PROJECT DELIVERABLE REPORT

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

D8.2 Operational Pilot Sites

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

<table>
<tr><th>Grant Agreement Number</th><th>814962</th><th>Acronym</th><th colspan="2">PALAEMON</th></tr>
<tr><td>Full Title</td><td colspan="4">A holistic passenger ship evacuation and rescue ecosystem</td></tr>
<tr><td>Topic</td><td colspan="4">MG-2-2-2018: Marine Accident Response</td></tr>
<tr><td>Funding scheme</td><td colspan="4">RIA - Research and Innovation action</td></tr>
<tr><td>Start Date</td><td>1st JUNE 2019</td><td colspan="2">Duration</td><td>44 months</td></tr>
<tr><td>Project URL

Project Coordinator</td><td colspan="4">https://palaemonproject.eu/

AIRBUS DEFENCE AND SPACE SAS</td></tr>
<tr><td>Deliverable</td><td colspan="4">D8.2 Operational Pilot Sites</td></tr>
<tr><td>Work Package</td><td colspan="4">WP8 – PALAEMON Application Field Trials, Evaluation and Outcomes</td></tr>
<tr><td>Date of Delivery</td><td>Contractual</td><td>M44</td><td>Actual</td><td>M44</td></tr>
<tr><td>Nature</td><td>R - Report</td><td colspan="2">Dissemination Level</td><td>PU-PUBLIC</td></tr>
<tr><td>Lead Beneficiary</td><td colspan="4">UAEGEAN (UAEG)</td></tr>
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<tr><td>Keywords</td><td colspan="4">ELYROS F/B ANEK, Ship Evacuation, Smart Evacuation Management piloting, Pilot Sites Preparation, Pilot Sites survey, Pilot Sites Assessment, Pilot Final Areas</td></tr>
</table>

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Revision History

Version	Date	Responsible	Description/Remarks/Reason for changes
0.1	01.09.22	UAegean	Initial version sent to the Consortium
0.2	31.01.23	UAegean	Version with the definitive pilot design (sent it to the Consortium)
0.3	22.02.23	UAegean	Section 2 finalised
0.4	07.03.23	UAegean	Section 4 finalised
0.5	10.03.23	UAegean	Section 5 finalised
0.7	22.03.23	UAegean	Version ready for internal review
1.0	23.03.23	UAegean	Final version after incorporating reviewers' comments

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Abbreviations

6DoF	6-degree-of-freedom
AE	Acoustic Emission
API	Application programming interface
AR	Augmented Reality
CMS	Condition Monitoring System
COTS	Commercial Off-The-Shelf
CPRI	Common Public Radio Interface
DFB	Data Fusion Bus
DFB	Data fusion bus
DoA	Description of Action
DSS	Decision Support System
DSS	Decision Support System
eCPRI	Evolved Common Public Radio Interface
EMSA	European Maritime Safety Agency
EPC	Evolved Packet Core
FMAGDM	Fuzzy Multi-Attribute Group Decision Making
GA	General Alarm
GCS	Ground Control Station
HMI	Human Machine Interface
ICT	Information Communications Technology
ICT	Information and Communications Technology
IMO	International Maritime Organization
IMO	International Maritime Organization
IMU	Inertial Measurement Units
IOT	Internet of Things
ISM	International Safety Management
ISO	International Organization for Standardization
LCA	Life cycle assessment
LSA	International Life-Saving Appliance Code
LSA	Life Saving Appliances
MCPTT	Mission Critical Push To Talk
MEV	Massive Evacuation Vessel
MOB	Man Overboard
NDT	Non-destructive tests
PA	Public Address System
PaMEAS	Passengers Mustering and Evacuation Process Automation System
PEC	PAssenger evacuation capacity
PEET	Pilot Exercise Evaluation Team
PIMM	PALAMEON Incident Management Module
PIMM	PALAEMON Incident Management Module
PTT	Push-to-talk
RCC	Rescue Coordination Centres
RoPax	Roll-on/roll-off passenger

RTLS	Real-Time Location System
SA	Standalone
SB	Smart Bracelet
SEM	Smart Evacuation Management
SHM	Structural Health Monitoring
SME	Small and medium-sized enterprises
SMS	Safety Management System tool
SOLAS	International Convention for the Safety of Life at Sea
SOP	Standard Operating procedure
SRAP	Smart Risk Assessment Platform
SRAP	Smart Risk Assessment Platform
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
TOPSIS	Technique of Ordered Preference by Similarity to Ideal Solution
TRL	Technology Readiness Levels
UAS	Unmanned Airborne System
UAV	Unmanned Aerial Vehicle
USAR	Urban Search and Rescue
VDR	Voyage data report
VHF	Very High Frequency
VR	Virtual Reality
VRG	Voyage Report Generator
VTOL	Vertical take-off and landing
VTS	Vessel Traffic Services
Weather Forecast Tool	WFT
WSM	Weather Service map

Executive Summary

The PALAEMON project will carry out two complete end-to-end trials in two different European cities (Athens and Spain), involving real end-users. In the Athens pilot site, four use cases will be implemented that involve an incident on board the ELYROS F/B, which requires the passengers to be mustered and ready for embarkation. To ensure a capable response to the incident, the PALAEMON SEM approach will be utilised, which involves organising the crew, guiding the passengers from their initial location to a secure area, and managing any unexpected passenger concerns.

The purpose of the pilot is twofold: to test the SEM approach in a real-world setting and to gather network, service, and performance KPIs to evaluate the approach against a set of predefined criteria. This deliverable is part of WP8, which focuses on testing the integrated SEM ecosystem through the pilot and driving the evaluation of the trial results, specifically T8.2 PALAEMON Ecosystem Setup and Deployment. The aim of this task is to define the most suitable KPI to assess impact as well as the most reliable methodologies to evaluate it. Furthermore, within this task a pilot realisation plan will be prepared, describing the steps and the evaluation procedures for each pilot.

This deliverable initially provides an overview of the PALAEMON Smart Evacuation Management approach and proceeds by presenting how the SEM platform assessment model is derived from the related literature and furthermore analyses it into specific KPIs via which the SEM platform can be evaluated in vivo conditions.

