Ref. Ares(2021)6276500 - 14/10/2021

PROJECT DELIVERABLE REPORT

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

D2.5 Final version of PALAEMON Use Cases Definition & Operational Requirements

A holistic passenger ship evacuation and rescue ecosystem

MG-2-2-2018

Marine Accident Response

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814962"

Document Information

Grant Agreement Number	814962	Acronym	PALAEMON	
Full Title	A holistic passenger ship evacuation and rescue ecosystem			
Topic	MG-2-2-2018: Marine Accident Response			
Funding scheme	RIA - Research and Innovation action			
Start Date	1st JUNE 2019	**Duration**	36 months	
Project URL	www.palaemonproject.eu			
EU Project Officer	Georgios CHARALAMPOUS			
Project Coordinator	AIRBUS DEFENCE AND SPACE SAS			
Deliverable	D2.5 Final version of PALAEMON Use Cases Definition & Operational Requirements			
Work Package	WP2 – Use case Driven Requirements and Architecture			
Date of Delivery	**Contractual**	M24	**Actual**	M28
Nature	R - Report	**Dissemination Level**	PU-PUBLIC	
Lead Beneficiary	University of the Aegean (UAEGEAN)			
Responsible Author	Petros Kavassalis	Email	pkavassalis@aegean.gr	
		Phone	+306932712734	
Reviewer(s):	David Gómez (ATOS), Georg Aumayr (JOAFG)			
Keywords	Ship Evacuation Management, Smart Evacuation Management, Evacuation Scenarios, Evacuation Use Cases, Quantitative requirements, KPIs			

Authors List

Name	Organization
Petros Kavassalis	UAegean
Costas Panou	UAegean
Konstantinos Bitsikas	UAegean
Maria Belesioti	UAegean
Manolis Sofianopoulos	UAegean
Alexandros Koimtzoglou	NTUA

Revision History

Version	Date	Responsible	Description/Remarks/Reason for changes
0.1	20/07/2021	UAegean	Report write-up
0.2	23/07/2021	UAegean	Input from NTUA
0.3	30/07/2021	UAegean	Improved Version
0.4	03/08/2021	UAegean	Improved Version
0.4	13/08/2021	UAegean	Improved Version
0.5	16/08/2021	UAegean	Feedback from key WP2 and WP8 partners
0.6	17/08/2021	UAegean	Improved Version
0.7	14/09/2021	ATOS	Internal review (David Gómez)
0.8	24/09/2021	JOAFG	Internal review (Georg Aumayr)
1.0	13/10/2021	UAegean and NTUA	Final Version and Release

Contents

List of Figures

List of Tables

Abbreviations

AR	Augmented Reality
D.	Deliverable
DSS	Decision Support System
EC	Evacuation Coordinator
EP	Evacuation Plan
GA	General Alarm
ICT	Information and Communications Technology
IMO	International Maritime Organization
IT	Information Technology
KPIs	Key Performance Indicators
LSA	Life-Saving Appliance
M	Month
MEE	Marine Emergency Evacuation
MEV	Mass Evacuation Vessel
MVZ	Main Vertical Zone
OOW	Officer on Watch
PaMEAS	Passenger Mustering and Evacuation Process Automation System
PIMM	PALAEMON Incident Management Module
Ro-Pax	Roll-On Roll-Off Passenger vessel
Ro-Ro	Roll-On Roll-Off Passenger vessel
SAR	Search and Rescue
SHM	Structural Health Monitoring
SEM	Smart Evacuation Management
SMS	Safety Management System
SOLAS	Safety of Life at Sea
SRAP	Smart Risk Assessment Platform
SSS	Smart Safety System
UAV	Unmanned Aerial Vehicle
VDES	VHF Data Exchange System
VDR	Voyage Data Recorder
WP	Work Package

Executive Summary

This deliverable (D2.5) is one of the key Deliverables of WP2's (Use Case Driven Requirements Engineering and Architecture) and the official continuation of D2.4 1[1]. It presents the final version of the PALAEMON Use Cases (i.e., evacuation scenarios in context) and Operational Requirements, defined first as a detailed list of actions that should be performed specifically with the contribution of the different PALAEMON system components and, second, in terms of Key Performance Indicators (KPIs) which should provide measurable value that can be used to demonstrate how effectively the PALAEMON Smart Evacuation approach is achieving effective operation in context.

Essentially, D2.5 concludes on Task 2.3 (Reference Scenarios and Pilot Operations Specifications and KPIs) by providing a carefully selected, focused and detailed definition of the use cases and application scenarios that help to explain the role of PALAEMON Smart Evacuation System in dealing with emergency conditions in a passenger ship business environment. These scenarios will serve as the basis for the design and organization of Project Piloting Activity within Work Package 8 which will deploy and test the final version of the PALAEMON on ANEK's Hellenic Spirit 1[2].

1 Introduction

This Deliverable, entitled "PALAEMON Use Cases Definition & Operational Requirements", is the second and definitive version of the main PALAEMON Task 2.3 document. As already mentioned, a first version of this Deliverable has been available earlier in the project life cycle (Aug 2020). Task 2.3 (Reference Scenarios and Pilot Operations Specifications and KPIs) is led by the University of the Aegean (UAegean - UAEG) which has coordinated the work of a large group of project partners, including the industrial ones. T2.3 is attached to WP2 (Use Case Driven Requirements Engineering and Architecture), coordinated by the NTUA.

According to the Grant Agreement (GA), T2.3 is expected to provide a detailed definition of the use cases and application scenarios that will drive the development of the PALAEMON overall architecture and feed the pilot deployment of this architecture within Work Package 8 (Field Trials, Evaluation and Outcomes). The work in this Task has, in fact, produced this specific outcome via a two-stages approach, covering two distinct periods (from M3 to M12 and from M18 to M27) where:

- Work in the first period delivered D2.4. This Deliverable has provided, a) a first approximation of the PALAEMON approach for Smart Evacuation Management (further elaborated within Work Packages WP5, PALAEMON on-board mustering tools and services and WP7, PALAEMON Integrated System and Technology Validation Trials) and, b) three clearly defined evacuation scenarios which have been designed to incorporate the initial draft of the technology-aided evacuation approach of PALAEMON.
- Work in the second period has collected further input from the PALAEMON Consortium partners (and other professional mariners out of the Consortium), analyzed more historical data and focused on two reference scenarios (a main reference/benchmark scenario dealing with a ship evacuation due to a fire onboard, and an additional scenario where evacuation becomes necessary after the grounding of a vessel) – while bringing further realism, credibility and operational complexity to the proposed scenarios.

During the first period (D2.4), we have formulated the following emergency evacuation scenarios: a) a fire-triggered evacuation scenario, b) an explosion-triggered evacuation scenario and, c) a collision scenario (with a requirement of a precautionary evacuation), as well as a methodology for scenario building consisting of the following:

1. Analysis and taxonomy of past accidents (taxonomy based on the type of accidents).
2. Further analysis of accident types that should be considered in the Reference Scenarios (more detailed research - interviews with marine technical experts).
3. Application of PALAEMON approach to increase the automation and efficiency of the evacuation process, as an "execution complement" to the Reference Scenarios. This approach incorporates several innovations, such as pre-defined rules, instant notifications and interaction of Bridge Command Team with passengers and crew, re-allocation of the evacuation paths etc.).
4. Scenarios Design in detail.
5. Definition of efficiency metrics for a technology-aided evacuation management (KPIs).

The approach of the first period has essentially delivered the basic elements of the evacuation scenarios and the potential contribution of PALAEMON components towards a technology-aided evacuation approach, with the PALAEMON architecture still in process. The approach of the second period delivers a more tangible and deployable version of the Reference Scenarios (Use Cases), and benefits from the concretization of the PALAEMON architecture. In general, in the second period (this Deliverable) we have refined the steps 1-6 as it is shown in the following Table (cells in grey colour).

Table 1: PALAEMON Evacuation Reference Scenarios – Change log towards v2 (D2.5 vs D2.4)

Steps	Stage One (D2.4)	Stage Two (D2.5)
1	Analysis and taxonomy of past accidents (type of accidents)	Analysis and taxonomy of past accidents (type of accidents)
		Added:
		Further analysis based on a more detailed research
2	Further analysis of type of accidents that should be considered in the Reference Scenarios (more detailed research - interviews with marine technical experts)	Further analysis of type of accidents that should be considered in the Reference Scenarios (more detailed research - interviews with marine technical experts)
		Added:
		Exploration of the structured information included in D2.3 1[3]
3	Development of MEE Reference Scenarios	Development of MEE Reference Scenarios
		Added:
		Augmented methodology (8 steps)
		Selection of two core Reference Scenarios (main reference and complementary scenario)
4	Application of PALAEMON approach to increase the automation and efficiency of the evacuation process (complement to Reference Scenarios)	Application of PALAEMON approach to increase the automation and efficiency of the evacuation process (complement to Reference Scenarios)
		Added:
		Updated PALAEMON-aided MEE Response Plans (with reference to mature PALAEMON architecture described in D2.7 1[4])
5	Scenarios for Pilot Development Design (Use Cases)	Scenarios for Pilot Development Design (Use Cases)
		Added:
		Focus on the evacuation process under fire conditions
		Complementary PALAEMON-aided MEE scenario: Evacuation in the case of grounding
6	Definition efficiency metrics for a technology-aided evacuation (KPIs)	Definition efficiency metrics for a technology-aided evacuation (KPIs)
		Added:
		Updated List of KPIs – with reference to the “fire onboard” MME Use Case (input to WP8)

Further, this Report is structured in the following sections:

Section 1 introduces the Deliverable, explains how it related to the other Deliverables of the Project's Work Package 2 (Use Case Driven Requirements – Engineering and Architecture) and highlights the differences between the previous and the current version (D2.5 vs D2.4).

Section 2 summarizes the Smart evacuation Framework of PALAEMON and the selected benchmark Use Cases (evacuation scenarios) that can enable truly user-based, evacuation use-case analyses.

Section 3 provides an up-to-date view of Use Case scenario definition, originally discussed in D2.4. It includes additional background information and a more detailed elaboration and discussion of the selected benchmark scenarios to form the basis of the system field tests in a later stage of the PALAEMON project (WP8).

Section 4 focuses on the main reference scenario for PALAEMON Smart Evacuation Management, i.e., a fire evacuation scenario, to design the Smart Evacuation operational details for each step of the process of evacuating passengers and crew from a Ro-Pax ship which caught fire in the open sea.

Section 5 designs evacuation quantitative requirements on system level and KPIs for the main benchmark scenario by narrowing to the targeted mail reference scenario, a similar analysis included in the previous version of this Deliverable (D2.4).

Finally, Section 6 contains a short conclusion of the Report and opens the pave to the Pilot Design process of Work Package 8 (WP8).

2 The generic framework for PALAEMON Reference/Benchmark Scenarios and Pilot Operations: Smart Evacuation Management (SEM) - updated July 2021

As we have already mentioned in multiple Deliverables (D2.3 1[3], D2.4 1[1], D2.7 1[4]), the PALAEMON Smart Evacuation Management concept and platform reflect current maritime evacuation process and regulation standards, as described in SOLAS guidelines 1[5]. Yet, the PALAEMON technology-aided evacuation approach extends and improves the prevailing evacuation practices (mostly depending on human power to assist the passengers during an emergency evacuation), by partially automating and monitoring the whole evacuation process, while dynamically changing the operation mode of all data sources and services.

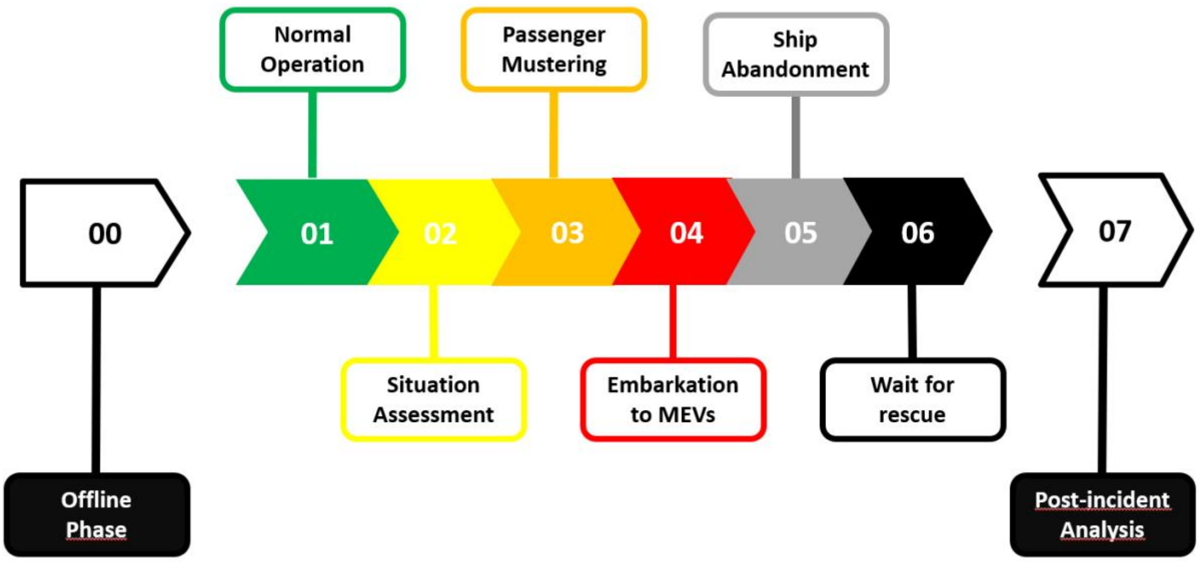

Figure 1: Maritime Emergency Evacuation standard flow and PALAEMON

Several PALAEMON system components participate in the redesigned, technology-aided, evacuation process, as shown in the following Figure.

