international conventions, after major accidents such sinking of the Herald of Free Enterprise in 1987 and Estonia in 1994, which resulted in hundreds of human losses. The EU maritime legislation, including those for passenger ships, complements the international and national framework for a safer navigation a cleaner environment. The European Union continues to be an important promoter for the continuous updating of international conventions at International Maritime Organisation (IMO) in the field of maritime safety and environmental protection but also for the promotion of a fair competitive market.

In the European Economic Community (ECC), ship safety is regulated at three levels - international, European and national levels. International maritime legislation consists mainly of conventions, protocols, codes, resolutions, rules or standards, adopted in an international conference or International Maritime Organization (IMO) and refers to passenger ships - ships carrying more than 12 passengers engaged in international voyages; in the European legislative technique most often, these are called international instruments. The most important conventions currently referred to are SOLAS and Load Lines Conventions which cover most of the requirements of construction and operation of the ship.

In addition to the improvements in technical regulations, the STCW Code and the International Code for Safety Management (ISM) were important steps in taking in to account the "human element", to provide international standards of training, certification and watchkeeping for seafarers and for the safe management and operation of ships.

At IMO level, the work in developing the safety regulations is based on the dual premise that the regulatory framework should place more emphasis on the prevention of a casualty from occurring in the first place and that future passenger ships should be designed for improved survivability so that, in the event of a casualty, persons can stay safely on board as the ship proceeds to port. However, one of the five pillars of guiding philosophy in the development of safety rules refers to Operations in areas remote from SAR facilities, which means, among other things, action taken to develop amendments to SOLAS Chapter III and guidance to assist seafarers taking part in SAR operations.[18]

The European Community legislative acts in the field of maritime safety, consist most often of directives and regulations. In order to apply the provisions of a Community act, reference may be made to an international instrument or the Community provisions will reproduce the international instrument partially or totally. In the latest case, the most recent amendments to the international instruments are not yet applicable until the relevant Community provisions have been amended.

The European Commission's Regulatory Fitness and Performance (REFIT) programme aims to ensure that EU legislation delivers results for citizens and businesses effectively, efficiently and at minimum cost and within this programme, the EU Commission envisages proposing a simplified regulatory framework for EU passenger ship safety. Its aim is to remove outdated, ambiguous or disproportionate requirements, and to further improve the effectiveness of

[18] http://www.imo.org/en/OurWork/Safety/Regulations/Pages/PassengerShips.aspx

search and rescue operations. Where appropriate, the Commission envisages stepping up the efforts to upgrade standards at the level of the International Maritime Organization.[19]

In order to improve the implementation of Community legislation on maritime safety and the prevention of pollution from ships, a single Committee on Safe Seas and the Prevention of Pollution from Ships, known as COSS, was established by the Regulation (EC) No 2099/2002 of the European Parliament and of the Council of 5 November 2002.

Besides the European Commission there are expert groups such as Passenger Ship Safety Expert Sub-Group which has the advisory role of European Commission in relation to the preparation of legislative proposals or the implementation of EU legislation. The members of the Commission expert groups can be individuals, organizations, Member States' authorities or other public entities.

As a series of maritime conventions (SOLAS, MARPOL) were adopted by IMO as a reaction of major maritime accidents (TITANIC, Torrey Canyon), after the ecological disaster provoked by the oil tanker ERIKA in December 1999, the European Commission proposed appropriate actions at Community level materialized through packages of safety measures known as *Erika I, II and III*.

The packages consist of measures on port state control, ship inspection, classification societies, monitoring control and information system for maritime traffic, setting up the European Maritime Safety Agency (EMSA), liability, compensation for damages of passengers, investigations of maritime accidents and places of refuge for ships in need of assistance.

The international regulatory framework on Passenger Ship Safety has had since its inception, deficiencies in definitions and inconsistent texts or difficulties in implementation. IMO has not always had the necessary tools for the implementation of the rules, the decision regarding the application remaining at national level. Nevertheless, the exemption/equivalence procedure in SOLAS is less costly compared with the European procedure, but the latter improve safety, as the measures are evaluated many times by different experts and adopted after risk evaluation while IMO take them into account only and communicates to other States[20].

7.2.1 Safety and standards of passenger ships

The passenger ships safety in European area is governed by a legal framework consisting of different legal acts; the most important is the Directive 2009/45/EC of the European Parliament and of the Council of 6 May 2009 on safety rules and standards for passenger ships.

This Directive was amended by the Directive 2017/2108 of the European Parliament and of the Council of 6 May 2009, whose provisions must be adopted by the Member States into national legislations, until 21 December 2019.

The main reference framework for safety standards is the SOLAS Convention 1974, with subsequent amendments, which includes internationally agreed standards for construction and operations of passenger ships and the corresponding resolutions adopted by IMO or others measures that complement and interpret that convention.

[19] https://ec.europa.eu/transport/modes/maritime/news/refit-passenger-ship-safety-legislation_ro
[20] https://publications.europa.eu/en/publication-detail/-/publication/0be15350-73fb-11e5-86db-01aa75ed71a1

The differences between the provisions of SOLAS and amended Directive 2009/45/EC will be highlighted with regards to the rules applicable to the passenger ships, in the field of safety evacuation systems and life-saving appliances.

The first important issue concerns the **scope** of the two regulations:

A. SOLAS Convention

Regulation 1 - … *the present regulations apply only to ships engaged on international voyages*.
Regulation 3 - … *do not apply to ships of less than 500 gross tonnage*
Section II – Passenger ships (more than 12 passengers) – *additional requirements*

B. Directive 2009/45/EC and Directive 2017/2108/EC

Article 3 - … *applies to the following passenger ships and craft, regardless of their flag, when engaged on domestic voyages* (a voyage in sea areas from a port of a Member State to the same or another port within that Member State)[21]:

a) New and existing passenger ships of 24 meters in length and above
b) High-speed passenger craft

The SOLAS Convention lays down some special rules for ships operating on short international voyages – the ship is not more than 200 miles from a port or place in which the passenger could be placed in safety.

On the other hand, to avoid the distortions of the competition, the common safety requirements apply to passenger ships engaged on domestic voyages in the Community, irrespective of the flag they fly. The EU Directive applies to a wider range of passenger vessels and includes those operating in domestic voyages but divided the passenger ships into different classes, depending upon the range and the sea state conditions.

Table 10 shows the sea area categories and describes the link between the sea areas and passenger ships Classes, according to the Directive 2017/2108/EC[22]. The Member States should establish and publish the list, in a public database available on the internet site of the maritime authority, of areas under its jurisdiction with the zones of operation using the criteria for classes set out according to Table 10.

[21] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:163:0001:0140:EN:PDF
[22] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32017L2108

Table 10: Sea areas and passenger ship classes.