Finally, it presents a detailed pilot realisation plan, describing the steps necessary for the evaluation procedures of the SEM platform by breaking down the pilot into scenarios/exercises with specific start conditions, interim steps and end results to ensure operational clarity and execution efficiency during the piloting actions.

1 Introduction

This is the Deliverable entitled "Operational Pilot Sites" of PALAEMON WP8 "Application Field Trials, Evaluation and Outcomes", the last Work Package of the project. WP8 was about the pilot application of the main project achievements, as they have been summarised in the Deliverables of the following WPs:

- WP4: PALAEMON Mass Evacuation Vessel
- WP5-WP6-WP7 (WP5: PALAEMON on-board mustering tools and services - WP6: PALAEMON Back-End Infrastructure - WP7: PALAEMON Integrated System and Technology Validation Trials.

In essence, as described in the GA and explained in the first Deliverable of WP8[1], the pilot activities should prove the feasibility and maturity of the outcomes of previous WPs through demonstration and testing in a relevant ship environment. Since the project has the two-fold objective of developing:

a) A mass centralised evacuation system, "based on a radical re-thinking of Mass Evacuation Vessels (MEVs)" and,
b) An intelligent ecosystem of critical components "providing real-time access to and representation of data to establish appropriate evacuation strategies for optimising the operational planning of the evacuation process on damaged or flooded vessels",

the pilot action has been implemented in two locations, under different settings:

I. In Spain, in the shipyard of Astander, a key Consortium participant, where the PAALEMON MEV construct has been tested through simulations and trails in close sea
II. In Greece (Port of Piraeus) where an operational version of PALAEMON Data Ecosystem supporting the needs of the evacuation operations has been successfully deployed onboard of a passenger ship provided by ANEK Lines, an international shipping company, operating in the South of Europe, and end-user member of the Consortium (ELYROS F/B).

As a result, the work in WP8 has been splitted into two parts, carried out by different actors and under different demonstration and testing principles. Consequently, the reporting on WP8 piloting action has been also organised in two groups of deliverables:

WP8 Deliverables - Series A (MEV)	PALAEMON Application Field Trials, Evaluation and Outcomes - Mass Evacuation MEV
WP8 Deliverables - Series B (SEM)	PALAEMON Application Field Trials, Evaluation and Outcomes - Smart Evacuation Management | SME (where the term Smart Evacuation Management refers to the operational version of PALAEMON Data Ecosystem)

In short, the Deliverables of WP8 are segregated in two distinct groups, the first reporting to the MEV pilot action and the second one to the SEM pilot, as shown in the following Table:

[1] PALAEMON D8.1 Report on Pilot Sites Preparation and Assessment

WP8 Deliverables - Series A (MEV)					
#	**Deliverable Title**	Lead beneficiary	Type	Dissemination level	Due Date[2]
D8.1	Report on Pilot Sites Preparation and Assessment: MEV Trial		R	Confidential	M44
D8.2	Operational Pilot Sites: MEV Trial		R	Confidential	M44
D8.3	PALAEMON application trial 1: MEV Trial		R&DEM	Confidential	M44
D8.6	PALAEMON Consolidated Pilots Evaluation: MEV Trial		R	Public	M44
D8.7	Operation Manual, Recommendations and Best Practices: MEV Trial		R	Public	M44
D8.8	Public release WP8: MEV		R	Public	M44

WP8 Deliverables - Series B (SEM)					
#	**Deliverable Title**	Lead beneficiary	Type	Dissemination level	Due Date[3]
D8.1	Report on Pilot Sites Preparation and Assessment: SEM Trial	UAEGEAN	R	Public	M44
D8.2	Operational Pilot Sites: SEM Trial	UAEGEAN	R	Public	M44
D8.4-5	PALAEMON application trial 2 and 3: SEM Trial	UAEGEAN	R&DEM	Public	M44
D8.6	PALAEMON Consolidated Pilots Evaluation: SEM Trial	UAEGEAN	R	Public	M44
D8.7	Operation Manual, Recommendations and Best Practices: SEM	UAEGEAN	R	Public	M44
D8.8	Public release WP8: SEM Trial	UAEGEAN	R	Public	M44

[2] See Second GA amendment
[3] See Second GA amendment

The Deliverable that follows is the **“edition SEM"** of the **Deliverable “Operational Pilot Sites”**, and the **second of the Series B (SEM) of the WP8 Deliverables** (submitted subsequently to D8.1b [2] Report on Pilot Sites Preparation and Assessment: SEM Trial). It provides directions and specifications for the PALAEMON Smart Evacuation Management Framework as well as a detailed pilot implementation and testing plan. It is the outcome of T8.2 “PALAEMON Ecosystem Setup and Deployment” which focused on: a) the selection of the suitable methodologies and KPIs to assess and evaluate the impact of the Smart Evacuation Management Framework, on the basis of the input provided by WP2 [1] and, b) the definition of concrete use cases/scenarios/exercises that make use of the functionality provided by the Smart Evacuation Management platform and demonstrate its effective capacity to manage complex emergency situations that may require the activation of the ship evacuation plan.

In more detail, this Deliverable includes the following chapters:

Chapter 2 presents takeaways from the previous Deliverable (D8.1 Report on Pilot Sites Preparation and Assessment [2]), with reference to the functional features of the PALAEMON Smart Evacuation Platform, its architecture and main components.

Chapter 3 provides an updated pilot implementation plan and its decomposition in scenarios exercise with concrete steps and outcomes that demonstrate the capacity of the Smart Evacuation to provide effective IT-enabled assistance to the evacuation process via people tracking, personalised emergency messaging and real-time process monitoring.

Chapter 4 discusses the appropriate evaluation framework and KPIs for the assessment of the performance, and therefore the potential impact of the PALAEMON Smart Evacuation Management approach on the ship evacuation “problem-solving” activity.