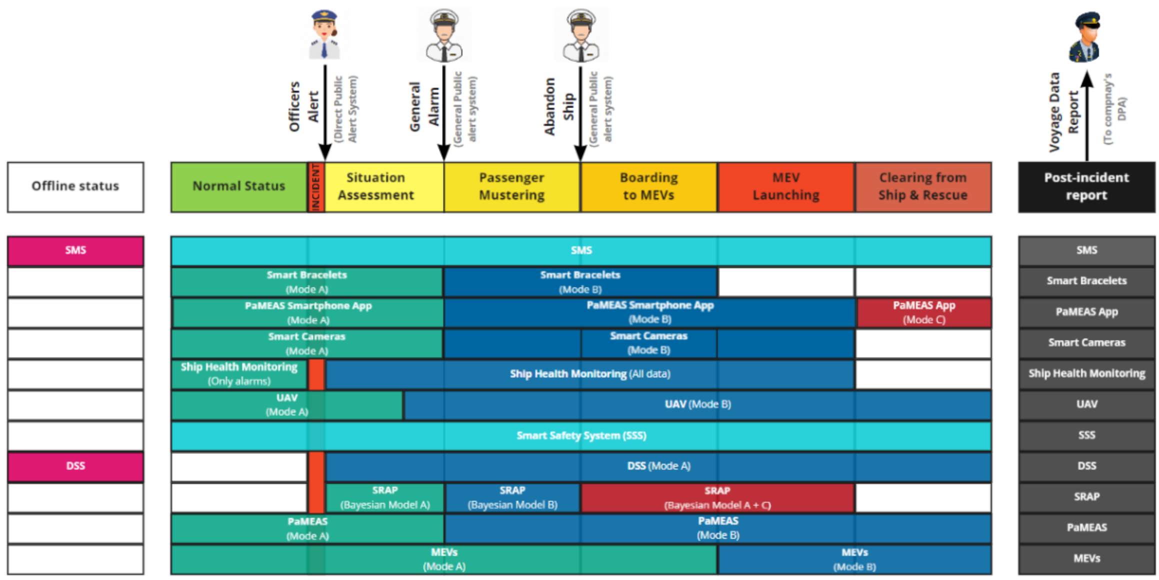

Figure 2: PALAEMON Components mapping to evacuation process unfolding

The PALAEMON platform orchestrates the components shown in Figure 2, to implement a "Smart Evacuation Management" methodology and technology infrastructure. In the previous version (v1) of this Deliverable (as well as in the Deliverables of WP5[1]), we have defined Smart

[1] Op. cit.

Evacuation Management as service layer that creates “evacuation intelligence” through collecting and processing data from different ship sources and by tracking the location of passengers and crew and notifying them in real time about the evacuation options and paths (in accordance with the evolution of the evacuation plan). More precisely, the term “Smart Evacuation Management” (SEM) defines a layer of functionality which provides enhanced evacuation possibilities to Evacuation Coordinator (ECs) and to Bridge Command Team, such as:

- Sensing/monitoring the structural integrity and the navigation capability of the ship.
- Data modeling and exchange between the different components of a highly interconnected ship.
- Tracking the status & location of resources and passengers, and reassess response plans if needed.
- Supporting the effective application of an Evacuation Plan (EP), when needed, by providing proper (personalized) guidance to crew and passengers based on their precise location and status (crowd monitoring and control).
- Managing incidents that could possibly hinder the timely execution of the EP.
- Integrating the concept of a MEV (Massive Evacuation Vehicles), to reduce the embarkation time to ship lifeboats and improve the process of the abandonment of the ship, and the use of UAVs (Unmanned Aerial Vehicles) to inspect the ship during evacuation.
- Enabling a post-evacuation analysis of the response, on the basis of Key Performance Indicators (KPIs), by means of mimicking the Voyage Data Recorder (VDR)[2] concept, harvesting all the information generating by our components and shipboard legacy systems.

Under this perspective, the evacuation of a ship includes more than the ad hoc, “manual” execution of pre-defined static plan, eventually supported by a “soft computing” approach. It becomes a real-time operation which integrates process management and monitoring methods and techniques, and the efficient orchestration of different technology systems -- much beyond the simple use of Decision Support Systems (DSS) and typical ship evacuation modeling software and simulations. In fact, as we have explained in the previous version of this Deliverable, Decision Support Systems are not anymore, the only available technological solution for an enhanced evacuation process. Increasingly, key enabling technologies are wireless and mobile networks, the smart networked devices of the passengers and crew, IoT infrastructures and other ship sensing technologies, smart cameras and so on. In the related literature, the topic of “Intelligent Evacuation Management Systems” 1[6] has emerged to signify a technology-assisted approach to evacuation management. PALAEMON augments this approach with: a) a complete technology stack for evacuation support, able to address the dynamic and constantly changing emergency evacuation landscape and, b) a technology-assisted evacuation scenario design and pilot activity that implements “in-vivo” the PALAEMON approach. As pointed out by Stefanidis et al. 1[7], the biggest challenge today for

[2] International Maritime Organization (IMO), IMO Resolution A.861(20) - Performance Standards for Shipborne Voyage Data Recorders (VDRs).”

ship evacuation is the integration of all the systems participating in ship evacuation and emergency response operations, under the guidance of an IT multi-layer platform.

PALAEMON in fact, builds such a multi-layer infrastructure which implements a SME approach, essentially aiming at improving "evacuability".

SEM goal: Improving on evacuability	Evacuability is a term used to signify performance-in-context, i.e., to measure the capability of passenger evacuation process. As it is explained in the relevant literature, the concept entails the appreciation of a wide range of parameters, such as: assessment of evacuation layout plan, evaluation of evacuation time, identification of potential bottlenecks, ease of saving appliances use, familiarization of passengers with the environment of the ship, crew training, evacuation procedures/strategies and design/modification for ease of evacuation, decision support systems and other IT facilities for evacuation management etc. Technically speaking, the term evacuability represents a risk measure for passenger evacuation at sea, expressed as an index. As explained by Vassalos et al *"it is essentially defined as the probability of an environment being completely evacuated no later than a given time elapsed after the alarm went off, in a given state of the environment and a given state of initial distribution of people onboard" 1[8]*.

The main challenges this infrastructure and approach are summarized in the Table below[3]:

Table 2: PALAEMON Smart Evacuation Management approach – summary of features

SEM challenge	Type	What is?
Operates within the limits of the "total passenger ship evacuation time"	Constraint	The total passenger ship evacuation time includes the passenger and crew awareness time, the time taken by the passengers and crew to actually assemble at the muster station, the time for embarkation to ship lifeboats and the launching of lifeboats time.
Deals with the evacuation procedural complexity	Constraint to be respected	Where does it come from? A typical evacuation operation includes the evacuation of thousands of passengers and crew, though complex evacuation routes, eventually affected by the conditions of the ship (e.g., path inaccessibility issues), congestion in the routes pointing to the mustering areas, the need of (manual) people counting, "unfamiliar" to passengers evacuation means such as life-saving applications and lifeboats, evacuation through the sea and waiting for rescue, etc.
Copes with a multi-factor problem	Constraint to be respected	Many factors affect the evacuation process, mainly, a) environmental and structural (ship) factors; b) procedural and population characteristics.
Optimizes a pre-defined evacuation plan	Constraint to be respected	Plans and procedures for ship abandonment are included in contingency plans (evacuation plans), and the evacuation management should strictly follow such a plan (describing procedures, evacuation routes and alternatives, other escape possibilities etc.).
Is data-driven	SME Provided Opportunity	With an SME approach, evacuation data is systematically collected, modeled, managed and interpreted in a homogeneous way, and accessed in real time by the authorized ship IT systems. This data is used to support the

[3] For a documented discussion of the PALAEMON Smart Evacuation Management approach, see D2.4.

SEM challenge	Type	What is?
		planning, execution, monitoring and post-emergency assessment of the evacuation process.
System-of-Systems	SME Provided Opportunity	With an SME approach, several state-of-the-art technologies for situation awareness, sensing, people monitoring and counting (including passenger indoor location identification services), real-time communication with passengers and crew, evacuation with help from ICT-equipped Mass Evacuation Vessels (MEVs) etc., are operationally connected, integrate with real-time data processing and event management technologies, to form an independent, smart situation-awareness and evacuation guidance multi-layer system/platform.
Adopts a semi-automated approach which recognizes and integrated in the technical design the primordial role of the Bridge Command Team	SME Provided Opportunity (constrained however)	An SEM system is designed to provide the following core functionality: a) Communicate personalized information intended to assist the evacuation task (e.g., way-finding instructions to passengers, post reassignment to crew, etc.). b) Issue advice and warnings (proximity to danger or deviation from a designated escape path). Essentially, the SEM system design is realistically grounded on current marine needs and best-practices that encourage innovation through added-value services, which fundamentally affect the relationship between the passengers, the crew and the ship environment and command during a MEE. However, this acts also as a constraint for further automation. SEM adopts a semi-automated approach, but as long as the levels of automation of ships permit it (i.e., automated door locking, automated public addressing systems, smart lighting and evacuation paths with LED indications, etc.). the system could be easily extended to intervene more directly in ship's control.

3 PALAEMON Use Case Context: Reference Scenarios and Piloting

To deliver to the above objective and challenges, two template evacuation scenarios are proposed in this Deliverable. They consider many factors that can play a decisive role during MEE (Maritime Emergency Evacuation): environmental factors, structural stability factors, other related to passengers and crew behavior, escape possibilities and their evolution during emergency, and many others. These scenarios take the form of a Use Case: they define the ways the users, i.e., passengers, crew and the Bridge Command Team can interact with the PALAEMON infrastructure and describe how the functionality of SEM in creatively integrated into the evacuation management process. Besides, they provide the narrow operational framework for the detailed definition of the PALAEMON pilot functionality and, in this capacity, they will support the deployment of the PALAEMON Smart Evacuation Management System in the pilot context of Field Trials (the first of these two scenarios proposed below will be the main reference scenario for the deployment of WP8).

3.1 Selection of Evacuation Scenarios to focus: Methodology

A scenario, in the context of this Deliverable, is a potential event or combination of events that could cause the abandonment of a ship and affect the overall evacuation process – typically because it could create a significant risk to the application of emergency evacuation response plans.

The scenario development attempted here allow the PALAEMON system engineers to anticipate potential events and create multiple functionalities to deal with these events to best effect. The scenarios will comprise alternate stories -with beginnings, middles and ends- and have twists and turns to show how the Marine Emergency Evacuation (MEE) environment might change over time. As a result, as already mentioned. the scenarios proposed can essentially support the piloting activity (field trials) of Work Package 8.

3.1.1 Good Scenarios

A good set of scenarios contains two to three different narratives. More than three scenarios tend to get confused with one another. Consequently, three scenarios were originally defined in Deliverable D2.4 1[1], in a way as to avoid running the danger that someone will try to pick the most moderate or most apparently plausible and forget about the other two. Each of the D2.4 scenarios contained enough detail to assess how the PALAEMON system should react in response to various contingencies occurring during the evacuation process.

Of the original scenarios, two were selected for further elaboration in this report. Their selection was based on statistics indicating that fire and grounding-related accidents to be the most common causes of ship abandonment, responsible for the largest number of losses during evacuation 1[9].

The fire and grounding-related scenarios are presented below, in Sections 3.5 and 3.6 respectively, where we address: (a) formulated with implementation details, and (b) customized to pry attention away from the ordinary MEE (without any deterring or disrupting incidents). It is noteworthy, that the very process of thinking about a range of possible contingencies during evacuation has been a useful opportunity for addressing PALAEMON system design issues that might otherwise be neglected. Moreover, it has proved to be a relatively low-cost insurance policy for the PALAEMON ecosystem, as future users will be less likely to be blindsided because some unwelcome surprises have not been considered and tackled accordingly during implementation and pilot testing.

3.1.2 The Process

The scenario development process, for the final version of the scenario-use cases of WP2, has started with internal (PALAEMON partners) consultation and extended review of the material included in the Deliverables of Work Package 2 (WP2), then literature research to draw implications from the ramified and refined scenarios, and finally summarizing the results into this Deliverable.