Sea Category/Passenger ship class	Description of the sea
Area A/ Class A – passenger ship engaged on domestic voyages in Areas A, B, C and D	A sea area outside of areas B, C and D.
Area B/ Class B – passenger ship engaged on domestic voyages in Areas B, C and D	A sea area, whose geographical coordinates are at no point more than 20 miles from the line of coast, corresponding to the medium tide height, but which is outside of areas C and D.
Area C/ Class C – passenger ship engaged on domestic voyages in Areas C and D	A sea area, whose geographical coordinates are at any point no more than 5 miles from the line of coast, corresponding to the medium tide height, but outside of sea area D if any. Additionally, the probability of the significant wave height exceeding 2,5 meters shall be smaller than 10 % for a period of one year for all-year-round operation, or for a specific period for seasonal operation, such as summer period operation.
Area D/ Class D – passenger ship engaged on domestic voyages in Area D	A sea area, whose geographical coordinates are at any point no more than 3 miles from the line of coast, corresponding to the medium tide height. Additionally, the probability of the significant wave height exceeding 1,5 meters shall be smaller than 10 % for a period of one year for all-year-round operation, or for a specific period for seasonal operation, such as summer period operation.

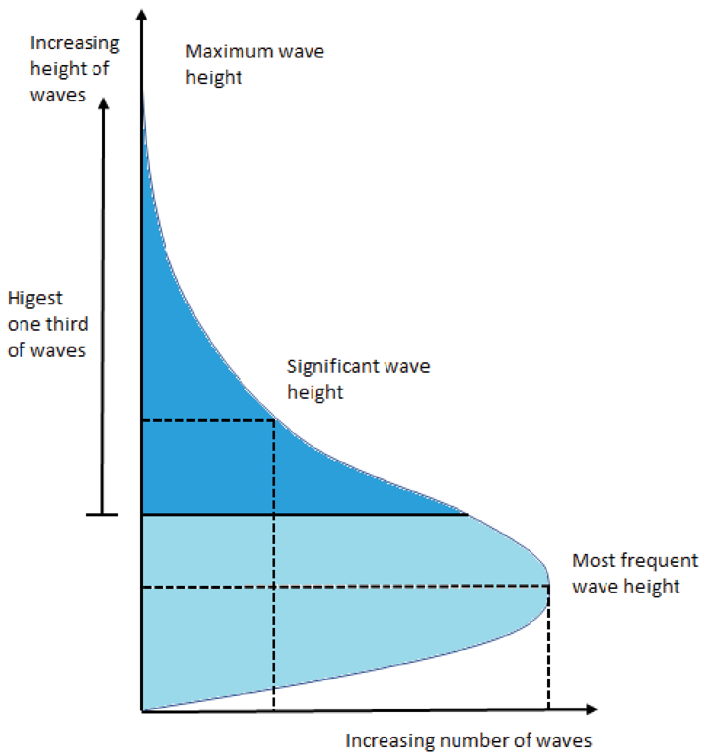

Figure 29: Significant wave height.

It is worth mentioning that the Directive introduces probabilistic criteria in the delimitation of certain areas of operation of passenger ships. The significant wave height, which is used as reference, is defined according to Article 2 of the Directive 2009/45/EC, as the average height of the highest third of wave heights observed in a given period. For better understanding, the highest third of waves is highlighted in dark blue in Figure 29.

It is easy to see that Class A vessels are fully compliant with SOLAS provisions, but the Directive 2009/45/EC provides, in Article 6 regarding *Safety requirements*, where SOLAS leaves the interpretation of regulations to the discretion of the Administration, the interpretations of the Annex I of Directive will be applied (actually, express technical provisions similar to those in SOLAS Convention).

7.2.2 Safety requirements for intact stability of passenger ships

Regarding the safety requirements of the Directive 2009/45/EC, those related to the PALAEMON project and the connection with the provisions of the 1974 SOLAS Convention or other relevant international provisions are highlighted.

In conjunction with the Intact stability; subdivision and damage stability, Part B Annex I Directive 2009/45/EC (18) establish that, all new class A, B, C and D ships of 24 meters in length and above shall comply with the provisions for passenger ships of the Code on Intact Stability as adopted by IMO through Resolution A.749. In the Part B (recommendations) of the IS Code, Chapter 4, is provided that a stability instrument installed onboard should cover all stability requirements applicable to the ship.[23] The software is subject to approval of the Administration and is good to know that any integrated system which controls or initiates actions based on the sensor-supplied inputs is not within the scope of this Code except the part calculating the stability.

7.2.3 Life-saving appliances for passenger ships

In Chapter III of the 1974 SOLAS Convention, the rules regarding the life-savings appliances and arrangements, mandatory for the ships that apply this convention are provided.

The provisions relating to Life Saving Appliances (LSA) are detailed in Annex I of Directive 2009/45/CE and refer to ships engaged in domestic voyages, however for the new existing class B, C and D ships, unless expressly provided otherwise, the definitions of the 1974 SOLAS Convention Reg III/3, shall apply. Also, the life-saving appliances including the launching appliances where applicable, shall comply with the regulations of Chapter III of 1974 SOLAS Convention, as amended, unless expressly provided otherwise in the paragraphs of the Annex I of Directive 2009/45/CE.

In Chapter III of the Annex I are established the provisions regarding LSA, and the most important one related to PALAEMON are detailed below.

1. The number of survival craft (lifeboats or life-rafts) onboard -for all classes B, C, D - shall be calculated so that it can take over 110% of the total number of persons the ship is certified to carry. Also, a marine evacuation system or systems complying with section 6.2 of the LSA Code may be substituted for the equivalent capacity of life-rafts and launching appliances required by same provisions. Section 6.2 of the LSA Code provides requirements related to marine evacuation systems, regarding constructions,

[23] Resolution MSC.267(85) (adopted on 4 December 2008) adoption of the INTERNATIONAL CODE ON INTACT STABILITY, 2008 (2008 IS CODE).

performance, life-rafts used in conjunction with this system, containers for marine evacuation system and marking used.[24]

2. The manning of survival craft and supervision observe Regulation 10 from SOLAS Ch III and is applied to all classes of passenger ships. There shall be a sufficient number of trained persons on board for assembling and assisting of untrained persons, meaning that the implementing of a new system such as PALAEMON, implies the proper training of the crew in its use.
3. An approved type of Marine Evacuation System (MES), complying with the section 6.2 of the LSA Code shall pe installed onboard of all classes of passenger ships (B, C, D), when the height from the embarkation station to the water is more than 4,5 m and the craft launching arrangements does not allow embarkation before it is on the water. The stowage of the MES, according to the (Annex I Ch. III - Art.8a) shall be in such a way that the shipside will not have any openings between the embarkation station of the ME S and the waterline. The communication between embarkation station and the platform of the survival craft shall be also ensured.
4. In all class B, C, and D ships, a decision support system (DSS) for the Master shall be provided on the navigational bridge (also according to the Regulation 29 SOLAS Ch III). The rule 5.3.6 of Ch III from Annex I of the Directive, stipulates the possibility of use of a computer-based decision-support system on the navigation bridge which provides all the information contained in the emergency plan or plans, procedures, check lists, etc., which is able to present a list of recommended actions to be carried out in foreseeable emergencies.
5. The Directive also establish certain technical requirements regarding the stowage of the survival craft for all classes of passenger ships, including the requirement that each survival craft to be stowed as near to the water surface as is safe and practicable and for the davit-launched crafts; the height of the davit head shall not exceed 15 meters to the waterline but the craft in embarkation position to stays clear of the waterline under unfavourable conditions of trim of up to 10^0 and listed up to 20^0. Each survival craft should be in a readiness so that two crew members can prepare it for embarkation in 5 minutes and the life-rafts associated with a MES shall be stowed close to the container containing the MES.