2 Smart Evacuation Management Onboard the Ship: Functionality, Architecture and Components

Deliverable D8.1b [2] defines an operational version of the PALAEMON Data Ecosystem, by cherry picking the components delivered by WP7 based on their deployability onboard ELYROS (the RoPax vessel that was provided for the piloting needs by ANEK Lines), their operational maturity and finally their impact on the evacuation-mustering process, which is the focus of WP8. This subset of the PALAEMON Data Ecosystem is referred to as the **Smart Evacuation Management (SEM)** platform. Essentially, the SEM platform is comprised of:

2. A **software platform** (microservices) - deployed onboard the ship with cloud connections (PaMEAS, PIMM, SRAP etc)[4].
3. A **network architecture** using advanced networking technologies (5G, WiFi6, BLE beacons) - also deployed onboard the ship

These components are integrated and deployed on the ship to implement an evacuation management re-designed model that augments and transforms existing evacuation procedures to a streamlined process (by establishing process management and real-time monitoring techniques). Via this integration of software and network components the SEM platform is able to:

[4] For a complete list of the modules and a description of their functionality please refer to D8.1b [2].

- Track passengers and crew position in real time (Indoor Positioning)
- Inform and alert passengers via personalised, location-based, notifications (a complement to the Public Address System - PA) sent to their cell phones - provide guidance on how to reach a muster station
- Assign tasks to crew, and monitor how the crew members perform the assigned tasks, through a MCPTT service
- Optimise coordination and provide real-time monitoring of the mustering and evacuation processes (from the reconnaissance of an accident until the embarkation of passengers and crew to LSAs)

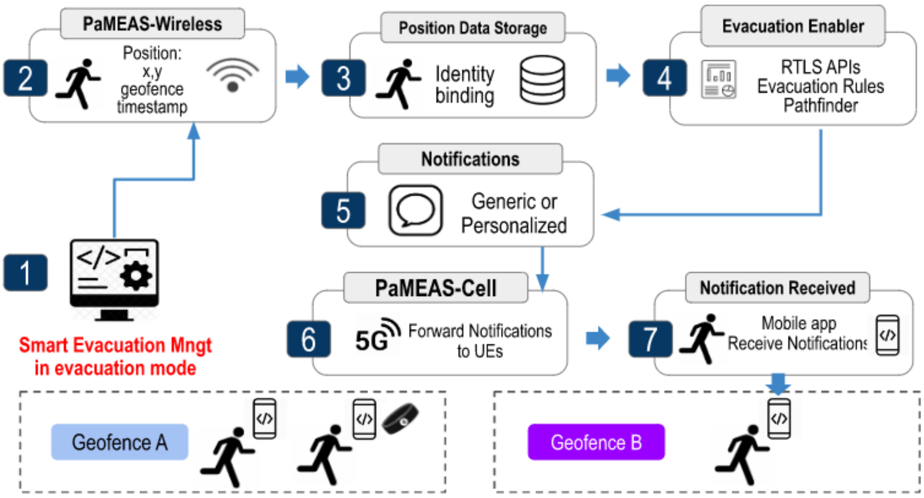


Figure 1. SEM Platform functionality

To support the piloting actions the SEM platform will be deployed onboard ELYROS using a hybrid approach. Specifically, physical constrained modules and hardware will be deployed onboard ELYROS on SEM platform servers and on the pilot spaces[5], while the majority of the software modules will be deployed on cloud servers. Of course, it is possible to deploy all modules of the SEM platform[6] on the physical servers that will be installed on ELYROS. However, this hybrid deployment approach enables better maintainability of the SEM platform enabling the technical partners to better monitor the status of the system (ensuring minimal downtimes)[7].

In order to verify the applicability of the SEM platform in the context of evacuation management and measure the exact effect the platform has on the evacuation management process the following actions took place:

1. A series of piloting scenarios and exercises were defined and presented in Chapter 3 of this deliverable.
2. A set of KPIs were defined, after a careful review of the related literature, and are presented in Chapter 4.

[5] this applies to hardware modules: BLE beacons, WiFi APs, 5G radio dots and 5G core server
[6] with the exception of some modules that must be installed at the premises of the land control operations of the shipping company for security reasons
[7] today's state of the art internet connectivity on maritime vessels exceeds speeds of 200Mbps, which surpass the needs of the SEM platform by a significant degree. As a result, any concern about the production capacities of the hybrid deployment model was dismissed.

3 Smart Evacuation Management Onboard the Ship: Pilot (Trail) implementation Topology and Plan

3.1 Pilot Topology

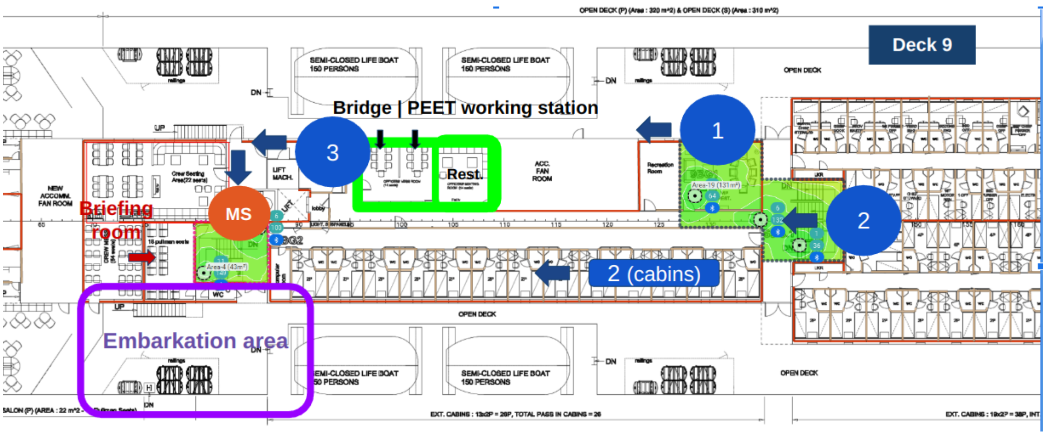


Figure 2. ELYROS Pilot Area

The figure above presents an overview of the specific areas of ELYROS in which the pilot will take place, as those were defined in detail in D81.b [2]. These areas were used as the context for the definition of the pilot scenarios/exercises to ensure that the outcome would enable the evaluation of the SEM platform in real settings. The details of the available pilot spaces are presented in the following table.