The scenario development work followed an orderly, methodical eight-step process, as illustrated in Figure 3. The process has two major parts: (a) choosing the scenario logics to flesh out (here, fire and grounding-related emergency evacuation), a task that comprises the first five steps, and, (b) telling the actual story, its implications and early indicators, which comprise the remaining three steps.

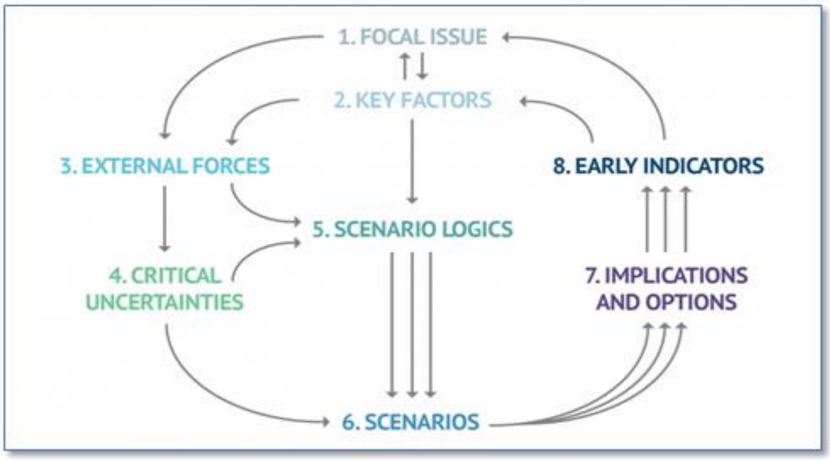

Figure 3: The eight-step scenario building process

<u>Step 1: Focal Issue</u>

The process has begun with identifying a rather open-ended focal issue: are there potential incidents or other kind of "surprises" that could disrupt an ordinary MEE. And if so, how should the PALAEMON system respond to effectively tackle them?

<u>Step 2: Key Factors</u>

Once the focal issue has been determined, the scenario team brainstormed a long list of factors that could affect the focal issue. Many of the key factors have been fairly obvious. They are the sort of things that would be addressed in a typical MEE exercise: different and non-predictable behavioral attitudes of the passengers, unexpected congestion patterns, time of the day at which evacuation takes place (daylight or night), possible heel and trim of the vessel, cut off of escape routes and/or embarkation stations, passenger and/or crew injuries, eventually failed lifesaving equipment, etc.

<u>Step 3: External Forces</u>

After identifying the key factors, the more remote forces operating in the wider sea area have been considered, e.g., maritime vessels obsolescence, especially in the Ro-Pax industry, weather conditions, nearby ships, air rescue response time, etc. that are often left out (in all or in part) of evacuation simulation exercises or abandon ship drills carried out in ports.

As with key factors, there is no proof for having thought of all possible external forces. This work calls for imagination and creativity. Once the scenario team has generated the list of critical key factors and external forces, the effort to come up with still more has become harder. However, the team has managed to keep things in proportion and address all of the obvious factors and forces that might affect the progress of a MEE.

<u>Step 4: Critical Uncertainties</u>

By following a methodical, step-by-step process, the scenario team has achieved a balance between the kind of free-form imagination and logical reasoning needed to discern “possible contingencies” based on knowledge and experience. Whereas steps two and three featured a divergent process in which the team tried to think of everything that could affect the focal issue, step four called for a convergent process of prioritization.

Through that process, the following uncertainties have been found as more critical in terms of impact on real-world applicability of the scenarios: Will some individual passengers start to panic? Will this ultimately lead to mass panic? How much valuable time will be lost before passengers are able to accept the fact that an emergency is taking place? Will crew lines of communication become confused? Will that cause a confusion in-chain of command?

Although the above uncertainties can easily turn into possible contingencies in a real-life situation, it is difficult to integrate them into scenario definitions. That is because scenarios are meant to provide the “script” of the pilot exercises and, as other “virtual” exercises, pilot exercises are taking place in an environment where psychology and actions of people are more predictable and easier to control.

Step 5: Scenario Logics

At this step the possible contingencies are decided that are worth developing as detailed scenarios. This is the challenge of step five, how to narrow down from the virtually infinite number of incidents that might disrupt an orderly MEE, to settle on just those that will lead system engineers to a better insight into the evacuation process which will be eventually reflected on their designs. The logic behind this choice of incidents has been the result of the scenario team's collective judgment regarding what is most important to the PALAEMON project’s objectives, but also of existing statistics regarding the most frequent incidents.

Step 6: Scenarios

The second major task of scenario building in D2.5 is actually telling the story of each chosen scenario. This process has started by requesting inputs from the project’s partners and experts/stakeholders with respect to fire -and grounding- related ship accidents. Once the members of the scenario team have accumulated enough working material, the narrative scenarios of Sections 3.5 and 3.6 have been drafted from the outlines included in that material.

Step 7: Implications and Options

At this step the aim is to figure out the implications of each scenario and the PALAEMON components associated with those implications. This requires using each scenario as the playing field on which the system’s response must be planned. After playing out each scenario to its conclusion one should stand back and look at the lists of system components that can be associated to each scenario. The components that show up on most lists are those that are often associated with what are called predetermined elements -contingencies that can be reliably predicted. For example, PaMEAS (the Passengers Mustering and Evacuation Process Automation System component of PALAEMON) is designed to cover these contingencies by means of predefined automated or dynamic (depending in the evolution of the mustering process) evacuation notifications, fixed geofenced zones for tracking the location of passengers and crew, etc. In a MEE whatever can be predicted should be predicted, but for the unpredictable remainder -such as the various disruptive incidents- key factors and external forces, scenarios will capture the alternatives in coherent bundles, and PALAEMON system components like Smart Safety System (SSS), PALAEMON Incident Management Module (PIMM), Decision Support System (DSS), Smart Risk Assessment Platform (SRAP), etc., will provide customized advice and orientation information.

Step 8: Early Indicators

Early indicators are the first signs of changes that differentiate the possible outcomes of each chosen scenario. For instance, early indicators might be found in the behavior of the most “rational” passengers, or in the ability of some crew to reach more informed decisions, indicating better assimilation of information and a more successful outcome of the evacuation procedure.

Early indicators are particularly important when a robust set of evacuation (business) rules that are predefined in the various system components cannot be applied in every possible situation. The PALAEMON ecosystem will rehearse, during the field trials, what should be done in each of these situations (contingencies). Then a close ear to the ground should be kept for early indicators that suggest movement in the direction of one set of (business) rules or another given certain unfortunate contingencies. When enough indicators have been accrued to give confidence on which scenario is unfolding, then the system can start to implement the set of rules most appropriate to that scenario.

3.1.3 Moving from Scenarios to PALAEMON-aided MEE Response Plans

Simple Use Cases, by themselves, neither determine MEE response plans no their associated technology for evacuation automation. They both need to be developed in light of a scenario. Think of scenarios as different hands of cards one might be dealt; think of response plans and the associated technology as the way one would play those cards.

Sometimes scenarios are developed after a response plan and their associated technology has been determined. In that case the scenarios serve as a kind of wind tunnel for stress-testing both the plan and the technology. Think of the technology and the response plan as a model airplane. Under which conditions will it fly? Under which conditions will it crash?

In D2.5 we understand scenarios as an insurance policy that, when applied to pilot test the PALAEMON system, will provide a safety net to protect the system from unpleasant surprises that might happen during real-world operation.

Given a good set of scenarios, the PALAEMON ecosystem can provide evidence that can help devise case-specific, customizable alternative response plans. Because such scenarios are sufficiently diverse, it is likely that no single emergency response plan will prevail across all of them. Thus, it is a good idea to have a response plan associated to each scenario, and this is the way T2.3 Evacuation Scenarios (augmented Use Cases) are presented in Sections 3.5 and 3.6.

3.2 Ship Accidents involving Fire and Grounding

As mentioned, in a MEE situation analysis it is not possible to take every thinkable accident scenario into account. After all, this is not necessary if the scenarios are to be used to derive basic actions plans. The objective therefore here, is to identify realistic operational scenarios that can be implemented within PALAEMON pilot development to allow for: (a) testing the various PALAEMON system's components, and (b) providing proof of their functionality and contribution-level to the successful and "smart" management of the evacuation process. The provision of technology-aided support to evacuation is an innovation challenge to which PALAEMON aims to respond in a consistent and realistic way[4] 1[4]. The field trials (based on what is described in this Deliverable) will subsequently prove the applicability of the proposed solutions, within the limited time window of the evacuation process and the complexity of evacuation operations.

Delivering to the above objectives, involved a detailed look at available historical data using accident case reports from the literature, and feedback from professional mariners who were either members of the PALAEMON team or unrelated to the project -- the aim was to bring realism and credibility to the scenarios.

As shown in Table 3, accident statistics on passenger ships 1[9] indicate that:

- ~50% of cases leading to abandonment are related to fire or grounding events
- ~50% of the abandonments require disembarkation at sea
- Fire, in 50% of the cases, require disembarkation at sea
- Grounding requires evacuation at sea in 70% of the cases.

Table 3: Major causes of ship abandonment

Basic Causes of Abandonment	Abandon at Sea (by any means)	Disembark at berth	**TOTAL**
Collision	1%	10%	**11%**
Contact	2%	11%	**13%**
Fire / Explosion	12%	13%	**25%**
Foundered	4%	0%	**4%**
Hull / Machinery Damage	2%	15%	**17%**
Wrecked / Stranded	21%	9%	**30%**
TOTAL	**42%**	**58%**	**100%**

It is clear from Table 3 that fire -and grounding- related accidents are very important to the shipping community, because of the frequency with which they occur and the severity of their implications. So, it goes without saying that a set of evacuation scenarios associated with these accidents should sit on top of the list as the best scenarios to go for in D2.5.

Another advantage of using a fire and a grounding scenario is the ease of understanding by the project team. Because they are so common, those scenarios can help the team's

[4] For a global overview of the PALAEMON system, see in particular D2.7

engineers gain a better intuitive understanding of the given problem-situation, and ensure that the correct decisions are taken to render the PALAEMON ecosystem capable of performing a greater variety of evacuation management operations at a finer grade.

For a more effective use of these scenarios, it is mandatory to put their definition in the context of the project's overall necessities. This is summarized in the Figure below.

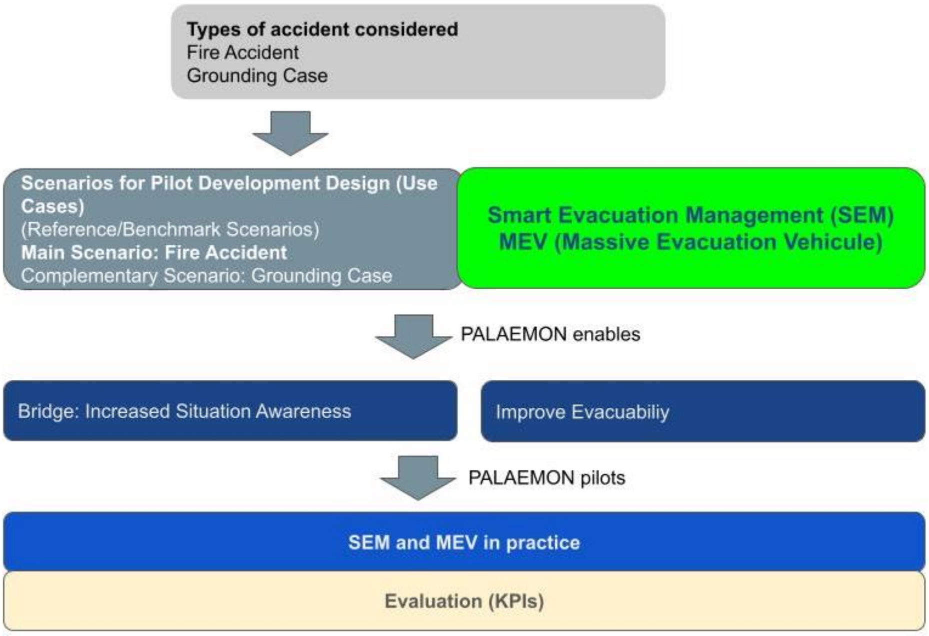

Figure 4: Context of application of the benchmark scenarios in the PALAEMON project

Figure 4 puts the two (reference/benchmark) scenarios into perspective so they can be better defined by linking their benefits and features to the roles they can fulfil in the project's infrastructure deployment and field trials on a real ship.

With the purpose of providing meaningful information to these tasks (project deployment and pilot trials), we have designed the fire and grounding scenarios of Sections 3.5 and 3.6 to be as simple, realistic and relevant as possible. They are anchored in a basic understanding of the overall MEE framework, including human factor, ship's safety processes and operating procedures. Taking all these factors into account, we can enable truly user-based evacuation use-case analyses and field trials running script.