7.2.4 Passenger Ship Safety Certificate

All passenger ships covered by this Directive will be inspected by the flag Administration and will be issued a certificate – Passenger Ship Safety Certificate, the format of which is set in Annex II of Directive 2009/45/EC and for a period not exceeding 12 months (Article 13).

7.2.5 Persons with reduced mobility

A novelty of this Directive is the introduction of requirements related to persons with reduced mobility, thus through Article 8, the Member States shall ensure that appropriate measures are taken based on the guidelines from Annex III, to enable persons with reduced mobility to have safe access to all passenger ships of Classes A, B, C and D.

Is important to be mentioned that, according to Article 9 of Directive, a Member State may adopt measures allowing equivalents for the regulations contained in Annex I, provided that such equivalents are at least as effective as such regulations.

[24] Resolution MSC.48(66) (adopted on 4 June 1996) Adoption of the INTERNATIONAL LIFE-SAVING APPLIANCE (LSA) CODE.

7.2.6 Registrations of persons sailing onboard passenger ships

In order to enhance the safety and possibilities of rescue of the passengers and crew on board passenger ships operating to or ports in Member States of the Community and to ensure that search and rescue and the aftermath of any accident which may occur can be dealt with more effectively, has adopted the Directive 98/41/CE of 18 June 1998 on the registration of persons sailing on board passenger ships operating to or from ports of the Member States of the Community. The Directive 98/41/EC is in accordance with the right of Member States from European Community to impose on passenger ships sailing to or from their port's certain requirements more stringent than those laid down in the SOLAS Convention.

According to Article 2, persons shall mean all people on board irrespective of age and passenger ship shall mean a sea-going ship which carries more than twelve passengers[25].

In this Directive responsibilities are set out for companies, Member States and ships in the matter of registration of persons on board passenger ships. Thus, the companies are required to count the persons before departing, communicate this information to the Master of the ship and record this number in a registrar together with other relevant information – name, sex, age category, special care or need of assistance in emergency situations - not later than thirty minutes after departure. The shipping company shall ensure that the information is readily available for transmission to the designated authority for search and rescue purposes.

The registration system set up shall be approved by the Member State, according to Article 10 of Directive 98/41/EC, and random check for the proper functioning of the system will be performed. The registration system also shall meet the following functional criteria:

- Readability - format easy to read,
- Availability - available to the designated authorities,
- Facilitation – no undue delay for passenger embarking/disembarking
- Security – data protection for loss, alteration, disclosure or access.

The Master of ship shall ensure before departure that the number of persons on board does not exceed the number of passengers that ship is permitted to carry.

7.2.7 Safety management

The adoption of the ISM Code – in 1993 by resolution A.741(18) - represented a step forward in the safety of ships by providing of an international standard for the safe management and operation of ships. The scope of the ISM Code was also laid down through SOLAS Convention in Chapter IX, introducing the obligation of companies to hold a Document of Compliance (DOC) issued by the Administration and the ships to hold a Safety Management Certificate (SMC), issued by the Administration or an organization recognized by Administration.

At European level, it was desirable to apply directly the ISM Code, in its up-to-date version, to ships flying the flag of a Member State as well as to ships, regardless of their flag, engaged exclusively on domestic voyages or on a regular shipping service operating to or from ports of the Member States and was done through Regulation (EC) No 336/2006 of the European Parliament and of the Council of 15 February 2006 on the implementation of the International Safety Management Code within the Community and repealing Council Regulation (EC) No 3051/95[26].

[25] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31998L0041
[26] https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=CELEX:32006R0336

The scope of Regulation 336/2006 was extended to:

- Cargo ships and passenger ships, flying the flag of Member State, engaged on international voyages.
- Cargo ship and passenger ships engaged exclusively on domestic voyages, regardless of their flag.
- Cargo ship and passenger ships operating to or from ports of the Member States, on a regular service, regardless of their flag.

However, this regulation does not apply to the passenger ships in sea areas Class C and D, according to Article 3.2 as defined in Directive 98/18/EC (defined as above).

One of the objectives of the safety management provided in the ISM Code is the continuous improvement of the skills of the personnel from the shore and from the ship on the safety management, including preparation in case of emergency. Such a situation is the evacuation of the ship and the measures that can be taken according to new approaches are proposed in PALAEMON and a revision of the procedures will be necessary if the proposed action and facilities will be implemented in the future.

7.2.8 Marine equipment

For the technical proposals of PALAEMON, it is useful to know some aspects related to the requirements that marine equipment must meet in order to be used on board vessels from the European Community. As is known, the international maritime safety conventions require flag States to ensure that the equipment carried on board ships complies with certain safety requirements as regards design, construction and performance, and to issue the relevant certificates but it leaves the flag administrations with a significant margin of appreciation.

At the European Union level, the solution was to harmonize the market through common rules of application of test and performance standards and uniform certification procedures. These were established by the Council Directive 96/98/EC reformed by the Directive 2014/90/EU of the European Parliament and of the Council on marine equipment.

Although the subject is very complex but well known by Recognized Organizations (RO) and classification societies, it is worth mentioning the main provisions related to marine equipment to be placed on board EU ships, and to ensure the free movement of such equipment within the Union, aspects which are the objective of this Directive.

1. The provisions of Directive 2014/90 shall apply to equipment placed or to be placed on board EU ships and for which the approval of the flag state administrations is required by the international instruments, according to article 3 (scope).[27]
2. Marine equipment that is placed on board an EU ships shall meet the design, construction and performance requirements of the international instruments as applicable at the time when that equipment is placed on board. (Art.4) The compliance of marine equipment shall be demonstrated solely in accordance with the testing standards and by means of the conformity assessment procedures.

The European Union shall pursue the development by the IMO and by standardization bodies of appropriate international standards, including detailed technical specifications and *testing*

[27] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014L0090

standards, for marine equipment whose use or installation on board ships is deemed necessary to enhance maritime safety, according to Article 8 of the Directive 2014/90.