Table 1. Deck 9 Pilot Area Characteristics

Demo Areas on Deck 9	Length	Width	Surface	Description
9BG1	6.54	5.30	34.15	VIP lounge
9BG2	10.30	5.30	54.59	Restaurant
9CG3	38.45	2.97	101.00	Restaurant Corridor
9CG0	8.68	6.20	53.61	Mustering Station (staircase)
9BG4	38.45	2.97	101.00	Cabin Corridor
GCab9223	2.75	3.85	10.5	Cabin
GCab9209	2.75	3.85	10.5	Cabin
S9-8.1	6.00	6.00	36.00	Staircase
9BGEVAC	28.88	7.79	224.97	LSA embarkation area

3.2 Pilot Plan

In D2.5 [1] an evacuation scenario[8] for Maritime Emergency Evacuation (MEE) that took into account various factors such as environmental, structural stability, passenger and crew behaviour, and escape possibilities, was presented. This scenario defined how the Smart Evacuation Management (SEM) is integrated into the evacuation process and provided the framework for the SEM pilot functionality. The scenario development process started with internal 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 summarising the results into D2.5 [1]. During a MEE situation analysis, it is not possible to take every conceivable accident scenario into account. However, it is not necessary to do so since the defined scenarios are to be used as basic action plans. The objective, therefore, was to identify realistic operational scenarios that could be implemented during the SEM platform pilot to allow for testing the various system's components [20] and providing proof of their functionality and contribution-level to the successful and smart management of the evacuation process. Accident statistics on passenger ships [21] indicate that fire related accidents are very important to the shipping community, because of the frequency with which they occur and the severity of their implications. As a result a fire-related scenario has been chosen in terms of its potential as the basis for the development of the SEM platform pilot activity. 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, such as 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 breathing. In addition, a fire may have a psychological effect on the people onboard affecting their behaviour, causing panic, shock, or paralysis of the passengers.

Based on this analysis in D2.5 [1] the following piloting plan was designed:

"*A Ro-Pax ship is sailing at her usual route with approximately 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. A smoke alarm is activated on one of the Decks. The incident is detected by the ship's smoke, heat and fire detectors at the respective deck, calling for immediate action.*" This scenario entails the following actions.

Table 2. Main Pilot Scenario Actions

#	*Pilot Plan 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*

[8] A scenario in this context is defined as 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 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 passenger 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.*

This action plan was analysed into various scenarios/exercises, which were designed to enable the evaluation of the capacities of the SEM platform. Specifically, the list of these exercises is presented below:

Table 3. Pilot Exercises/Actions

Exercise Name	Description	Actions
PreEvac1	Emergency Assessment Task Management - Dispatch two firefighting teams to reduce and contain the fire	● Order the emergency team to move to incident location ● Order the firefighting team to move to incident location ● Collect feedback from the crew teams ● Review the received feedback
PreEvac2	Crew to their Evacuation Positions	● Instruct Crew to reach their designated positions for Evacuation ● Obtain the list of emergency teams and their current position ● Verify positions
Must1	Augmented GA alarm - Direct the move of a group of passengers from area x to muster station	● Alert Messages to Passengers (different languages) ● Notify Passengers and track their positions ● Help passengers trapped in their cabin
Must2	Instruct passengers about alternative escape routes	● Notify Passengers and track their positions
Must3	Assist a passenger remained behind (review passenger profile)	● Passenger injury issue detected - via SEM ● Bridge verifies the passenger issue has been resolved - via SEM
Must4	Face an incident - involvement of the medical team	● Passenger health incident detected - via SEM ● Bridge verifies the passenger incident has been resolved - via SEM

Embark1	Evacuations groups and Embarkation Preparation	● Create evacuation groups ● Notify passengers about their evacuation group ● Verify presence in the embarkation area

To better evaluate the SEM platform and maximise feedback, several pre-piloting and piloting actions are planned to be executed both onboard ELYROS and in the lab. Each such action will consist of the execution of a series of the aforementioned scenarios (with possible slight variations).

As a result, the update pilot plan **is planned to be implemented in two phases**.

1. The **first phase** aims to validate the proper functionality of all of the SEM components deployed on ELYROS. Additionally, the goal of these exercises will be to gather measurements about the effectiveness of the platform based on the KPIs defined in this report and optimise the platform based on the gathered feedback.
2. The **second phase** is designed as **two pilot runs**. The first pilot run, **Pilot Run (A1)**, aims to validate the SEM platform in real circumstances covering all of the functional requirements of the system as those are expressed in D2.5 [1] and will be further expanded upon on D8.6. The second run, **Pilot Run (A2)** will act as the **Demo** of the SEM platform. As part of Pilot Run (A2) end users will be invited to participate, review the functionality of the system in action under real circumstances and will be asked to evaluate its overall capabilities and the added value (if any) the system provides in interviews which were recorded and will be made available.