As already mentioned, there are different factors that make up an evacuation scenario and these should all be clearly defined in such a way that they unambiguously describe the scenario. Ideally the different factors may relate to:

- the total number of people on board;
- the demographics of the ship's population;
- the type of accident the ship is exposed to;
- the time of day when the mustering alarm sounds, the weather condition at the time of accident (influencing the movement of the vessel); and
- the lack of accessibility of different parts of the vessel (e.g., due to an accident) etc.

Especially the impact of disabilities of passengers for the evacuation time was shown in a study of PALAEMON by JOAFG. High effects and high significant results showed that the gait speed of people with disabilities is reduced up to 68% which leads to slowing down evacuation speed for all passengers due to the architecture of ships at this time.

Although the current IMO requirements 1[10] regarding evacuation times from passenger ships correspond to the requirements related to confinement of fires within each main fire zone, grounding can also become critical regarding evacuation from passenger ships (depending on the ingress of water). This is because this type of accident generally leaves less time for evacuation than fire accidents, especially if there is ingress of water, although fire accidents allow for a smaller reaction/containment time. If a ship should sink subsequent to a grounding accident, it will obviously impose an absolute maximum time for evacuation, the time it will take the ship to sink or capsize, making evacuation no longer possible.

In a typical fire accident on the other hand, it will be more crucial to rapidly evacuate certain affected fire zones than to rapidly abandon the whole ship. Only rarely will a fire result in damages that are extensive enough to cause the ship to sink, and fires that do escalate will normally be delayed by firewalls separating the fire zones. Furthermore, those ships that sink due to a fire will normally start sinking after a certain period of time. People on board that are not directly exposed to the fire will thus generally have enough time to abandon the ship before the fire spreads throughout the ship. For those people occupying the areas of the fire (within the same fire zone), however, there may be very little time available to escape before heat and toxic gas becomes a major threat to life and health.

In this context of variable abandonment times, there are two fundamentally different types of evacuation from a passenger ship that can be distinguished i.e., precautionary evacuations and emergency evacuations. A precautionary evacuation can be initiated in potentially dangerous situations even though there are no immediate threats to the people on board. Considering the risk associated with the evacuation process itself, the necessity of a precautionary evacuation will be thoroughly considered before it is initiated. In such situations, the time used in the evacuation process will not be critical and a typically precautionary evacuation scenario will be to direct the ship ashore and to abandon ship there, or to proceed to an anchorage where the respective damages can be assessed.

The characteristics of an emergency evacuation are much more different from that of a precautionary evacuation. In such circumstances the overall objective will be to muster as quickly as possible and to abandon the ship before it is too late. Failure to evacuate people in time will be fatal and the time spent escaping from the ship will be crucial. Such evacuations will typically only be carried out in case of a serious incident, such as a grounding with subsequent water ingress, or a fire that has escalated and run out of control.

The Reference Scenarios developed in the following Sections correspond to emergency evacuations in extreme circumstances involving such incidents.

3.3 Focus on the evacuation process under fire conditions

With the aim to provide more meaningful information to the PALAEMON's pilot-field trials, the scenario team deemed necessary to focus on one reference scenario over the other and elaborate it further. For reasons explained in the previous Section, a fire on a ship at sea is always serious and dangerous and very common case, the fire-related scenario has been chosen in terms of its potential as the basis for the development of the PALAEMON pilot activity.

The possibility of a fire breaking in a Ro-Pax passenger ship is a not very different than that in a cruise line **Error! Reference source not found.**. Ro-Pax ships contain enclosed car decks whereas cruise liners have laundry rooms, where fires are most likely to start. Between one out of three and one out of four onboard fires will start from these areas and escalate and spread to other parts of the ship, while the remaining will be confined and extinguished within the fire origin. Other places where fires are likely to occur are accommodation areas, public spaces and car decks or laundry rooms for Ro-Pax passenger ships and cruise liners respectively.

A fire might trigger the initiation of a MEE, and it may influence the evacuation performance, primarily, in two different ways. First, a fire might totally cut off some of the escape routes, e.g., corridors or stairways, so that alternative routes must be used. Secondly, smoke and poisonous gas produced in the fire might spread through the corridors and slow down people that use them for escape due to reduced visibility or difficulty to breathe. In addition, a fire may have a psychological effect on the people onboard affecting their behaviour, causing e.g., panic, shock, or paralysis of the passengers.

Escape from the affected fire zone will normally be more critical than abandonment of the whole ship in case of a fire. A fire-related scenario should therefore take into account that people occupying the zone where a fire starts need to evacuate the fire zone to muster somewhere else on the ship, away from the fire. The time allowed for such evacuations should be rather short, as heat and smoke might be fatal in a few minutes. However, a more fitting fire scenario to the needs of the PALAEMON project would be that of a fire that escalates and forces everyone onboard to abandon the ship. The time allowed for evacuation in this scenario will typically be quite long, but the fire might cut off some of the escape routes and/or some embarkation stations.

3.4 Presentation of the two scenarios in detail

The next two Sections (3.5 and 3.6) present the fire and the grounding scenarios in a structured way. Both scenarios are given in rich detail to ensure that they can be handled with success from the PALAEMON system and its components. In Section 3.7, the focus is given on the “mechanics” of the fire accident which will be readily applied as the basis for the development of the PALAEMON piloting actions in a later project stage (Work Package 8).

Both scenarios are shown in detail, in Table 4 and Table 5. The first two columns of the Tables (Phase, Main event) draw a line between the major contingencies leading to the evacuation decision, and the incidents marking the transition (through the different evacuation phases) towards the completion of the process for each scenario. The third column (PALAEMON system action) lists in chronological order the sequence of critical actions taken to tackle evacuation contingencies. Finally, the fourth column (PALAEMON component) names the PALAEMON components executing the respective actions.

3.5 Main Benchmark Scenario: Evacuation in the case of a Fire Accident

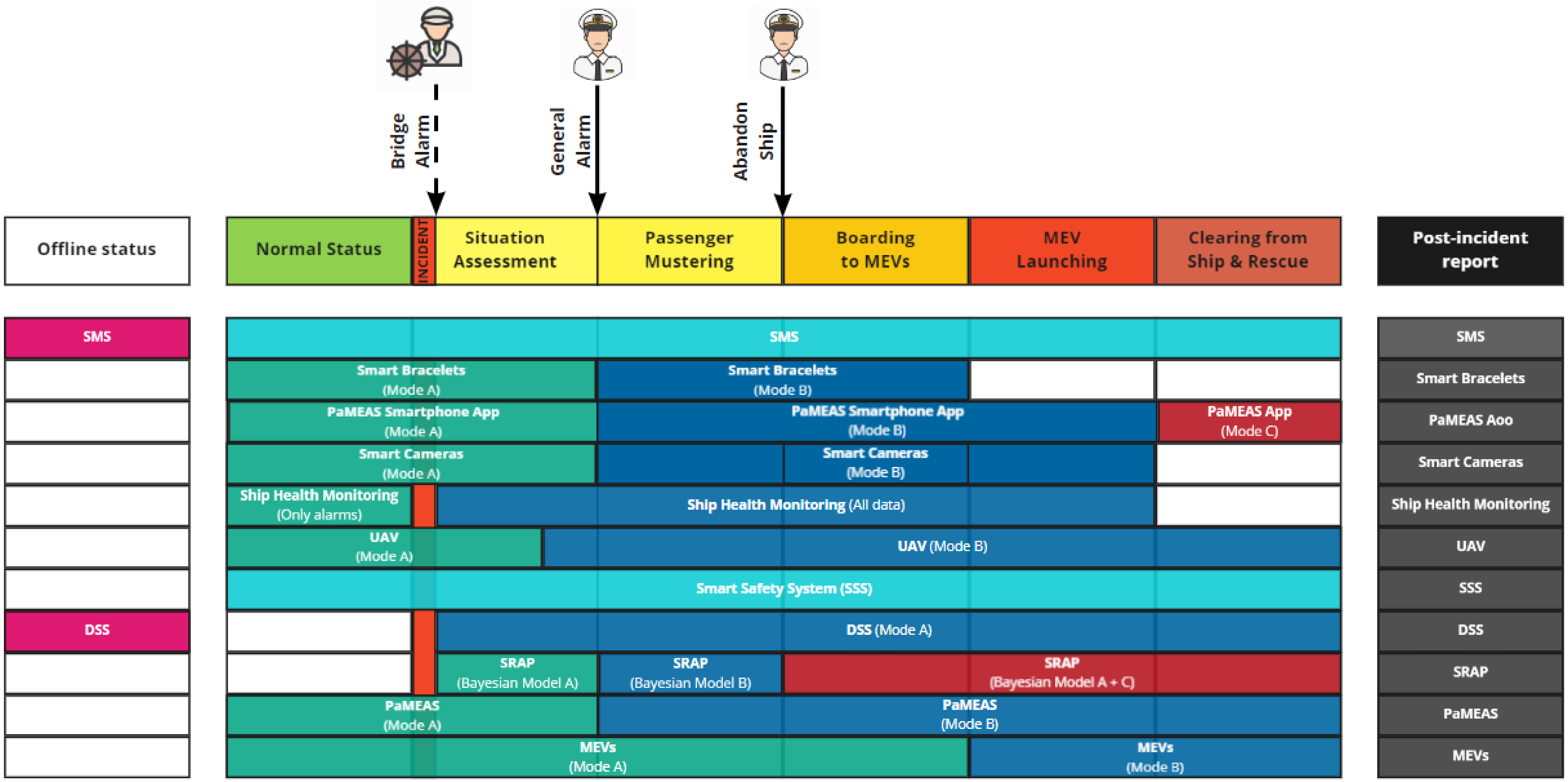

Table 4: The fire scenario

WP2 - D2.5 Evacuation Scenarios - Basic Use Cases | Fire Accident Scenario
Scenario Description: A Ro-Pax ship is sailing at her usual route with more than 1000 passengers on-board, including 200 cars and trucks. The vessel is a Ro-Pax Ferry which has several Decks. The vessel also has more than one Car Decks (closed and open). We assume that the openings that allow passengers to get on and off are located in the port and starboard side of the vessel. During the night, a smoke alarm is activated on the open Car Deck, when the Master is not on the bridge. The incident is detected by the ship's smoke, heat and fire detectors at the respective deck, calling for immediate action. Scenario actions: 1/ The fire cannot be contained by firefighting teams and the **Master sounds the General Alarm** and **launches the Mustering process.** 2/ The Mustering process is in progress when it is observed that two passengers were blocked in their cabin. Necessary actions are taken to reach out and assist them and the Mustering process is completed successfully. 3/ During the mustering process, the fire spreads on the starboard side of the ship making the use of the survival equipment impossible. The ship management relies on the PALAEMON Smart Evacuation Management capabilities to re-route passengers to other embarkation stations from which they can freely evacuate. 4/ Additionally, during the evacuation process, a crew firefighting team member is injured and the necessary actions are taken to save him. 5/ Finally, the fire goes out of control and the **Master orders to abandon the ship**. Crew members re-route passengers originally assigned to starboard embarkation stations to the port embarkation stations from which they can board on the MEVs and abandon the ship.

Phase	Main event	PALAEMON System action	PALAEMON Component
Normal	The ship is sailing at her usual route		
Incident awareness	A smoke alarm goes off in the car deck	The alarm is shown in the SSS (Smart Safety System). The SRAP (Smart Risk Assessment Platform) (Mode A) and the DSS (Decision Support System) are activated. Standard actions to be taken in the case of a triggered smoke alarm (according to the SMS [Safety Management System) - contingency plan procedures] are displayed on the PIMM (PALAEMON Incident Management Module). The SRAP system dynamically provides a risk level indication, which should help in the assessment of the situation. The assessment of the situation is shown on the PIMM, providing the Officer on Watch (OOW) and the Master (who has already been informed about the incident, while on his way to the bridge) with an indication of the severity of the incident.	SSS PIMM DSS SRAP SMS
		Live feed from the cameras supervising the area of (and around) the activated heat and smoke detectors is displayed on the PIMM. The fire's precise location is detected	SSS Smart Cameras