The marine equipment whose conformity has been demonstrated shall have the *wheel mark* affixed to it (Figure 30).

3. The conformity assessment procedures shall be set out in Annex II of the Directive 2014/90/EC and the Member State shall ensure that the manufacturer has the conformity assessment carried out, through a notified body, for a specific item of marine equipment.
4. The EU declaration of conformity shall state the fulfilment of the requirements been demonstrated and the manufacturer shall assume the responsibility and the obligations, guaranteeing that marine equipment has been designed and manufactured, in accordance with the technical specifications and standards provided for in the international instruments (Art.16).

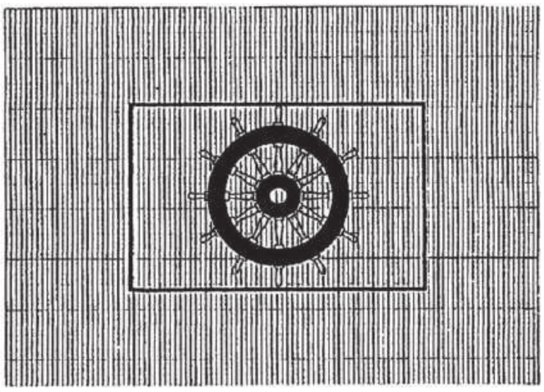

Figure 30: Wheel mark – Annex I, Directive 2014/90/EC.

5. The Member States shall notify the Commission and the other Member States of bodies authorized to carry out conformity assessment tasks and shall designate a notifying authority, that shall be responsible for setting up and carrying out the necessary procedures for the assessment and notification of conformity assessment bodies and the monitoring of notified bodies (Art.17,18).
6. According to Articles 30 and 31, in exceptional circumstances of technical innovation and for testing or evaluation, the flag State administration may permit marine equipment which does not comply with the conformity assessment procedures to be placed on board an EU ship if certain conditions set out in the Directive 2014/90/EC are fulfilled.

Such situations can be encountered in the activities of PALAEMON and must be adequately considered.

7.3 Cybersecurity and Privacy regulations

7.3.1 Cybersecurity issues and threats

The maritime sector, including the ships themselves, are becoming more and more dependent on information and communications and are becoming part of a vast network where all the actors in the maritime field belong – authorities, administrations, operators etc. Becoming part of this information system everybody is also exposed to malicious actors who could use the technologies of the system in a harmful way. According to EMSA, the concept of cybersecurity represents those measures aimed at securing the use of the information, operational and telecommunication system. It can be considered a collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment, organization and user's assets[28].

Over the past years, Information Security has become a high priority for ship owners, managers, charterers, and other stakeholders of the maritime Industry. The main reason lies on the fact that vessels rely more and more on software and cyber-physical systems, as the automation and connectivity on-board are increasing significantly. Cyber-physical systems enable the industry to build Safer and Smarter vessels, but at the same time open the door to cybercrime. Cyber security is becoming critical not only for data protection but also for safe and reliable operations. Stakeholder driven requirements are increasing, be it through concerns about critical infrastructure and public safety or from board members who push for risk reduction and towards securing business continuity.

Within PALAEMON, cybersecurity importance is two-fold, as (a) passenger/cruise ships accommodate a very large number of passengers, each one carrying sometimes more than one devices that will connect to the ship's legacy network (e.g., WiFi), and (b) the evacuation digital ecosystem that will be developed is of high criticality, as the proper evacuation of the ship and the saving of all lives on-board relies on it.

The amount of reported malware (generic malicious software) is increasing exponentially the past years. Approximately 800 million malware attacks were recorded in 2018 (Figure 31), while an increase of 110% of attacks on industrial control systems was observed between 2015 and 2016 (Figure 32).

[28] http://www.emsa.europa.eu/implementation-tasks/maritime-cybersecurity.html

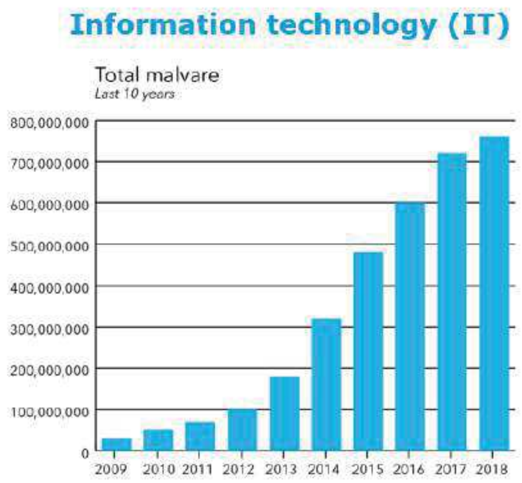

Figure 31: Recorded Malware and attacks on industrial control systems.

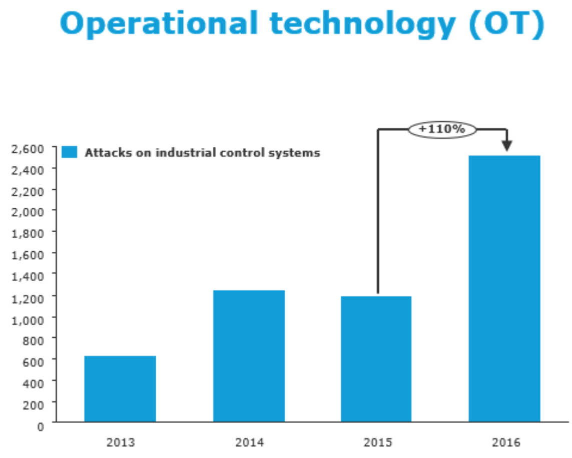

Figure 32: Attacks on industrial control systems.

More specifically, many different cyber-attacks/incidents have been reported in the maritime industry. Indicative examples include:

- AIS spoofing (wrong data)
- GPS jamming and spoofing
- Malware allows full access to vessel systems
- ECDIS ransomware and chart spoofing
- PMS system shore and vessel attack
- Hacking of cargo tracking system for smuggling purposes (containerships)
- Loss of fuel control and ballast water valves due to ECDIS update
- Loss of main switchboard due to ransomware
- NotPetya ransomware causing vessel shutdown for 48 hours
- NotPetya caused Maersk up to 300 million USD loss
- Hackers took “full control” of navigation systems for 10 hours
- Pirate attack supported by Cyber-attack.

As shown above, cyber-attacks may target various systems on-board a vessel. We can separate the systems/potential targets into two main categories, as shown in Figure 33.

- Information Technology (IT) are systems that use information, e.g. IT networks, e-mail, PMS, electronic certificates. The risk for these systems is mainly on finance and reputation. Typically, these systems are covered by the IT department.
- Operation Technology (OT) are systems that rely on software to operate e.g. PLCs, SCADA, monitoring systems, ECDIS, etc. Currently, all the industry stakeholders focus on the OT mainly for two reasons:

  A. Incidents involving such system pose risk to human life, property, and the environment, apart from finance and reputation.