3.2.1 Phase A: Pre-piloting actions

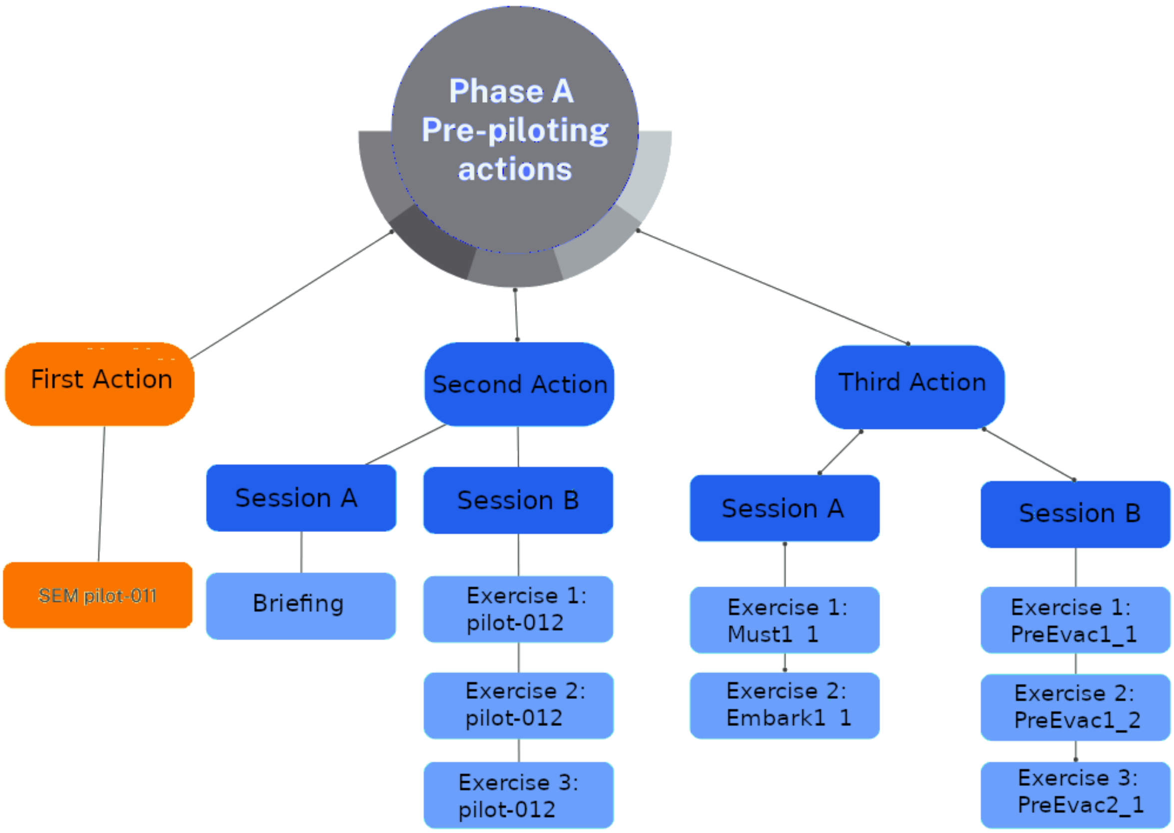


Figure 3. Pre-pilot action organisation

The pre-piloting actions are decomposed into the following scenarios/exercises

Table 4. Pre-pilot exercises actions and outcomes

First Action	Second Action	Third Action
SEM pilot-011	Pilot-012 (variation A)	Must1_1
	Pilot-012 (variation B)	Embark1_1
	Pilot-012 (variation C)	PreEvac1_1
		PreEvac_1_2
		PreEvac2_1

First Action. The first pre-piloting action (SEM pilot-011: Measure the effectiveness of SEM emergency messages) will take place at the National Technical University of Athens (NTUA). Its purpose is to test the SEM platform's emergency alert and notification capabilities. The experiment will involve students who will be given instructions on how to act in an emergency situation and will be equipped with eye-tracking goggles to measure their perception and decision time when receiving messages from the SEM platform (via the PALAEMON passenger mobile app). The reactions of the users will be recorded using the eye-tracking goggles and the captured videos will be analysed after the end pilot action to evaluate the capacities of the SEM platform. The experiment will consist of three message sessions, and is aimed to calculate the time it takes for passengers to perceive and verify emergency information and to decide on an evacuation path. The collected data will be used to gain insights on how to improve the SEM system.

Table 5. Measure the effectiveness of SEM emergency messages

Action	SEM pilot-011
Start event: Alert Message Received	The test subject is notified via the PALAEMON passenger app about the receipt of an emergency message
	The test subject reads the message. Once they comprehend its content they look at a designated control object
	The test subject is notified via the PALAEMON passenger app about the receipt of a mustering instruction emergency message
	The test subject reads the message. Once they comprehend its content and are ready to act on it they look at a designated control object
	The test subject is notified via the PALAEMON passenger app about the receipt of a embarkation instruction message
End event: Passenger comprehended instructions of Embarkation message	The test subject reads the message. Once they comprehend its content and are ready to act on it they look at a designated control object

Second Action. The second pre-pilot action (SEM pilot-012: Evaluate the usability of the PALAEMON apps (for passengers and crew) will take place on board ELYROS and will involve students acting as passengers and members of the PALAEMON project overseeing the exercises. The main goals are to measure the effectiveness of the SEM platform and the usability of the PALAEMON passenger app. The pilot experiment will consist of **two sessions**.

- The first is to brief the pilot users about the scopes of the PALAEMON project and the use of the PALAEMON passenger app.
- The second session will include **three piloting exercises** covering the alerting, mustering, and embarkation preparation phases. Eye-tracking technology will be used to measure passengers' comprehension time and their ability to follow instructions (and will be further complemented by stop watches in case not enough

eye-tracking goggles are available for all passengers). The results will be used to refine and improve the system. The specifics of each action to be implemented are defined in the following tables.

Table 6. Evaluate the usability of the PALAEMON apps (for passengers and crew - First Exercise

Action	Pilot-012: First Exercise
Start event: Master initiates passenger alerting	The Master via the SEM platform UI initiates the transmission of the alert messages to the passengers
	The passengers receive on their PALAEMON passenger apps the alert messages
End event: Passengers are alerted and ready to take action	The Passengers read the alert messages after reaching for their phones and once the comprehend the situation they are ready to take action

Table 7. Evaluate the usability of the PALAEMON apps (for passengers and crew - Second Exercise

Action	Pilot-012: Second Exercise
Start event: Master authorises the send of mustering instructions	The Master via the SEM platform UI initiates the transmission of the mustering instructions to the passengers
	The passengers receive on their PALAEMON passenger apps personalised mustering instructions, guiding them from their current locations to the Muster Station
	The passengers read the instructions, and once they comprehend them initiate their trip to the Muster Station
End event: Passengers arrive at the Muster Station	The Passengers after following the received instructions arrive at the Muster Station

Table 8. Evaluate the usability of the PALAEMON apps (for passengers and crew - Third Exercise

Action	Pilot-012: Third Exercise
Start event: Master authorises the assignment of embarkation groups	The Master via the SEM platform UI initiates the generation and transmission of the embarkation groups for the passengers
	The passengers receive on their PALAEMON passenger apps personalised messages informing them about their

	embarkation group
	The passengers read the instructions and form a line under the guidance of the crew
End event: Passengers arrive at the LSAs	The Passengers arrive at the LSAs in an ordered fashion with pre-formed groups

Third Action. The third pre-piloting action will involve students from NTUA and members of the project overseeing the execution of the action and taking measurements. This pre-piloting action will be implemented under several scenarios/exercises (PreEvac1, PreEvac2, Must1 and Embark1). The execution will be implemented in **two sessions**.