Phase	Main event	PALAEMON System action	PALAEMON Component
		at Deck NX (Car Deck) towards the bow at the starboard side. The exact position of the fire is displayed on the SSS.	Legacy systems (cameras) PIMM SSS
	Incident investigation starts	The Master orders the Response Team (via radio communication and PaMEAS Messaging Service) to proceed and investigate the area of the incident, to provide an in-situ assessment of the situation and initiate the first response actions.	PaMEAS PIMM
		The emergency response team is dispatched to make a visual assessment of the situation. The position of the team is continually tracked by PaMEAS (receiving location information from their Smartphones and Smart Bracelets) and displayed in the appropriate Visualization Tool. The Master monitors/assesses the situation with the assistance of the risk level indication (SRAP), with all the available information shown on the PIMM.	AR Glasses PaMEAS PIMM SRAP
		Using the AR glasses (eventually the PaMEAS Messaging Service, too) the emergency response team reports that it is impossible to approach the exact fire location due to dense smoke, but their assessment is that the fire is spreading fast. The drencher system in the Car Deck is activated.	AR Glasses PaMEAS
		The Bridge Command Team is informed that, at this point of time, there is no trapped or injured person in the area of the fire. The response team searches the aft part of the Car Deck and confirms that no trapped or injured persons are in the area. PaMEAS should confirm this information by tracking the position of the crew.	PaMEAS PIMM SSS
	Attempts to control and extinguish the fire	The crew members and the emergency response team are informed about the status of the incident through radio communication and PaMEAS Messaging Service.	PaMEAS SB
		The fire/emergency response team remains safely positioned adjacent to the fire, behind the nearest fire doors, setting up the firefighting equipment (fire hoses, pumps, etc.). The boundary cooling squad arrives and starts peripheral cooling (where applicable) to avoid potential fire spread towards other spaces. The main emergency (firefighting) team also arrives on the spot. The position of the teams is tracked continually by PaMEAS and displayed on the appropriate Visualization Tools (PaMEAS, PIMM, AR Glasses).	PaMEAS PIMM AR Glasses
Situation assessment	Fire area / deck isolation	The Master orders the closing of the fire doors and the ventilation system at the affected area to prevent further propagation of fire and smoke. He/she also orders the closing of the local electric system (local black-out). The response teams confirm the	Smart Safety System AR Glasses SRAP

Phase	Main event	PALAEMON System action	PALAEMON Component
		isolation of the area. If the Car Deck is open, a UAV may be launched to assist the monitoring of the situation.	UAV
		Adjacent smoke and heat detectors are activated. The Bridge Command Team monitors the activated detectors via the SSS. One fire door cannot be closed remotely due to a defective electrical circuit. Two crew members are dispatched to go and close it manually. The area has no electricity and lighting. Communication with the dispatched crew is done through radio communication, the PaMEAS Messaging Service and, eventually, through their AR Glasses. Their vision and orientation are also supplemented by the AR Glasses.	AR Glasses SSS SRAP PIMM
		The main firefighting team attempts to extinguish the fire. Bridge Command Team monitors, in real time, the position of the crew members. The team reports that the drencher system has no effect on the fire. Due to the time of the incident, some of the passengers have been withdrawn in their cabins, while some are in the ship's lounges of the Passengers Decks. No passenger has yet realized that there is a fire onboard.	AR Glasses Smart Cameras Smart Bracelets PIMM SRAP PaMEAS
Evacuation Plan is activated	Master decides to sound the General Alarm	To decide on whether to sound the GA or not, the Master evaluates the severity of the following factors (among others): ● Criticality/extent and evolution of the incident; ● Passenger proximity to fire and their awareness; ● Vessel's ability to maintain stability, considering all scenarios of firefighting water flow (from the drencher system and hoses); and ● Functionality of the firefighting system, as well as vital machinery systems and equipment, condition of crew and passengers, and prevailing conditions.	SRAP DSS PIMM
	Search and Rescue authorities are informed (MAYDAY SIGNAL)	The Bridge Command Team alerts the search and rescue authorities and nearby vessels and provides/transmits the required information (e.g., the number of passengers onboard, vessel condition, position, prevailing weather conditions, etc.).	VDES Legacy systems (communications)
	Evacuation protocol activated - Crew Notification about Evacuation launch	The evacuation protocol for summoning passengers at the muster stations is activated. Prior to sounding the General Alarm, a series of systematic announcements and notifications is initiated only for crew members, who are instructed to proceed to their designated positions (mainly through PaMEAS Messaging Service). The position of the crew members is continually tracked by PaMEAS and displayed on the appropriate Visualization Tools.	PaMEAS SB PIMM AR Glasses
	Launch of Evacuation Process (Sounding of the General Alarm)		

Phase	Main event	PALAEMON System action	PALAEMON Component
Mustering process	All systems in Evacuation Mode	With the GA going off, PaMEAS (Mode B / Evacuation Mode) and SRAP (Mode B) are activated.	PaMEAS SRAP
	Passengers Instructions for mustering	PaMEAS provides instructions sent to the passengers' personal notification devices (smartphones, smart bracelets) in the form of easy-to-read messages on how to prepare for evacuation and reach the muster station location (including primary escape paths, alternative escape paths etc.). In parallel, automated instructions are broadcasted over the ship's public address system.	PaMEAS SB PIMM
		Signaling of the routes of escape for passengers using emergency lighting is activated (because of an eventual local black-out, escape routes are marked with dedicated emergency IoT lighting).	PaMEAS
	Crew Notification	Crew teams (firefighters, damage-control units, boat preparation units, passenger mustering personnel, first-aid units, etc.) are informed - via radio communication and PaMEAS Notification Service - to move to their predesignated emergency posts.	PaMEAS SB
	Risk assessment & Passengers' Position Tracking while mustering	SRAP (via the PIMM) provides the Bridge Command Team with risk level assessments. PIMM and PaMEAS monitor the mustering process (by vertical zone, deck and geofences).	SRAP PIMM PaMEAS
		Designated crew is in position (in stairways, corridors, etc.) to provide on-the-spot assistance to passengers to evacuate safely to the muster stations. The crew communicate and receive instructions using PaMEAS Messaging Service and AR Glasses (crew provided with AR Glasses).	PaMEAS AR Glasses
		PaMEAS is continuously tracking the exact position of passengers within the different geofence areas and informs the Bridge Command Team about the evolution of the mustering process.	PaMEAS PIMM
		Stairway and other possible areas of congestion are monitored with Smart Cameras and, to identify eventual bottlenecks. PaMEAS also recognizes and verifies congested areas and routes.	Smart Cameras PaMEAS SRAP DSS
		PaMEAS is tracking the location, status and move of passengers, reports on the Bridge Command Team, which evaluates the need for possible response plans reassessment and provides input to PaMEAS. As a result, PaMEAS can suggest	PaMEAS

Phase	Main event	PALAEMON System action	PALAEMON Component
		alternative paths in the case some paths are crowded, blocked or even unavailable (because of the deterioration of the situation of the ship).	
	Counting passengers in Muster station	Passengers have started to arrive at the Muster Stations and passengers' counting is taking place. Crew members regularly report to the bridge the number of counted passengers. This number is checked and contrasted with the PaMEAS auto-count data which come in a continuous flow. Next, crew members provide life jackets to the passengers (those who have not picked a life jacket from their cabin or a lounge area).	PaMEAS SRAP DSS
		The Bridge Command Team monitors the progress of the mustering process, in relation to the time from the moment the GA went off. The status and the location of passengers as well as the crew members are tracked and monitored continuously to detect situations that could possibly delay evacuation, assistance is needed, or require the reassessment of emergency plans.	SRAP DSS PaMEAS
Trapped passengers	Identification of trapped passengers	The mustering process progresses normally as the PaMEAS flags the OOW that two passengers are still in their cabins and not as would be expected at that stage of the evacuation, on their way to a Muster station.	PaMEAS SB
		Two crew members of the passenger assistance team are instructed to rush quickly to the aid of the trapped passengers. PaMEAS provides them with the passengers' (approximative) location and the AR Glasses (if available to this Team) may help them to spot the exact position of the passengers.	PaMEAS AR Glasses
	Inspecting the rest of the vessel for trapped and remaining passengers	Other crew inspecting the rest of the vessel report for passengers who have eventually been left behind (in the case that the list of passengers reaching a mustering station does not include all passengers and crew on board). The process is conducted with the assistance of PaMEAS and AR Glasses.	PaMEAS AR Glasses
Mustering completed		Muster stations report the completion of passengers' mustering and counting. The information is verified via PaMEAS. Updated instructions are forwarded to the passengers' personal notification devices (smartphones and smart bracelets) as well as over the ship's Public Address system.	PaMEAS SRAP DSS
Crew Reporting on the situation	Reporting from firefighting teams on site	The fire squad leader reports that the fire is out of control and that the boundary cooling of the fire is not possible anymore.	PaMEAS AR Glasses Smart Cameras
		The starboard MEV preparation team reports that lifeboats have caught fire on the starboard side.	PaMEAS

Phase	Main event	PALAEMON System action	PALAEMON Component
		The Bridge Command Team is informed by the crew but also has visual reconnaissance via the deployed UAV. A fire squad is ordered to attempt to contain the fire in the MEVs.	AR Glasses Smart Cameras UAV SRAP
		Dispatched fire squad reports the extent of the damage to the MEVs on the starboard side.	AR Glasses Smart Cameras UAV
Incident management loop	Injury of a crew member (reported by the crew)	In addition, a crew member from the firefighting squad on the Car Deck has fainted and requires immediate assistance. The incident is reported to the Master.	PaMEAS
		The Bridge Command Team uses PaMEAS to verify location, and PIMM to classify the incident and assign priority.	PaMEAS PIMM
		The Bridge Command Team assigns readjusted resources to the incident, based on the incident's location and ship's response plans, and notifies the assigned units that they have been dispatched to the incident (via PaMEAS Messaging Service).	PIMM PaMEAS
		The Bridge Command Team checks if the response teams specifically recommended or selected for the incident are positioned at their designated post locations (if not, the Bridge Command Team) pull offs units assigned to other tasks with a lower priority status to handle the current incident of higher priority.	PaMEAS PIMM
		The Bridge Command Team advises the assigned crew team of the best route to respond to the incident - through PaMEAS Messaging Service.	PaMEAS
		While on scene, the assigned team reports that the injured crew member is sustaining fractures of the forearm (via PaMEAS Messaging Service and AR Glasses).	PaMEAS AR Glasses
		Assigned team is ordered to move the injured crew member to the first aid designated area; the route to be used is also indicated via PaMEAS Messaging Service.	PIMM| PaMEAS
	Incident management loop end	The operation is successful, and the crew team proceeds to the first aid services.	DSS PIMM PaMEAS
Ship abandonment	The fire is spreading rapidly	The fire squad leader reports that the fire is spreading out of control on the starboard side of the ship making the approach to the survival equipment on that side practically impossible. The situation is monitored via the UAV.	Smart Cameras AR Glasses UAV

Phase	Main event	PALAEMON System action	PALAEMON Component
	Master decides to abandon ship	Master assesses the condition of the vessel and MEVs, taking also into consideration that the mustering process has been completed.	SRAP DSS PaMEAS
	Search and Rescue Authorities are informed	Search and Rescue Authorities and nearby vessels are informed of the ship abandonment decision.	VDES Legacy systems (communications)
	Assistance to embarkation	Crew embarkation teams are deployed to assist passengers to proceed to the embarkation stations of port side MEVs. They communicate and receive instructions through PaMEAS Messaging Service.	DSS PIMM PaMEAS
	Abandon ship is announced		
Boarding the MEVs	Passenger Embarkation to MEVs	Relevant instructions are broadcasted to the passengers via PaMEAS as well as over the ship's public address system to facilitate the embarkation process.	PaMEAS SB
		Passengers are led to the embarkation stations by designated crew members.	PIMM PaMEAS
		Boarding the MEVs is initiated.	
		Real time counting of passengers on-board MEVs is performed and confirmed by PaMEAS.	PaMEAS SB PIMM MEV
MEV launching	Rescue process	MEVs are launched.	
		Master and Bridge Command Team abandon the ship using one of the remaining MEVs at the port side, after the evacuation process has been fully completed.	
		MEVs and life rafts are clear of the ship and waiting for rescue.	

3.6 Additional Benchmark Scenario: Evacuation in the case of Grounding

Table 5: The grounding scenario

WP2 - D2.5 Evacuation Scenarios - Basic Use Cases | Grounding Scenario
Scenario Description: A cruise ship is sailing at her usual route with 2600 passengers and 1100 crew members on-board. The vessel has a total of 19 Decks. Boarding to the MEVs is done on Deck 5. All Passengers cabins are located above this deck. The main restaurants, bars, stores and the theatre are located on Decks 3, 4, 5. All decks are above the waterline. The vessel sails during daylight close to the shore and she runs aground on the port side. The damage from the grounding is a hull breach below the waterline and there is ingress of water into two consecutive compartments of the vessel. Scenario actions: 1/ The incident is immediately realized by the OOW and the Master. 2/ The Master assesses the condition of the vessel and decides to **sound the General Alarm and launch the Mustering process**. 3/ The affected compartments of the ship are immediately sealed, but the high water ingress causes the vessel to develop a list. This causes extra problems to the Mustering process, with the greatest of these occurring in the staircases where overcrowding is observed. 4/ A structural failure of the watertight subdivision bulkhead leads to the flooding of a third adjacent compartment. The vessel list rate is increasing rapidly. 5/ In addition, three passengers are injured on their way to Muster Station. The necessary actions are taken to provide assistance to the injured passengers as the Mustering process moves to its completion. 6/ Finally, the **Master orders the abandonment of the ship** as the flooding progresses rapidly and the list is out of control.