  B. OT systems are not covered from a cyber security point of view.

Regarding point B, it should be noted that IT departments of ship managers usually cover the IT systems but lack the technical and operational knowledge to cover OT systems as well.

Therefore, it is critical to have IT department cooperate with Technical, Operations, and HSQE departments to have a proper understanding and be able to cover these systems in practice.

Figure 33: Vulnerable systems on-board a vessel.

From the above analysis, the PALAEMON system falls under the category of OT systems and should be treated likewise from the shipping company when it comes to cybersecurity. There are various ways for a ship manager to start building Cyber Resilience. IMO guidelines refer to BIMCO guidelines, which refer to ISO 27001 (Information Security). These documents describe what needs to be done but not how. Therefore, DNV GL has issued the Recommended Practice RP-0496 (2016), which shows the practical steps towards improving cyber resilience. On top of that DNV GL has been developing and releasing the following (Figure 34):

1. Recommended practice – Cyber security resilience management for ships and mobile offshore units in operation (RP-0496);
2. Cyber Secure class notation (Rules for Classification Part 6, Chapter 5, Section 21);
3. Cyber Security Type approval programme (CP-0231);
4. Integrated Software Dependent Systems (ISDS) (OS-D203);
5. Recommended practice – Cyber Security in the oil and gas industry based on IEC 62443 (RP-G108)

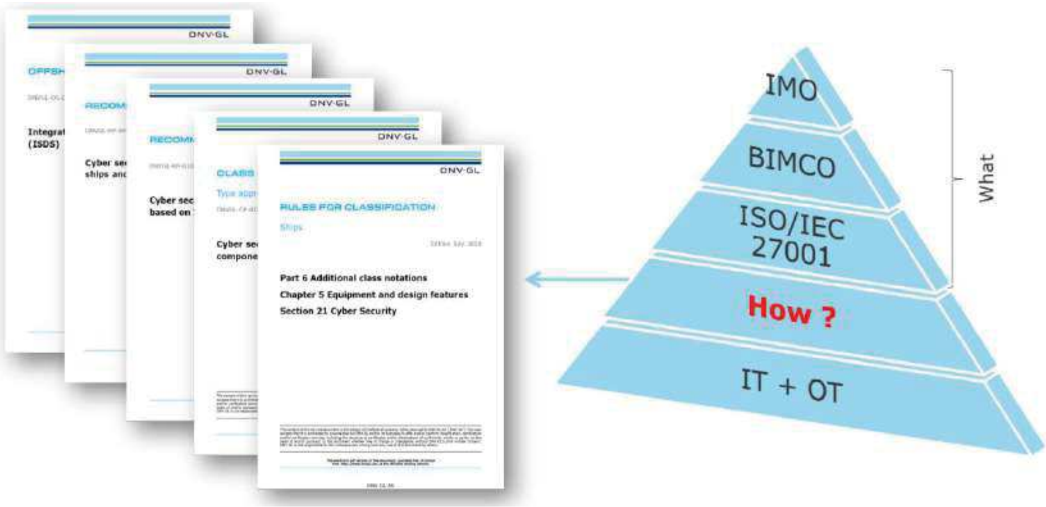

Figure 34: DNV GL documents/programmes on Cyber Security.

Cybersecurity approach covers both vessels in operation and new buildings. Specifically, for new buildings, it should be noted that today the majority of such new investments rely significantly on new technologies built to increase safety, efficiency, but also communicate data to shore (which opens a vast range of opportunities through utilisation of big data analytics and machine learning techniques). PALAEMON digital infrastructure will heavily depend on data acquisition and transmission, so it is necessary to be cyber proof against attacks.

Two types of cyber-attacks can be distinguished:

1. **Intentional**: "passenger attacker", equipped with a considerable amount of affordable gear and attack scripts that are publicly available. With the occupancy capacity of modern cruise vessels (<7K passengers and crew), there is a non-negligible risk that a small percentage of the population on board are gifted with hacker skills of one level or another. The first scenario thus starts with a passenger tampering with a passenger-facing crew terminal, hoping to install malware.
2. **Unintentional**: During a maintenance operation, a service engineer connects an infected laptop to the marine automation monitoring systems. After connecting the laptop, it causes malware to rapidly propagate from the marine automation networks to other normally isolated networks if there aren't enough security barriers in place such as network segregation.

7.3.2 European regulations on maritime cyber-security

Even if concerns about potential threats about information security began in 1990s, many cases of cyberattacks came after 2000. The Council of Europe Convention on Cybercrime, 2001, also known as the Budapest Convention, is a binding international treaty that provides an effective framework for the adoption of national legislation and a basis for international co-operation in this field.

In 2011, European Union Agency for Cybersecurity (ENISA) published the first study, Analysis of Cyber Security Aspects in The Maritime Sector (2011), that analyses cyber security in the maritime sector and identifies key insights and considerations.

Starting from 2013, the first public cases of cyber vulnerabilities affecting ships were reported and in 2017 losses of hundred million dollars for transport shipping and logistic companies and tanker companies were revealed after cyberattacks.

The Cybersecurity strategy of the European Union (2013) with the motto “An open, safe and secure Cyberspace” was launched, and the EU vision is articulated in five strategic priorities:

- Achieving cyber resilience;
- Drastically reducing cybercrime;
- Developing cyber defence policy and capabilities related to the Common Security and Defence Policy (CSDP);
- Develop the industrial and technological resources for cybersecurity;
- Establish a coherent international cyberspace policy for the European Union and promote core EU values.

Some of them were later transformed into norms, of which the most important, related to PALAEMON outcomes are the following:

- Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act).
- 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).
- The EU Maritime Security Strategy takes into consideration the Cybersecurity strategy of the Union, European security Strategy or the Internal security strategy.

In the maritime sector, the International Ship and Port Facility Security Code (ISPS Code) is taken into consideration according to Regulation (CE) 725/2004 on enhancing ship and port facility security, whose objectives are to introduce and implement Community measures in the face of the threats of intentional unlawful acts and to provide a basis for the harmonized interpretation and implementation and Community monitoring of the special measures to enhance maritime security adopted by the Diplomatic Conference of the IMO in 2002, which amended the SOLAS Convention and established the ISPS Code. Some of paragraphs of the ISPS Code Part B – recommendations, becomes mandatory through this Regulation, such as ship security assessments (issues regarding radio and telecommunication systems, including computer systems and networks and consider all possible threats and vulnerabilities), ship security plan and port facility security assessment.

The Regulation 336/2006 on the implementation of the ISM Code, described before, requires companies to assess all risks to its ships and establish appropriate safeguards.

The European Union Maritime Strategy Action Plan, adopted in 2014 and revised in 2016, put in practice the strategy and includes a number of actions related to the main areas of interest and some specific action refers to cybersecurity such as: capability development, risk management, protection of critical maritime infrastructure and crisis response, research and innovation, training and education.