- The **first session** will focus on the SEM platform's interaction with passengers, with two exercises covering alerting, mustering, and embarkation (Must1_1, Embark1_1) with the project members taking measurements of the relative times the passengers require to complete the tasks using stopwatches.
- The **second session** will focus on emergency assessment and activation of the evacuation process, with three exercises primarily involving the crew (PreEvac1_1, PreEvac1_2, PreEvac2_1) with the project members taking measurements of the relative times the crew members require to complete the tasks using stopwatches. The results of these tests were used to evaluate the SEM platform under specific D8.6b PALAEMON Consolidated Pilots Evaluation.

Table 9. Must1_1 actions and outcomes

Action	Must1_1
Start event: Journey progressing as normal	The passengers are distributed randomly (as they please) on the piloting areas of Deck 9
	The Master via the SEM platform UI initiates the alerting of the passengers
	The passengers receive on their PALAEMON passenger apps the alert messages
	The Passengers read the alert messages after reaching for their phones and once the comprehend the situation they are ready to take action
	The Master via the SEM platform UI initiates the transmission of the mustering instructions to the passengers
	The passengers receive on their PALAEMON passenger apps personalised mustering instructions, guiding them from their current locations to the Muster Station
	The passengers read the instructions, and once they comprehend them initiate their trip to the Muster Station

Action	Must1_1
End event: Passengers arrive at the Muster Station	The Passengers after following the received instructions arrive at the Muster Station
Start event: Master authorises the sending of mustering instructions	The Master via the SEM platform UI initiates the transmission of the mustering instructions to the passengers

Table 10. Embark1_1 actions and outcomes

Action	Embark1_1
Start event: Passengers are gathered at the Muster Station	Mustering has been completed and all passengers are mustered at the Muster Station
	The Master via the SEM platform UI initiates the generation and transmission of the embarkation groups for the passengers
	The passengers receive on their PALAEMON passenger apps personalised messages informing them about their embarkation group
	The passengers read the instructions and form a line under the guidance of the crew
End event: Passengers arrive at the LSAs	The Passengers arrive at the LSAs in an order fashion with pre-formed groups

Table 11. PreEvac1_1 actions and outcomes

Action	PreEvac1_1
Start event: Alert Displayed on PIMM	Fire alarm is triggered and an emergency notification is displayed on the SEM platform UI of the bridge (PIMM)
	Master changes the state of the SEM platform to emergency assessment
	Master uses SEM platform MCPTT capacities to instruct emergency response team members to investigate incident
	Emergency response team members acknowledge order and move to incidents location
End event: Emergency	The emergency response team members provide feedback

Action	PreEvac1_1
response team members provide feedback	via live video streaming and audio to the bridge (using the MCPTT capacities) that the incident is real

Table 12. PreEvac2_1 actions and outcomes

Action	PreEvac_112
Start event: Master receives reports about incident	The emergency response team members provide feedback via live video streaming and audio to the bridge (using the MCPTT capacities) that the incident is real
	Master uses the SEM platform capacities to verify the proximity of crew members and passengers to the incident
	Master uses SEM platform MCPTT capacities to instruct fire fighting team members to take action
	Firefighting team members acknowledge order and move to incidents location
End event: Firefighting team members provide feedback	The firefighting team members uses the SEM platforms MCPTT capacities to report that the fire is out of control

3.2.2 Phase B: Piloting actions

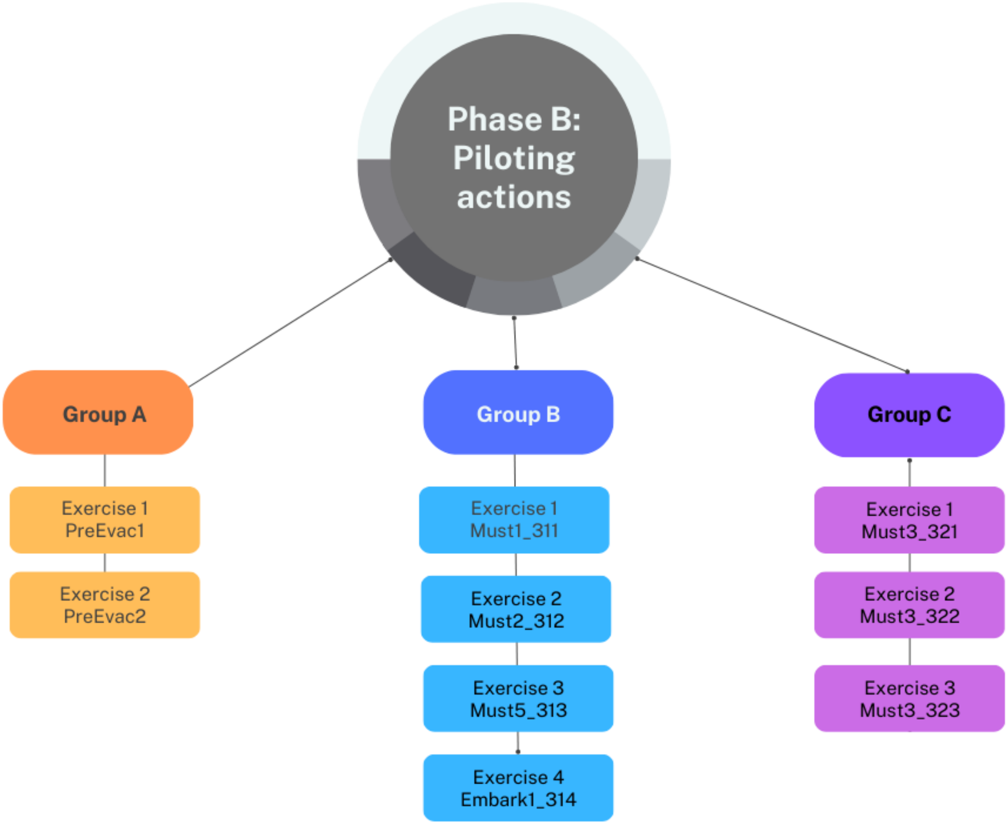


Figure 4. Piloting Actions plan

The SEM platform will conduct its final pilot run and demonstration on the ferry ELYROS. The pilot will involve students from the National Technical University of Athens acting as passengers, the ship's Master and crew officers as end-users, and representatives from HMOD and the ISOLA project to evaluate the performance of the SEM platform. The Pilot Exercise Evaluation Team (PEET) will also be present to operate the SEM platform. During the pilot, all participants will be equipped with 5G phones with the PALAEMON app pre-installed, and will be connected to the PALAEMON 5G Standalone (SA) Network.