Phase	Main event	PALAEMON System Interaction	PALAEMON Component
Normal	The ship is sailing at her usual route close to the shore		
Incident awareness	Ingress of water	Suddenly a power grounding occurs and the bilge alarms in two consecutive compartments are activated. These alarms and the respective compartments are shown in the SSS//Smart Safety System. The SRAP/Smart Risk Assessment Platform (Mode A) and the DSS/Decision Support System are activated. The actions that should be carried out in response to the alarms (according to the SMS/Safety Management System - contingency plan procedures) are displayed on the PIMM. The SRAP system provides a risk level indication for the assessment of the situation. The indication is shown on the PIMM to assist the Master to assess and monitor the condition of the vessel to decide about the next steps.	SSS PIMM DSS SRAP SMS
Situation assessment	Stop propulsion and drop anchor	The Master orders to stop the propulsion. An estimation of the extent of the damage as well as the condition of the hull is provided by the Structural Health Monitoring Toolkit. The Bridge Command Team, via the cameras, checks the affected	SSS Smart Cameras

Phase	Main event	PALAEMON System Interaction	PALAEMON Component
		compartments where there is the ingress of water. Master orders to drop starboard anchor to avoid drifting of the vessel ashore.	Legacy systems (cameras) SHM
	Isolation of the compartments	The PaMEAS assists the Bridge Command Team to check that there is no person trapped on the damaged compartments. The Master closes the watertight doors and hatches of the flooded compartments to stop the propagation of the flooding. The bilge system in the compartments is activated.	PaMEAS SRAP PIMM
	Incident investigation starts	The Master orders the Response Team (via radio communication and PaMEAS Messaging Service) to proceed and investigate the area of the incident, to provide an in-situ assessment of the situation and initiate the first response actions.	PaMEAS SB PIMM
		A special (coded/covert) announcement is made via the Public Address System and PaMEAS Messaging Service, to inform the crew members and the respective response teams about the incident. Designated crew members equipped with AR Glasses are informed via the AR widgets regarding the condition of the incident.	PaMEAS AR Glasses
		Passengers have realized that something has happened because of the intense vibrations caused by the grounding.	
	Attempts to control the flooding	The Response Team makes a visual assessment of the condition around the damaged compartments and initiates flooding countermeasures. The position of the response team is continually tracked by PaMEAS and displayed on the appropriate Visualization Tools (PaMEAS, PIMM). The UAV is launched to assist in the assessment of the damage and the monitoring of the situation. The Master monitors/assesses the situation with the assistance of the risk level indication (SRAP) and available information shown on the PIMM.	AR Glasses PaMEAS PIMM SRAP UAV
		The response team reports (via the PaMEAS Messaging Service and, some members of the team through their AR Glasses) that the watertight doors/hatches are properly closed and that there is no ingress of water to the adjacent compartments. However, they report that the bilge system in the compartments cannot control the water ingression.	PaMEAS AR Glasses
Evacuation Plan is activated	Master decides to sound the General Alarm	To decide on whether to sound the GA or not, the Master evaluates the severity of the following factors: ● Criticality/extent and the escalation of the incident/situation; ● Passenger proximity to the flooding and their awareness;	SRAP DSS PIMM

Phase	Main event	PALAEMON System Interaction	PALAEMON Component
		• Vessel's ability to maintain stability, considering scenarios of the two consecutive compartments as well as possible flooding of another adjacent compartment; and • Functionality of the bilge system, the vital machinery systems and equipment, the condition of crew and passengers, and the weather conditions.	
	Search and Rescue Authorities are informed (MAYDAY SIGNAL)	The Bridge Command Team alerts the Search and Rescue Authorities and the nearby vessels and provides/transmits the required information (e.g., the number of passengers onboard, vessel condition, position, prevailing weather conditions, etc.).	VDES Legacy systems (communications)
	Evacuation protocol activated - Crew Notification about Evacuation launch	The evacuation protocol for summoning passengers at the muster stations is activated. Prior to sounding the General Alarm, a series of systematic announcements and notifications is initiated only for crew members, who are instructed to proceed to their designated positions (mainly through PaMEAS Messaging Service). The position of the crew members is continually tracked by PaMEAS and displayed on the appropriate Visualization Tools.	PaMEAS SB PIMM AR Glasses
	Launch of Evacuation Process (Sounding of the General Alarm)		
Mustering process (unit phase)	All systems in Evacuation Mode	With the GA going off, PaMEAS (Mode B / Evacuation Mode) and SRAP (Mode B) are activated.	PaMEAS SRAP
	Passengers Instructions for mustering	PaMEAS provides instructions sent to the passengers' personal notification devices (smartphones, smart bracelets) in the form of easy-to-read messages on how to prepare for evacuation and reach the muster station location (including primary escape paths, alternative escape paths etc.). In parallel, automated instructions are broadcasted over the ship's public address system.	PaMEAS SB PIMM
		Signaling of the routes of escape for passengers using emergency lighting is activated (because of an eventual local black-out, escape routes are marked with dedicated emergency IoT lighting).	PaMEAS
	Crew Notification	Crew teams (damage-control units, boat preparation units, passenger mustering personnel, first-aid units, etc.) are informed - via radio communication and PaMEAS Notification Service - to move to their predesignated emergency posts.	PaMEAS SB
	Risk assessment & Passengers' Position Tracking while mustering	SRAP (via the PIMM) provides the Bridge Command Team with risk level assessments. PIMM and PaMEAS update on the mustering process (by vertical zone, deck and geofences) until its completion.	SRAP PIMM PaMEAS
	Vessel list	The vessel starts to take a list towards the port side, because of the flooding.	

Phase	Main event	PALAEMON System Interaction	PALAEMON Component
Mustering conditions worsen	List makes evacuation more difficult	Stairways and other possible areas of congestion are monitored by Smart Cameras and PaMEAS, to identify any congestion issues. Due to the list of the vessel, passengers start to face difficulties in their moving to the Muster Stations.	Smart Cameras PaMEAS SRAP DSS
Mustering accelerated		Designated crew is in position (in stairways, corridors, etc.) to provide on-the-spot assistance to passengers to evacuate safely to the muster stations. The crew communicate and receive instructions using PaMEAS Messaging Service and AR Glasses (crew provided with AR Glasses).	PaMEAS AR Glasses
	Counting passengers in Muster station	Passengers have started to arrive at the Muster Stations and passengers' counting is taking place. Crew members regularly report to the bridge the number of counted passengers. This number is checked and contrasted with the PaMEAS auto-count data which come in a continuous flow. Next, crew members provide life jackets to the passengers (those who have not picked a life jacket from their cabin or a lounge area).	PaMEAS PIMM SRAP DSS
Bilge alarms and Routes Congestion	Flooding progresses	A new alarm, this time from the SHM (Structural Health Monitoring) is triggered. It appears that cracks have started to develop on a watertight bulkhead in one of the flooded compartments.	SHM
	Bilge alarms	Bilge alarms in the adjacent compartment have also been activated. The Bridge Command Team monitors the alarms via the SSS. Master orders the team on-site to check the adjacent compartment.	SSS SRAP PIMM PaMEAS AR Glasses
	Response to the alarm	The response team confirms the structural failure of the watertight subdivision bulkhead. The team's leader is instructed to get away from the compartment and the watertight doors are shielded. Communication with the crew-members is provided via PaMEAS Messaging Service and the AR Glasses.	AR Glasses PaMEAS PIMM SHM
	Vessel list is out of control	The vessel list is gradually increasing towards the port side. The movement of the passengers to the Muster Stations is becoming slower.	SHM PaMEAS
		The status and the location of passengers and crew are tracked to identify possible problems, provide assistance wherever is needed, or reassess the emergency response plans. SRAP monitors the risk level of each area.	PaMEAS SRAP DSS

Phase	Main event	PALAEMON System Interaction	PALAEMON Component
		To reduce the congestion, the Bridge Command Team relocates passengers to other escape routes which, according to SRAP, are characterized as of low risk and can safely lead to other Muster Stations. PaMEAS informs the passengers in this regard.	SRAP PaMEAS
	Congestion	Due to the vessel's increasing list a congestion is gradually evolved at the forward part of the vessel in the stairways between Deck 7 to Deck 6. The congestion location is identified by the Smart Cameras and SRAP characterizes this area as of high risk.	Smart Cameras PaMEAS SRAP AS DSS
Injured and Trapped passengers	Injured passengers	The congestion has increased. Three passengers have been injured on their way to the Muster Station and they cannot move. PaMEAS detects no movement for these passengers. A flag is raised in PIMM.	PaMEAS PIMM
		The injured passengers are pinpointed and the response team is informed by the Bridge via PaMEAS Messaging Service and AR Glasses.	Smart Cameras PaMEAS SB AR Glasses
	Injured passengers are rescued	A response team reaches the location of the injured passengers and provides assistance to the nearest Muster Station. The team reports that passengers were collected and delivered at the Muster Stations.	AR Glasses
	Inspecting the rest of the vessel for trapped and remaining passengers	Other crew inspecting the rest of the vessel report for passengers who have eventually been left behind (in the case that the list of passengers reaching a mustering station does not include all passengers and crew on board). The process is conducted with the assistance of PaMEAS and AR Glasses.	PaMEAS AR Glasses
	Master orders response teams to evacuate	The Master orders the teams on-site to evacuate the incident location as it is not possible anymore to control the flooding.	PaMEAS AR Glasses
Mustering completed		Muster stations report the completion of passengers' mustering and counting. The information is verified via PaMEAS. Updated instructions are forwarded to the passengers' personal notification devices (smartphones and smart bracelets) as well as over the ship's Public Address system.	PaMEAS SRAP DSS
Ship abandonment	Master decides to abandon ship	Master assesses the condition of the vessel and MEVs, taking also into consideration that the mustering process has been completed.	SRAP DSS PaMEAS

Phase	Main event	PALAEMON System Interaction	PALAEMON Component
	Search and Rescue Authorities are informed	Search and Rescue Authorities and nearby vessels are informed of the ship abandonment decision.	VDES Legacy systems (communications)
	Assistance to embarkation	Crew embarkation teams are deployed to assist passengers to proceed to the embarkation stations of port side MEVs. They communicate and receive instructions through PaMEAS Messaging Service.	DSS PIMM PaMEAS
	Abandon ship is announced		
Boarding the MEVs	Passenger Embarkation to MEVs	Relevant instructions are broadcasted to the passengers via PaMEAS as well as over the ship's public address system to facilitate the embarkation process.	PaMEAS SB
		Passengers are led to the embarkation stations by designated crew members.	PIMM PaMEAS
		Boarding the MEVs is initiated.	
		Real time counting of passengers on-board MEVs is performed and confirmed by PaMEAS.	PaMEAS SB PIMM
MEV launching	Rescue process	MEVs are launched.	
		Master and Bridge Command Team abandon the ship using one of the remaining MEVs at the port side, after the evacuation process has been fully completed. UAV may fly around the vessel spotting people that may have fallen into the water.	UAV
		MEVs and life rafts are clear of the ship and waiting for rescue.	

4 Fire Evacuation Scenario: Analysis and Operational Details

Following the above scenarios definitions and discussion, this Section provides the operational details for each step of the process of evacuating passengers and crew from a Ro-Pax ship which caught fire in the open sea (fire reference scenario).

The operational analysis that follows is intended to determine the sequence of events that will take place when running the fire-scenario in the field trials, and define the actions that need to be taken when certain incidents occur that may jeopardize the smooth progress of the evacuation process.

More specifically, the analysis will cover the following emergency contingencies:

- Fire on board a Ro-Pax ship and actions to prevent escalation of the fire.
- Abandonment of the ship and mass evacuation of passengers.
- Accidents, involving passengers trapped and crew injured.
- Rescue of trapped passengers.
- Rescue of injured crew.
- Medical assessment and care for injured crew.

The following Section describes the main operational considerations of this analysis.

4.1 Basic Considerations

In the IMO guidelines for ship evacuation analysis (i.e. MSC Circ. 1238) [9], a fire onboard is not considered to explicitly impact passenger performance. Evacuation scenarios 3 and 4 (in MSC Circ. 1238) that describe the most common disaster situations at sea (including fire), pay no attention to the possible impact that fire-related hazards may have on the evacuating population. In the IMO scenarios, a fire is only considered as a “factor” that forces passengers to move from an affected fire zone into other zones. But in real life situations it is very likely that passengers within the affected zone will be impacted by spreading fire hazards like smoke, toxic gases and heat in a way that might limit their movement towards a safe zone.

To account for the impact of these hazards in the fire-related benchmark scenario, we assumed that smoke obscuration in the affected fire zone could cause a reduction in passengers travel time of 10% of the maximum allowed assembly time 1[12]. This is the simplest way to consider fire-related hazards in our scenario without having to run any complex simulation models. To simplify this scenario even further we assumed that only a single deck within the Main Vertical Zone (MVZ) affected by the fire will be impaired by fire hazards (the deck where the fire has started). It remains to be seen during the field trials whether the reduction in passenger speed caused by these hazards will create the need for alternative routes in order to relief congestion and speed up the times of passengers escaping the fire zone.