In conclusion, all the actions that involve the implementation of computer systems, should take into consideration the above information for safe use onboard ships.

7.3.3 Data privacy

The second aspect of regulations regarding data, is the new regulations for protection of private data. The EU General Data Protection Regulation (GDPR)[29], which overhauls a data protection regime dating from 1995, has come into force across the European Economic Area (EEA), including in the UK, since 25 May 2018 and applies to all businesses established in the EEA and a large number established outside of the EEA.

The GDPR covers how organisations collect, store and use ‘personally identifiable information’. It aims to give individuals greater control over how their personal data is collected, held and used, and by who. The regulation revolves around citizens’ consent. In broad terms it asks organisations to:

- Lawfully, fairly and transparently process personal data;
- Collect it for a specific, explicit and legitimate purpose;
- Only collect the data that’s necessary to that purpose;
- Take steps to ensure data is accurate and kept up to date;
- Keep data in such a way that it can be identified and kept for no longer than necessary;
- Use appropriate technical or organisational measures to ensure the data’s security;
- Be able to demonstrate compliance with the principles of the GDPR.

The operation of the PALAEMON system will involve gathering and processing data from passengers, such as age, and location within the vessel, all being personal data, and some even very sensitive. This makes imperative the implementation of an appropriate data protection regime within the PALAEMON system and proper information to the passengers as to what data will be collected and towards what purpose they will be utilized. The current registration processes on cruise ships (e.g., during booking and/or embarkation) include certain pieces of information, such as age, that may be useful for the PALAEMON system.

The potential distribution of a consent form with the booking is a first step, where the passengers will be asked if they agree with the collection of the necessary personal data from the digital components of PALAEMON (bracelets, glasses, cameras, WiFi etc.). The data that will be collected will be only the necessary ones for processing from the PALAEMON system and will be used towards the better/optimal evacuation strategy in case of emergency. This should be clarified in the consent form, ensuring the passengers that their private data will only be used in case of emergency and will not be shared or distributed to any other parties.

Certain cruise line companies have already very elaborate privacy policies and require a lot of personal information from the passengers, before booking a ticket, for the safety of all the passengers and crew on-board. For example, most of the dominant cruise liner companies transfer a record of the personal data the passengers provide during the booking process onto the cruise ship for use if the passenger requires medical assistance. Additionally, they check booking details against law enforcement registers and internal records for the safety of everyone onboard. They also ask the consent of the passengers to compare any photo they provide before the cruise with images taken during embarkation to help identify the passengers and to speed up the boarding process. Closed-Circuit TeleVision (CCTV) cameras onboard are also used, in order to match images against the photograph the passenger has provided for identification. Security staff may also be equipped with body

[29] https://eur-lex.europa.eu/eli/reg/2016/679/oj

cameras, but the passengers will be notified in case recording is required for any possible incident onboard.

The above privacy policies can be initially followed and further enhanced within the context of PALAEMON, which will require the collection, handling and processing of additional data, compared to the current practice on passenger vessels.

7.3.4 IoT functionalities

On top of its architecture, PALAEMON is likely to introduce IoT functionalities which also must be secure and conform with privacy principles.

A simplified IoT security model is offered by ITU-T Recommendation Y.2060 through the security capabilities layer reported in Figure 35**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**. It includes generic security capabilities that are independent of applications.

ITU-T Y.2060, which provides an overview of the Internet of Things, clarifies the concept and scope of IoT, identifies the fundamental characteristics and high-level requirements of the IoT and describes the IoT reference model. In addition, the Recommendation ITU-T Y.2060 lists the following as examples of generic security capabilities, as illustrated in Figure 35:

- **Application Layer:** authorization, authentication, and application data confidentiality and integrity protection, privacy protection, security audit, and anti-virus.
- **Network Layer:** authorization, authentication, user data, and signalling data confidentiality, and signalling integrity protection.
- **Device Layer:** authentication, authorization, device-integrity validation, access control, data confidentiality, and integrity protection.

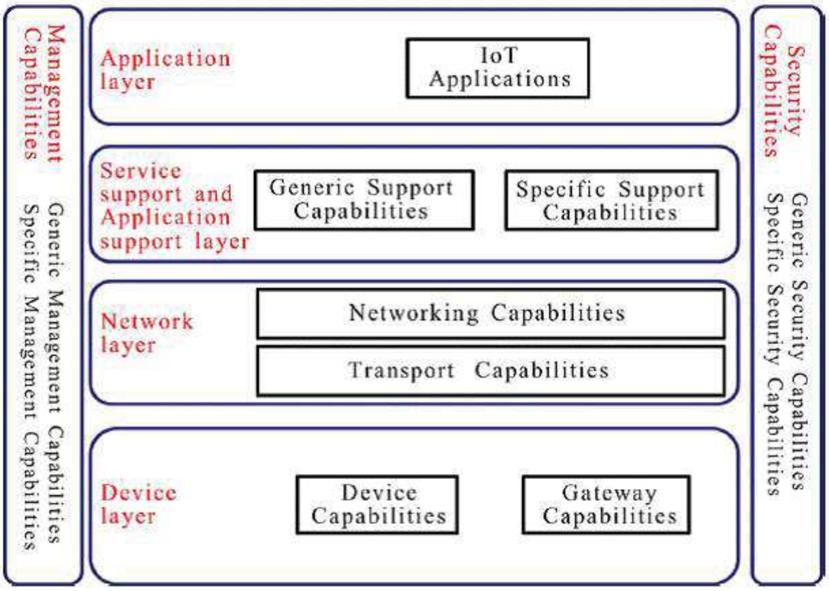

Figure 35 – ITU-T Recommendation Y.2060 IoT Reference Model.

7.3.5 Review of Current Technology for Security and Privacy in IoT

IoT Security – State of the Art

Security plays an important role in participative approaches, as the system deeply depends on the collaboration between users. However, malicious third parties may inject wrong data into the system and masquerade the identity of innocent users. Consequences can be dramatic as a malicious node can lie about its position in order to compromise services provided by the system. Therefore, communication needs to be secured in order to avoid any wrong or malicious usage of data collected by the system. Privacy needs also to be considered, as users may want to keep their personal information secret, such as location. The system should be able to detect malicious or erroneous nodes. It should also be combined with privacy preserving mechanisms to avoid tracking.

User identity management consists of data belonging to a user. Such identity may encompass the current context. Therefore, the user identity shall not be considered as static information but, rather. as potentially dynamic information. In the electronic world, a user is represented by one or more digital identities. At any time, each user exposes one Digital Identity.

A digital Identity is provided by an Identity provider and consumed by one or more service providers also called identity consumer. To authenticate a user on a system, the user shall prove he owns an object or provides required credentials.