The pilot will simulate a fire emergency scenario onboard ELYROS to test the entire emergency handling process, from emergency detection to mustering of passengers and handling passenger incidents. The PALAEMON SEM platform will be used to coordinate the crew's response and track the location of each crew member and provide real-time information on their status as well as the status of the emergency. The bridge will be able to review all available information to evaluate the situation and take action accordingly. Various other passenger-related incidents will also be simulated, to evaluate the capabilities of the SEM platform.

In detail, the core pilot plan is designed to be separated into **three pilot groups** of exercises namely, **Pre-evacuation**, **Mustering & Evacuation**, and **Issue/Incident Management**. These groups are based on the corresponding evacuation phases and involve a variety of pilot exercises, each exercise consisting of key pilot actions that are outlined in the section below.

Table 13. Pilot groups

Pilot Group A: (Pre-evacuation) Actions	Pilot Group B: (Mustering and Evacuation) Actions	Pilot Group C: (Issue/Incident Management) Actions
Pre-evacuation 1 (PreEvac1)	Must1_311 (Must1)	Must3_321 (Must3)
Pre-evacuation 2 (PreEvac2)	Must2_312 (Must2)	Must4_322 (Must4)
	Must5_313 (Must5)	Must_323 (Must1)
	Embark1_314 (Embark1)	

3.2.2.1 Group A: Pre-evacuation pilot group

The goal of the pre-evacuation group of exercises is to ensure that the SEM platform can contribute to the optimization of the processes necessary for the coordination of the emergency response teams, complementing existing capabilities and enhancing the process with additional features (for example video streaming of the emergency incident to the bridge). Furthermore, this group of exercises is designed to deal with the preparatory actions required to take place prior to the sounding of the general alarm. Specifically, with the optimization of the efforts required to coordinate the crew members to assume their emergency posts and the verification of the completion of this task. In detail this group of exercises will consist of the SEM Pilot-11 Pre-evacuation 1 exercise and the SEM Pilot-12 Pre-evacuation 2 exercise which are described in detail below.

3.2.2.1.1 Pre-evacuation 1 pilot exercise

The Pre-evacuation 1 pilot exercise will involve two critical components: emergency assessment and dispatching of firefighting teams. During this action, an emergency assessment will be conducted first to determine the severity of the situation and the appropriate response. Once the assessment has been completed, firefighting teams will be dispatched to the affected area with the necessary equipment and supplies to contain the fire and provide feedback to the Bridge. This exercise is essential to ensure a well-planned and coordinated response in the event of an actual emergency.

Previous actions assumed: Specifically, this pilot exercise involves a scenario where it is assumed that a fire has been reported on Deck 9 in the right staircase[9], due to a machinery explosion. This fire caused the activation of the ship's fire and smoke sensors which triggered the fire/smoke alarms in the SEM infrastructure as well.

Pilot exercise starts: Once the triggered fire/smoke alarm is presented to the Muster.

Pilot exercise steps: The Muster who manages the SEM system, will change the status of the system to "Emergency Situation Assessment" and will instruct the team to proceed to the

[9] For a detailed view of the piloting spaces please refer to D8.1b [1]

location of the fire on Deck 9 and investigate. Meanwhile, the main firefighting team, composed of two crew members, will be instructed to proceed to Deck 9 and attempt to contain the fire using the SEM infrastructure. The team will arrive at the location and report on the situation via the SEM infrastructure, which will be reviewed by the Bridge. In addition to the reports, the Bridge will also review the recommendations of the SEM system on how to proceed with the decision to muster.

Pilot exercise ends: The pilot action will reach its conclusion when the Bridge decides to activate the Evacuation Procedure via the SEM to ensure the safety of the vessel, personnel, and passengers.

The detailed actions of the exercise are presented in the following table:

Table 14. Pre-evacuation 1

Action	PreEvac1
Start event: Detection	The PIMM module displays the Fire/Smoke alarm (received via SSS) - Smoke Detector: Deck 9 - kitchen
	The Bridge initiates on PIMM the dispatching of the fire emergency response team ("Situation Assessment" Status)
	The Bridge uses the onboard DSS to review the action plan as defined by the ICM code
	The Bridge establishes a MCPPT communication with the crew team ("Team Dispatcher" button) (Fire Team: x05)
	The SEM platform provides real time crew location tracking
	The fire team reports on a fire that is spreading fast
End event: Activation of Evacuation Protocol	The Bridge evaluates the situation and and decides to initiate the sending of the Crew Assume Posts messages ("Activate Evacuation Protocol")

3.2.2.1.2 Pre-evacuation 2 pilot exercise

The Pre-evacuation 2 pilot exercise will require the crew to move to their designated evacuation positions before the sound of the general alarm (GA) during an emergency situation. This pilot action is a crucial part of the Pre-evacuation 2 pilot exercise, which is conducted to train the crew members to respond quickly and efficiently in case of an emergency. The exercise aims to simulate real-life emergency situations and test the crew's ability to carry out their roles and responsibilities during such situations. By requiring the crew to move to their evacuation positions before the GA, the exercise will ensure that the crew is prepared to evacuate passengers as soon as possible.

Previous actions assumed: Based on previous assumptions, a fire has broken out on Deck 9 in the right staircase (9BG1+) due to a machinery explosion. The ship's fire and smoke sensors have detected the fire, triggering alarms both in the SEM infrastructure and physically on the bridge using existing infrastructure. In response, the bridge has instructed the emergency response team and fire fighting teams to move to the location of the fire and provide feedback. Furthermore, the bridge has made the decision to activate the Evacuation Procedure via the SEM infrastructure to ensure the safety of the vessel, personnel, and passengers.