Likewise, the following assumptions were made on how passengers and crew will move around the affected MVZ:

- Access to the affected zone is restricted for all passengers.
- Assembly stations within the affected MVZ are no longer usable by passengers[5].
- Passengers within the affected MVZ exit the zone horizontally, moving to assembly stations in adjacent zones.
- Passengers may only move through the affected MVZ on decks that are the same level with adjacent assembly stations.
- Stairways within the affected MVZ are non-usable for both passengers and crew.
- Passengers and crew may only use the stairways (primary and secondary) in the unaffected zones.
- No heel and trim conditions were assumed to apply in this scenario, causing no effect on the mustering process duration.

For the initial distribution of people on board (upon sounding of the general alarm) and life vest collection options, the following assumption were made:

The scenario unfolds during the night:

- 50% of passengers are in their cabins -they collect life vests from their cabins and then proceed to the assembly station with their life vest. The rest 50% of the passengers are given life vests at the assembly stations.
- 60% of crew are in their cabins. From the remaining 40%:
  - 50% is in the service areas
  - 25% at their designated emergency posts
  - 25%, originally at their designated post, then dispatched to the rescue of distressed passengers.

  All crew members collect life vests from their cabins.

4.2 Main Events and Actions

The following main events and actions are assumed to take place when running the fire benchmark scenario:

Activation of the plans

Ship

- Activation of the ship's emergency plan.
- Emergency reported by the ship.

S&R emergency services

- Report of ship emergency received.
- Activation of the emergency plan for the rescue teams.

[5] This might cause overcrowding in the adjacent stations and affect the overall evacuation dynamics, in the sense those significant changes might be needed to the evacuation plan to avoid congestion in these stations

- Emergency plan for the rescue teams deployed.

Actions

Secure the fire-affected zone

- Evacuate passengers from the affected zone.
- Restrict access to the affected zone.

Fire control

- Dispatch firefighting teams to reduce and contain the fire.
- Dispatch other emergency teams (if needed) to assist in this task.
- Bring in additional fire-fighting equipment from other ship zones (if needed).

Passengers

- Passengers guided to the muster stations.
- Uninjured passengers gathered at the muster station and counted.
- Care provided to uninjured passengers (food, warm clothes, etc.).
- Rescue of trapped or injured passengers.
- Injured passengers taken to ship's infirmary.
- Passengers guided to the embarkation stations.
- Passengers guided to embark the MEVs.

The above hierarchical structure comprises a first level of staging of the fire reference scenario. It includes the main events and actions that should be taken to secure the applicability of the scenario as well as the responding actors and their assigned mandates. When this scenario is finalized (in the field trials phase) there will be additional staging, at second and third level, which will include more detail on the actions and events that will eventually run in the trials, as well as more information on how the chosen technological solutions will address operational needs.

5 Fire Evacuation Scenario: KPIs

Although the unpredictable nature of fire-related MEE situations makes it difficult to know for certain if everything will go as planned until after a fire has occurred, relying only on "seeing what happens when the fire occurs" to assess the PALAEMON SEM system's performance, cannot provide all the ingredients needed to craft a good system. It is therefore important to be able to measure how well the system is designed to perform, not just watch how well it performs after the fact. Though current measurement approaches provide information on many of the key inputs to a good system design and have made some progress toward outcome assessment, they do not make it possible to reasonably anticipate the system's performance before incidents actually occur and the design is tested against reality.

With that in mind, the assessment of the PALAEMON SEM system's performance should be linked to the measurement of the impact on emergency response reliability, which requires determining what might go wrong in a fire-related accident and anticipating what the impact of particular incidents would be on the success of the evacuation operation. In some cases, fire damaged or destroyed critical equipment (e.g., MEVs or other LSAs) might derail the entire evacuation response effort -they could cause catastrophic failures where there are limited options for adaptation or improvisation to reconstitute capabilities and effectiveness. For non-catastrophic failure modes (e.g., an embarkation point that has been cut off from the fire) there may be options for the crew to dynamically adjust "on-the-fly" and find ways around the failure. Depending on if and how rapidly such adjustments can be made, the overall impact of a fire possibly leading to a failure could be reduced to a minimal level. Understanding the scope of potential consequences of different fire incidents is important to the development of indicators for measuring the performance of the PALAEMON SEM system. Fire incidents that would result in failure of the entire MEE response (which pose much more risk) are treated in specialized ship evacuation protocols and are not considered in this analysis. Fire incidents that would just reduce the system's total capacity or effectiveness and should be taken into account in the development of the system's performance indicators are illustrated in Figure 5.

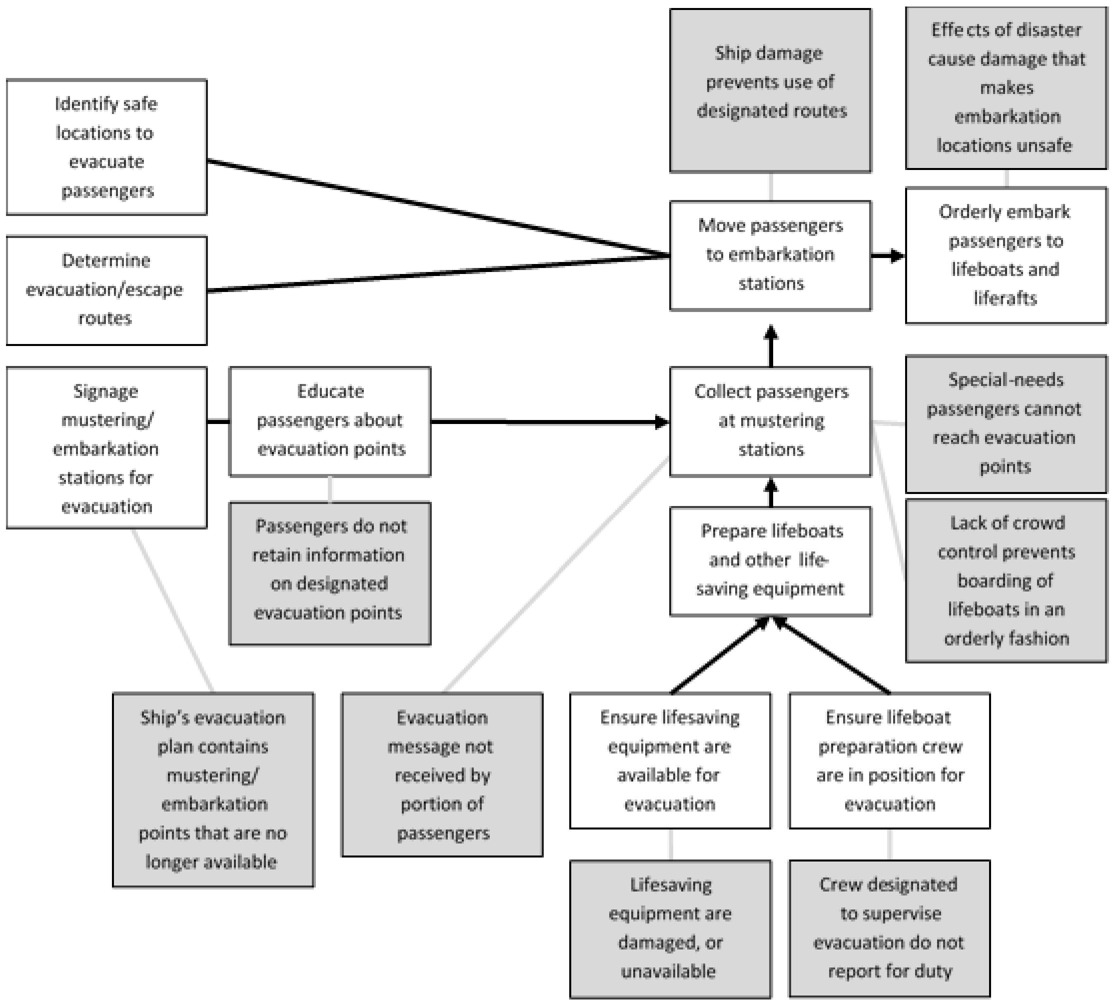

Figure 5: Incident analysis for identifying system performance indicators

The general steps of the MEE response operation, needed to actually trigger the evacuation and carry it out, are shown in the white boxes. Possible fire-related incidents, which when occurring, might disrupt the evacuation operation are included in the gray breakout boxes linked to the steps of the response. Rather than being exhaustive, the incidents shown are intended to illustrate some of the possible elements that would have to be considered in developing the PALAEMON SEM KPIs. For example, an identified fire-related incident/failure is that muster or embarkation stations that are included in the ship’s evacuation plan are no longer available. While this failure would not threaten the entire operation, it would disrupt it and could result in a significant reduction in its effectiveness. With the PALAEMON system in place, crew might find ways around the possible failure and evacuate passengers to other muster/embarkation stations or temporary areas of refuge. Therefore, the “expected number of safe evacuees at time t” could be a good measure of performance as it could capture the effect that the system has on the overall emergency response. Another indicator could be the “expected time needed to evacuate k persons” that captures equally well the effect of incidents of lower priority (such as breakdowns in crowd control or damage at the designated points for evacuees embarking the life-rafts) on the overall emergency response quality.

Summarizing, the PALAEMON SEM KPIs should capture certain safety requirements all of which fall in three typical categories:

1. Qualitative requirements e.g., evacuation should be safe.
2. Quantitative requirements on system level e.g., the total evacuation time should be below 60 minutes (for Ro-Pax, and ships having no more than three main vertical fire-zones) or below 80 minutes (for ships having more than three main vertical fire-zones).
3. Detailed requirements to component solutions e.g., doors should be wider than 1.2 meters, etc.

The first category of requirements is too vague to consider for the needs of this deliverable. The third category of requirements, frequently used in evacuation simulation models, are easily assessed, but one does not have any guarantee that good components necessarily compose a good system. Based on these observations this Section will focus on the second category of requirements, which can lead to KPIs that better highlight the performance of the PALAEMON SEM system. To assess whether the system copes with these requirements it is necessary to measure the performance of the system in field trials which will be carried out later in the project.

In the literature, little has been written about performance measures of ship evacuation response systems. Several sources have discussed different measurement methods albeit in the context of network flow models, either deterministic 1[13]1[14]1[15]1[16], stochastic 1[17]1[18]1[19]1[20], or simulation methods 1[21]1[22]1[23]1[24]. The cited references are concerned with a few performance measures only, and some of them are mainly oriented towards optimization of an evacuation response system with respect to some small subset of the performance measures.

Without any significant help from the (poor) background research, we have decided to review the most relevant of the performance measures listed in the literature in order to identify potential gaps requiring either the development of new measures/indicators or the revision of existing ones.

Table 6 shows the most common performance measures, of which some are more pertinent for the purposes of this study, while some others are less.

Table 6: The long list of relevant performance measures with operationalization

Field	Indicators/ Measures	Operationalization
General evacuation process performance	Process complexity	• Number of elementary operations to complete the evacuation process
	General process information	• Available time for evacuation • Nr of passengers to be evacuated • Ship's occupancy rate (%) • Nr of incoming calls for help per time unit
	Level of response	• [Nr of handled incidents] / [total nr of incidents*] * 100
	Perceived response performance	• Qualitative scale (e.g., Likert) on the successful application of response plans
	Resource utilization	• % of crew actively involved in the evacuation to total crew ratio
Time-related evacuation process performance	Throughput	• Expected time needed to evacuate k persons • Nr of processed incidents during evacuation per time unit
	Process efficiency	• Expected number of safe evacuees at time unit • [Σ(finish time − start time) of all handled incidents] / [number of all handled incidents]
	Process cycle time, process effort, process lead time	• Time for handling the evacuation process end-to-end • Aggregated personnel-time of all activities associated with the evacuation process • [Evacuation alarm time] − [crew response time]
	Processing time	• Time actually spent on a request for help (crew ingress/egress time excluded)
	Average incident lead time	• [Σ(Dispatch time – call-in time)] / [total number of handled incidents]
	Average incident handling time (lifecycle)	• [Σ([incident call-in time] + [information collection time] + [crew sourcing, response units' assembly and follow-up time] + [response unit's time to incident site +

Field	Indicators/ Measures	Operationalization
		processing time + time back to post]) / [total number of handled incidents]
	Evacuation process waiting time	• Average time lag between evacuation sub-processes, when an incident is waiting for further processing • Time between the receipt (by crew) of the order to evacuate and the start of passenger evacuation
	Value added	• [Average incident handling time] / [Average incident lead time]
Evacuation process performance related to quality	Error prevention	• Number of mistakes • [Nr of tasks with errors] / [Total Nr of tasks per evacuation instance/process] • Nr of repeated problems
	Evacuation/response plans compliance, due time performance	• % of evacuation sub-processes' cycle times realized according to the evacuation plan or response plans • [Number of completed sub-processes on time] / [number of all completed sub-processes] * 100
	Rework time, evacuation efficiency	• Time to redo work for an evacuation problem that was solved partially or totally incorrect the first time • Average time spent on solving problems occurring during the evacuation process
	Integration capability	• Time to access and integrate information
Passenger performance	Perceived passenger satisfaction	• Qualitative scale on general satisfaction (e.g., Likert), possibly indexed as the weighted sum of judgements on satisfaction dimensions (e.g., satisfaction with the PaMEAS interfaces and services, perceived value, satisfying end-user needs, responsiveness, friendliness, availability, security) – input received through a questionnaire
	Perceived passenger easiness	• Qualitative scale (e.g., Likert) on the degree of easiness to understand broadcasted advice and instructions, and to navigate oneself in the ship following illuminated markings and public address system notifications
	Passenger query time, resolution time, response time	• Average time between receiving and responding to a passenger problem or inquiry for information

Field	Indicators/ Measures	Operationalization
	Passenger waiting time	● [Time for receiving information about an evacuation sub-process or incident] + [time for following status updates] ● Max Nr of passengers in the queue asking for instructions ● [Handled requests] / [total requests]
	Reliability	● [Late response on instruction requests] / [total Nr of requests]
Crew performance	Perceived crew satisfaction	● Qualitative scale on general satisfaction (e.g., Likert), possibly indexed as the weighted sum of judgements on satisfaction dimensions (e.g., satisfaction with the PaMEAS interfaces and services, perceived value, satisfying end-user needs, responsiveness, friendliness, availability, security)
	Average crew saturation, resource utilization to perform duties	● [Time spent on response assignments] / [time waiting at evacuation posts] ● % of evacuation time that a resource is busy
	Process users	● Nr of crew actually involved in the evacuation process
	Workload	● Average Nr of response assignments handled per crew

To put this long list into the perspective of monitoring and measuring the PALAEMON SEM system's performance, a clear set of objectives is needed to agree how a specialized and comprehensive set of KPIs should look like. These objectives will help narrow down the options of Table 6 and decide which are the best choices in the context of this study.