Many technologies are available and shall be compared regarding some criteria to be addressed by the application. The main criteria are defined in Table 11.

Table 11: Identity Criteria.

Criteria	Description
Selective Disclosure	The user can choose which attributes to disclose to the service providers
Un-traceability	Even if the credential issuer and service providers collude, they cannot track the use of a credential back to the user identity
Un-linkability	Service providers must not link different transactions by the same user even if the user uses the same credentials, unless he uses the same pseudonym
Predicate on Attributes	Ability to compute semantic data on attributes and to integrate it in the issued token

Analysis of Security Risks

In a Wireless Sensor Network (WSN), when two new entities that do not know each other would like to securely communicate, they must mutually prove to each other their identity and their legitimacy.

This stage is called “authentication” and consists of assuring the authenticity of each interlocutor involved in the wireless communication process. Many authentication schemes are available and all of them require an initial secure wireless channel. So, the problems of the secure key’s pre-distribution and of the node deployment are open and must be solved to enable the authentication through a secure channel.

Once the nodes are authenticated and supplied with their own secure communication channel, they can exchange confidential messages. Cipher techniques are used to encrypt the message and ensure the confidentiality; their complexity and their size in the memory space may vary. The sent messages may be signed in order to prove the identity of the sender. Facing ever more inventive and powerful hackers, the security of wireless communication leading to the use of secret keys is not only acquired once. The time and the regular renewal of the secret keys are essential to the durability of the system security.

Security needs in a Wireless Sensor Network

A WSN may not rely on a fixed infrastructure: in a Mobile Ad-hoc Network (MANET), sensors depend on each other to keep the network connected, resulting in increased vulnerability to security attacks. The design of a security scheme to assure the safety of the network during the deployment of the nodes and during the lifespan of the network is essential and must take into account several network requirements:

- **Availability**: network services survival in case of service denial,
- **Confidentiality**: information is not disclosed to illegitimate entities,
- **Integrity**: integrity of the delivered message,
- **Authentication**: capability of each node to identify the others,
- **Non-repudiation**: message origins cannot be disclosed.

In a WSN, the security mechanisms must be scalable. The usual security techniques based on authentication protocols, digital signature and encryption are essential, but they are not sufficient. Additional practices should be applied: the path redundancy to handle messages from one node to another contributes to the network availability. The threshold cryptography, which consists of sharing the deep secret between several nodes of the network, should be another approach to reinforce security.

The main known attacks

A hacker of a WSN will act to reach a given goal. To determine a hacker's intention, we can observe his strategy. An attack sequence could be depicted in three phases:

1. Collecting information,
2. Exploiting the collected information,
3. Causing damage.

Five main intentions could be retained:

1. Eavesdropping,
2. Breaking communication,
3. Throughput or battery corruption,
4. Authentication access to use network services,
5. Authorization access to obtain resources or cipher keys.

Attacks can be classified according to their action levels inside the network.

Physical layer attacks:

- **Jamming**: It consists of jamming the wireless radio channel. The hacker sends a signal in the same radio frequency as the legitimate receiver to create fading. This can be achieved with a laptop (with high energy resources) or a simple malicious node, within the same network. Jamming attacks are a subset of Denial of Service (DoS) attacks in which malicious nodes block legitimate communication by causing international interference in networks. Many approaches exist to counter such attacks. One solution consists in changing the carrier frequency or the spread spectrum codes during the data transmission. As it is complex and costly to apply, it is only used for military applications. Lighter solutions are to slide from one channel to another by frequency hopping or to isolate the spectral channel perturbed by jamming.

- **Tampering**: It consists of taking the whole control of a node. This attack implies a physical access to the node and could be invasive (access to the node hardware) or non-invasive (electromagnetic listening). A hacker could take the control of a node via its JTAG port or via the Bootstrap Loader (BSL) which allows the read-write in the internal node memory. There are no miraculous solutions to avoid these attacks. But it is easy to take precautions by deactivating the JTAG port at the node deployment or password-protecting the BSL.

Link layer attacks:

- **Collision**: It consists of sending signals to cause interference and discharge the node battery. In practice, changing of only one bit of the message is enough to corrupt the Cyclic Redundancy Check (CRC) and requires very little energy. Such an attack is very easy to realize and is very difficult to detect. Error correcting codes may be employed to correct the errors when few bits are corrupted. But this technique leads to additional computing costs and an overhead on the exchanged messages.
- **Exhaustion**: It consists of introducing a collision into the frame at the end of the communication in order to force the node to continuously reemit the same packet. In order to prevent these attacks, requests should be ignored when they are identical or become too numerous. Another solution is to attribute a time interval to the node to access the transmission channel.
- **Link Layer jamming**: It consists of finding a data packet to disrupt the communication. This attack is as efficient as jamming attacks at the physical layer, but it is more energy efficient. It is based on the MAC protocol timings observation and statistical prediction to determine the time arrival of the data packets. Changing the time slots between two data groups at the MAC layer could be an efficient countermeasure.

Routing layer attacks:

- **Selective forwarding**: A malicious node cancels any messages in order to lose data. An example of such an attack, called the black hole, is when the hacker destroys all the messages. The nearer from the base station the node is, the more efficient the attack is. The weakness is increased if the messages are not ciphered and if the hacker can read their contents. A multi-path routing protocol can be useful to counter this attack. Any nodes could also supervise their neighbouring traffic.
- **Sinkhole**: A malicious node tries to identify all the possible paths in order to create a false topology. This attack could be realized when an intruder compromises a node inside the network and launches an attack. Then the compromised node tries to attract all the traffic from neighbour nodes based on the routing metric that used in routing protocol. When it managed to achieve that, it will launch an attack. Due to communication pattern of wireless sensor network of many to one communication where each node send data to base station, makes this WSN vulnerable to sinkhole attack. Such an attack could be led from a PDA and exploits the non-authentication of

the links or identities. To avoid the sinkhole attack, each node could verify that its neighbours communicate in two directions.

- **Sybil**: A node or a device takes many identities that may not necessarily be lawful. It does not impersonate any node, but fast it only assumes the identity of another among several nodes, causing redundancies in the routing protocol. The goal is to fill the neighbour memory with useless information. It exploits the weakness of non-authentication of the node identity. The Sybil node tries to communicate with neighbouring nodes by using the identity of the normal node and in the process a single node gives many identities in the area to other nodes in the network which is illegal. The use of identity authentication efficiently protects against the Sybil attack only in a centralized network. In a MANET, the Sybil attack remains possible.
- **Hello flood**: It consists of bombarding the network with "hello" messages to saturate the node resources. This attack needs power radio devices to broadcast in the whole network. Authentication assures a protection against this attack. It is also possible to check the bi-directionality of the link with a neighbour node.
- **Routing cycles**: It consists of setting up a cyclic path between a source node and a destination node to make messages turn around in circles in an infinite loop. This attack is easy to detect by limiting the path length or by using a tree routing protocol.
- **Wormhole**: It consists of relaying a message on a long way to make the nodes believe that they have a lot of neighbours and to saturate their resources. This attack needs sophisticated radio devices to establish a communication channel on a long way. Any protocols, like Mutual Authentication with Distance-bounding (MAD), are protected against the wormhole attack.

Application layer attacks:

- **Flooding**: It consists of creating a congestion in order to discharge the battery or to saturate a node's memory. The hacker sends successive requests to establish the connection with a node until its death. This attack could be led from a powerful laptop with high energy resources. It could be avoided by the node using a "client puzzle" challenge.
- **De-synchronization**: It consists of de-synchronizing the communication between two nodes in order to cut the established dialog. A simple method to avoid this attack is to use authentication and encryption.

User information and authentication

User privacy requirements are mandated by the GDPR regulation. It enforces the principle through which user data should be collected only at a minimum level and retained in the system for the minimum duration that is required for the system operation. Moreover, the user consent must be obtained for sharing any private or sensitive data.

User information is required for enrolment to the system, interaction with high level services such as car sharing, or direct authorization to use a car. The system must provide enrolment of user data to ensure high assurance authentication supported by strong credentials. At the same time, the system should work in semi-anonymous or pseudonymous mode to provide levels of privacy that are in line with GDPR. Even if pseudonyms are used and no private information is disclosed in the user identifier, the pseudonym may be used for tracking. If this information is submitted to the IoT cloud, then potential attackers may be able to locate the user or reconstruct his past behaviour. This implies that information should be anonymized before it sent to the IoT cloud and must be anonymized before it is persisted.

Therefore, classical PKI schemes without additional measures cannot be used even if the certificate is anonymous. The certificate or public key fingerprint allows unique user identification. Usage of a scheme that preserves user privacy by design is mandatory for any user authentication and identification of the user in the cloud data. This level of privacy may be achieved by deployment of a polymorphic scheme, zero-knowledge-proof scheme such as IDEMIX or U-prove or at least by deployment of PKI with very short-lived anonymous certificates without linking possibility. It also implies that information must be anonymized before it is sent to the IoT cloud.

The system must also provide the possibility of inspection and investigation in case of security or traffic incidents with retrieval of the real user identity and identification of all actors.

User authentication must implement the following requirements:

- High level enrolment and strong link to real user identity,
- Semi-anonymous[30] user authentication to IoT cloud,
- Semi-anonymous identification without disclosure of private data for data stored in the cloud,
- Polymorphic scheme preventing user tracking for all data stored in IoT cloud,
- Possibility of investigation of incidents with recovery of real user identity by an authority.

[30] The user is granted access to the service, but his/her digital identity related data remains confidential even if valid credentials are used to authenticate.

8 Conclusions

This report provides a comprehensive description and analysis of the current state-of-the-art in maritime evacuation, based on a thorough survey of the relevant international literature. The information included in this report will be used as a basis for identifying user needs and determining requirements for the components of the PALAEMON system. The main conclusions are summarized below.

Maritime evacuation is a time-sensitive process due to the instability of the ship in an emergency situation (e.g., fire/explosion, flooding etc.), the variability of the external conditions and the unpredictability of human behaviour in such cases. In the initial stages of the evacuation process, communication and information flow is crucial for the Master to correctly assess the situation and decide whether to evacuate or not. One of the most challenging processes during a maritime evacuation is determining the location and managing the mustering of the passengers. This process includes locating all the passengers, which is time-consuming, and managing passengers with potentially reduced mobility (e.g., people with disabilities, elderlies etc.). The success of this process strongly depends on proper training for the crew (e.g., crowd management, crisis management, human behaviour etc), unobstructed information flow, and correctly following the emergency procedures.

The analysis of selected case studies of major marine accidents and incidents involving lifeboats has also highlighted several challenges and problems with the currently employed LSAs. Maritime evacuation may be conducted in a highly dangerous ship environment that includes conditions such as severe heel and list, fire, and smoke, which make mustering the passengers very difficult (i.e., reduced mobility). Adverse conditions may also incapacitate the evacuation systems and equipment, for example, due to loss of power in the event of a black-out. A major contributing factor for the major accidents analysed was that the Master and/or the crew did not properly follow the emergency procedures. Another major contributing factor was the Master's incorrect initial assessment of the situation, which in many cases led to a delayed decision to evacuate and/or poorly informing the crew and passengers. The incidents involving lifeboats have highlighted that correct maintenance of the equipment is very important and properly training the crew to use it. However, the design of existing LSAs often disregard the importance of the human-machine interface that may make the equipment hard to use and/or maintain.

The main challenges with managing human behaviour in emergency situations include: 1) huge number of untrained persons to be evacuated in a complicated and unfamiliar environment, 2) potentially inclement weather conditions, 3) the uncertainty of the abandonment with survival crafts, and 4) the uncertainty of what happens even after a successful abandonment due to the adversity of the maritime environment. The characteristics of maritime evacuation also affect analysis and simulation efforts that aim to contribute to comprehensive planning. An additional limitation of the existing analysis methodologies, including the IMO framework for evacuation analysis, is that data and parameters provided in the guidelines are based on data from civil building experience. However, maritime evacuation is quite different, and many additional parameters should be considered in modelling.

From the analysis of the international regulatory framework governing maritime evacuation, the following major constraints for the PALAEMON system have been identified:

- Requirements regarding the necessary personal life saving appliances can be taken into consideration and scaled up for the new Mass Evacuation Vessels (MEVs) that will be designed in PALAEMON.
- The existence of a fire safety zone at the embarkation decks before the survival crafts will be challenging in the proposed MEV concept.
- The PALAEMON system must be designed to reduce (to the extent possible) the time required for evacuation, as per the SOLAS requirements.
- Considering the strong presence of ICT-related innovations, cybersecurity and data privacy should be included in the requirements of the PALAEMON components.

The European Union legal framework for passenger ships successfully complements the international and national ones, which should lead to a safer exploitation of these ships and a reduction of the risks related to this type of transport. This report highlights the main European requirements regarding the safety of passenger ships from a technical, operational or information point of view. These specific requirements are supplemented by those generally applicable to all types of ships – standards of training, certification and watchkeeping for seafarers (STCW Convention), prevention of pollution of the marine environment by ships (MARPOL Convention) or seafarer's rights and living conditions aboard (MLC Convention).

If, over time, the progress of the maritime sector and its current activity was based on what is called tradition, nowadays, the main characteristic of progress and activity, around which all the others revolve, is safety. The great number of stakeholders in the maritime industry makes it necessary to have this legal framework, and the aspects related to the safety of transport can never be put on a secondary level, regardless of the level of legislation.

The success of PALAEMON represents a step forward for the safety of the passenger ships, through the new vision on the issues related to emergency situations that these ships may encounter in operation.

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