The following objectives have been identified for this purpose:

1. To demonstrate the ability to prioritise and use the resources and assets needed for maximum effectiveness during evacuation response operations.
2. To demonstrate the ability to locate trapped or injured passengers and crew in ship's sweeping (cleared) zones.
3. To demonstrate the ability to provide immediate assistance to meet the needs of trapped or injured passengers and crew.
4. To demonstrate the ability to conduct rapid situational reassessment when a disruptive (to evacuation) incident occurs.
5. To demonstrate the ability to provide accurate passenger counts and identification in assembly stations.

6. To demonstrate the ability to collect and readily communicate information to the bridge during emergency operations.

The above objectives can then be used to filter out the less relevant KPIs of Table 6 and focus on what's more important for the needs of the PALAEMON project. The short list of KPIs resulting from this filtering process is shown in Table 7.

Table 7: PALAEMON's list of KPIs with operationalization

Field and Objectives	KPIs	Operationalization
Time-related evacuation process performance (Obj. 2, 4, 5, 6)	Throughput	• Expected time needed to evacuate k persons • Nr of processed incidents during evacuation per time unit
	Process efficiency	• Expected number of safe evacuees at time unit • [Σ(finish time − start time) of all handled incidents] / [number of all handled incidents] • Average time spent to collect and communicate information about position and name of passengers travelling to muster stations • Average time spent to collect and communicate information about position and name of passengers entering muster stations • Average time spent to collect and communicate information about position and name of passengers travelling from muster stations to embarkation stations • Average time spent to collect and communicate information about position and name of passengers embarking Life-Saving Appliances (LSA) • Average time spent to collect and communicate information about position and name of passengers permanently identified as requiring specific care, as soon as danger is identified • Average time spent to collect and communicate information about position and name of passengers in ship's sweeping zones
	Process cycle time, process lead time	• Time for handling the evacuation process end-to-end • [Evacuation alarm time] − [crew response time]
	Processing time	• Time actually spent on a request for help (crew ingress/egress time excluded)

Field and Objectives	KPIs	Operationalization
	Average incident lead time	● [Σ(Dispatch time – call-in time)] / [total number of handled incidents]
	Average incident handling time (lifecycle)	● [Σ([incident call-in time] + [information collection time] + [crew sourcing, response units' assembly and follow-up time] + [response unit's time to incident site + processing time + time back to post]) / [total number of handled incidents]
	Evacuation process waiting time, set-up time	● Average time lag between evacuation sub-processes when an incident is waiting for further processing ● Time between the receipt (by crew) of the order to evacuate and the start of passenger evacuation
Passenger performance (Obj. 1, 2, 3, 4)	Passenger query time, resolution time, response time	● Average time between receiving and responding to a passenger problem or inquiry for information
	Passenger waiting time	● [Time for receiving information about an evacuation sub-process or incident] + [time for following status updates]
Crew performance (Obj. 1, 2, 6)	Resource utilization to perform duties, emergency response teams gathering	● [Time spent on response assignments] / [time waiting at evacuation posts] ● % of evacuation time that a resource is busy ● Average time spent to collect and communicate information about position and name of emergency response teams' crewmembers anywhere on the ship

The KPIs suggested above are capable of providing proof of the PALAEMON SEM system's functionality and for describing its performance i.e., how the system is likely to affect the overall evacuation process. They do not address any technical issues such as system throughput, latency, etc., which is subject to the performance engineering solutions that will be adopted during the process of the project.

Against these KPIs, the performance of the various PALAEMON components will be field tested in WP8 to provide proof of their contribution-level to the successful outcome of evacuation operations.

6 Conclusions

This report has presented the results of a scenario analysis that led to the definition of two benchmark scenarios that can enable truly user-based, evacuation use-case analyses. The report provides a more up-to-date view of Use Case scenario definition, originally discussed in the previous version of this Deliverable. It includes additional background information and a more detailed elaboration and discussion of the selected reference scenario(s) to form the basis of the system pilot-field tests at a later stage of the PALAEMON project. The proposed scenarios (the main reference scenario and the complementary one) cover the following issues:

- Detailed definition of the use cases and pilot-field scenarios based on the feedback received by the project partners and on information that should be collected from external sources.
- A detailed list of issues and threats for ship evacuation that need to be prevented or mitigated in a passenger ship environment under a “Smart Evacuation Management” approach.
- A definition of innovative user scenarios with reference to advanced crew and passenger management, MEV (Mass Evacuation Vessel) deployment, ship monitoring, passengers’ security, etc., in conditions of ship evacuation.

These scenarios have been completed with the relevant KPIs that will allow for the evaluation of these scenarios in real conditions, as PALAEMON evolves from design to pilot development. In fact, the evacuation scenarios proposed here, with the related KPIs, will support the project activities within WP 8, where the PALAEMON evacuation process and evaluation framework will be drafted and adjusted to the deployment of the project concepts in real settings.

References

[1] PALAEMON D2.4: First version of PALAEMON Use Cases Definition & Operational Requirements (2020).

[2] https://www.anek.gr/en/vessel/hsf-hellenic-spirit/

[3] PALAEMON D2.3 Final version of PALAEMON Requirement Capture Framework.

[4] PALAEMON D2.7 PALAEMON Architecture (v2).

[5] IMO, 1999, Interim Guidelines for a Simplified Evacuation Analysis on Ro-Ro Passenger Ships. MSC/Circ. 909. London, UK: International Maritime Organization.
IMO, 2002, Interim Guidelines for Evacuation Analyses for New and Existing Passenger Ships. MSC/Circ. 1033. London, UK: International Maritime Organization.
IMO, 2006, Passenger Ship Safety. STW 38/5/1. London, UK: International Maritime Organization.
IMO, 2007, Guidelines for Evacuation Analysis for New and Existing Passenger Ships. MSC.1/Circ. 1238. London, UK: International Maritime Organization.
IMO, 2010. Strategy and Planning (A) Monitoring of Performance. London, UK: International Maritime Organization.
IMO, 2016, Revised Guidelines for Evacuation Analysis for New and Existing Passenger Ships. MSC.1/Circ. 1533. London, UK: International Maritime Organization.

[6] Ibrahim A. M. et al, 2016, Intelligent Evacuation Management Systems: A Review, ACM Transactions on Intelligent Systems and Technology 7(3):1-27, available at https://dl.acm.org/doi/10.1145/2842630.

[7] Stefanidis F., et al, 2019, Ship Evacuation and Emergency Response Trends, Design & Operation of Passenger Ships 2019, available at https://www.researchgate.net/publication/337619932_Ship_Evacuation_and_Emergency_Response_Trends.

[8] Vassalos D. et al, 2002, Evacuability of Passenger Ships at Sea, available at https://www.researchgate.net/profile/Marcus_Bole2/publication/237657474_Evacuability_of_Passenger_Ship_s_at_Sea_By/links/568bac3508ae051f9afc573e/Evacuability-of-Passenger-Ships-at-Sea-By.pdf.

[9] Corrignan P., Breuillard A., Maurier P., 2011. Evacuation of passenger ships: challenges and research activities, 4th International Workshop on Technologies for Search and Rescue and other Emergency Marine Operations available at: http://www.ifremer.fr/web-com/sar2011/Presentations/SARWS2011_CORRIGNAN.pdf

[10] IMO, 2001, SOLAS Amendments 2000. International Maritime Organization, London, UK, ISBN 92-801-5110-X.

[11] Vanem, E. and Skjong, R. (2004). Fire and evacuation risk assessment for passenger ships. In: Proceedings of the 10th International Fire Science and Engineering Conference 2004, vol. 1. Edinburgh, Scotland, July 5–7, 2004, pp. 365–374, ISBN 0 9541216-4-3.

[12] Final Report - SAFEGUARD (Ship evacuation data and scenarios), available at: https://cordis.europa.eu/project/id/218493/reporting.

[13] Chalmet, Luc & Francis, R. & Saunders, P. (1982). Network Models for Building Evacuation. Management Science. 18. 90-113. 10.1007/BF02993491. available at: https://www.researchgate.net/publication/225411643_Network_Models_for_Building_Evacuation.

[14] Choi W., Hamacher H.W. and Tufekci S. (1988). Modeling of building evacuation problems with side constraints. European Journal of Operational Research 35 98-110. Available at: http://www.sciencedirect.com/science/article/pii/0377-2217(88)90382-7.

[15] Francis, Richard. (1981). A "Uniformity Principle" for Evacuation Route Allocation. Journal of Research of the National Bureau of Standards. 86. 10.6028/jres.086.023. available at: https://www.researchgate.net/publication/266532010_A_Uniformity_Principle_for_Evacuation_Route_Allocation.

[16] Hamacher H. W. & Tufekci S., 1987. On the use of lexicographic min cost flows in evacuation modeling, "Naval Research Logistics (NRL), John Wiley & Sons, vol. 34(4), pages 487-503, August. available at: https://ideas.repec.org/a/wly/navres/v34y1987i4p487-503.html.

[17] Karbowicz, C. J., and J. MacGregor Smith. 1984. "A K-Shortest Paths Routing Heuristic for Stochastic Network Evacuation Models." Engineering Optimization 7 (4): 253–280. available at: https://www.tandfonline.com/doi/abs/10.1080/03052158408960642.

[18] Smith, J.M. (1991). State-dependent queueing models in emergency evacuation networks. Transportation Research. B 25B/6 373-389 available at: https://www.sciencedirect.com/science/article/pii/019126159190031D.

[19] Smith, J.M. (1992). Multi-objective routing in stochastic evacuation networks, in: J. Sullivan (ed.), Proc. of the 1992 Int. Emergency Management and Engineering Conference, Florida, April 1992, The Society for Computer Simulation, 113-117. available at: http://www.sciencedirect.com/science/article/pii/S0377-2217(08)00744-3

[20] Talebi, K., and Smith, J. 1985. Stochastic Network Evacuation Models. Comput. Oper. Res., 12(6), p.559–577. available at https://dl.acm.org/doi/10.1016/0305-0548%2885%2990054-1.

[21] Drager K.H., Loves, G.G., Wiklund, J., et al. "EVACSIM. A comprehensive evacuation simulation tool", in: J. Sullivan (ed.), Proc. of the 1992 Int. Emergency Management and Engineering Conference, Florida, April 1992, The Society for Computer Simulation (SCS), 1992, 101-108. available at: https://www.semanticscholar.org/paper/EVACSIM-A-comprehensive-evacuation-simulation-tool-Drager-L%C3%B8v%C3%A5s/f34375769827d8b07c375736b619ad7e776c4896.

[22] Glowacki A. (1992). Using simulation to prepare for emergency mine fire evacuations, in: J. Sullivan (ed.), Proc. of the 1992 Int. Emergency Management and Engineering Conference, April 1992, The Society for Computer Simulation, 79-83.

[23] Kisko T.M. and Francis R.L. (1981). EVACNET+: A network model of building evacuation, in: Computer Simulation in Emergency Planning, The Society for Computer Simulation (SCS).

[24] Ozel F. (1992). Simulation modeling of human behavior in buildings. Simulation 58/6 377-384 available at: https://journals.sagepub.com/doi/abs/10.1177/003754979205800604.