Pilot exercise starts: The PreEvac_121 pilot action will commence by providing crew members with instructions to promptly move to their assigned emergency positions, leveraging the SEM infrastructure.

Pilot exercise ends: The pilot action will reach its conclusion when the Bridge verifies through the use of SEM, that all crew members have arrived at their designated positions.

The detailed actions of the exercise are presented in the following table:

Table 15. Pre-evacuation 2

Action	PreEvac2
Start event: Crew Alerting	The SEM platform notifies the crew members - via MCPTT app (messaging and voice channel) (x03-x04-x05) x03: MS x04: corridors
	The PIMM module displays in real time the location of the crew members and crew confirm positions via MCPT
End event: Evacuation alert	Once the positions assumed, the Bridge sounds the GA - The SEM platform alerts the passengers (“Alert Passengers” status)

3.2.2.2 Group B: Mustering and Evacuation pilot group

The objective of the second group of exercises is to assess the efficiency of the Smart Evacuation Management (SEM) infrastructure in handling a range of emergency scenarios. The system will be tested to ensure that it can quickly alert passengers in the event of an emergency, guide them safely and quickly from a public area to a pre-designated muster station in an orderly manner, and respond to updates to the evacuation procedure as needed. Additionally, the SEM system is expected to monitor and report the progress of the mustering process, including detecting passengers who may have left the muster station unexpectedly and alerting the crew to return them to safety. Finally, the system will be tested to ensure that it can efficiently prepare passengers for embarkation. By performing these actions, the system aims to ensure the safety and security of all passengers and crew during an emergency evacuation.

3.2.2.1 Mustering 1 pilot exercise

Mustering 1 pilot exercise is designed to enhance the safety and security of passengers in emergency situations. It will include several key actions starting with directing a group of passengers from a specific area to their designated muster station using an augmented GA alarm. Additionally, the exercise will provide instructions to passengers about alternative escape routes to ensure that they are aware of all possible means of egress. It will also deal with the management of passengers leaving a muster station, ensuring that they are accounted for and directed to safety as required. Finally, it will involve the designation of evacuation groups and preparation for embarkation, allowing for an organised and efficient evacuation process. Overall, the exercise plays a critical role in preparing crew members and passengers for emergency situations, ensuring that they are able to respond effectively and minimise risks to human life and property.

Previous actions assumed: In the assumed previous actions, the evacuation protocol for summoning passengers to the muster stations has been activated. Additionally, the crew emergency position has been verified, ensuring that all crew members are in their designated emergency positions, ready to respond to the emergency. Furthermore, the general fire alarm is continuously ringing, alerting passengers and crew members of the emergency.

Pilot exercise starts: The pilot exercise will begin with an alert action from the SME system, notifying passengers of an imminent evacuation due to a fire threat caused by a machinery explosion.

Pilot exercise steps: Passengers will receive mustering instructions from the SEM system, directing them along evacuation routes. However, some passengers will encounter blocked paths due to smoke, prompting the SEM to issue updated instructions on alternative routes to ensure their safety. During the mustering, one passenger will leave the muster station to retrieve a valuable item from their cabin. The SEM system will detect this and immediately alerts both the passenger and the crew member responsible for the muster station, instructing the passenger to return immediately. The crew member will ensure that the passenger returns to the muster station, maintaining order and safety during the evacuation process. Once all passengers have been gathered in the muster station, the Master will use the SEM infrastructure to change the status of the system to "Embarkation," initiating the process of creating evacuation groups. Passengers will be notified of their assigned evacuation groups and move to their designated embarkation stations. The Bridge will verify the presence of passengers in the embarkation area through the SEM infrastructure.

Pilot exercise ends: The pilot exercise will conclude once the Muster verifies that all passengers have been gathered and counted at the Embarkation Station.

The detailed actions of the exercise are presented in the following table:

Table 16. Mustering 1

Action	Must1_311
Start event: Evacuation alert	The Bridge initiates on PIMM the process of alerting passengers (“Alert Passengers” status)
	The SEM platform automatically alerts the passengers with emergency (fire) alert messages

	The Bridge changes the “state” of PIMM to “Mustering” status
	The SEM platform calculates the appropriate evacuation paths and sends personalised notifications to passengers on how to reach the Muster Station (A862059 - A862057 etc.)
	The Bridge/EC monitors the ordered execution of the mustering (the progressive move of the passengers towards the Muster Station)
	As passengers move to the muster station, the Bridge/EC views “geofence population reports” (lists of passengers located at the different geofences) - all emptying except the Muster Station ones…and verifies the number of passengers arriving at the MS vs the passengers assigned to it
End event: Passengers at Muster Station counting	The SEM platform automatically counts the passengers and crew gathered at the Muster Stations (the list of passengers in Muster Station becomes available to Bridge/EC)

Table 17. Mustering 2

Action	Must_312
Start event: The start of the Mustering operation	The Bridge changes the “state” of PIMM to “Mustering”
	The SEM platform sends personalised notifications to passengers on how to reach the Muster Station
	The Bridge/EC monitors the ordered execution of the mustering (the progressive move of the passengers towards the Muster Station)
	The Bridge is notified via PIMM about the Smoke Alarm on a specific Geogence and decides to remove this area from the available evacuation paths
	The SEM platform sends to passengers a message alerting them to avoid racing the hazardous area
	After a while, the SEM platform sends notifications to passengers with updated instructions on how to reach their assigned muster station - depending on their current location - in such a way that avoids the hazardous area (if the original instructions required them to move through the hazard area)
	As passengers move to the muster station, the Bridge/EC views “geofence population reports” (lists of passengers located at the different geofences) - all emptying except the Muster Station ones…and verifies the number of passengers arriving at the MS vs the passengers assigned to it

End event: Passengers at Muster Station counting	The SEM platform automatically counts the passengers and crew gathered at the Muster Stations

Table 18. Mustering 3

Action	Must5_313
Start event: Muster Station attendance report completed	The Bridge/EC reviews the status of the mustering via PIMM
	A passenger abandons the muster station, heading towards their cabin x057
	The SEM platform detects the move out the Muster Station and, automatically, alerts the passenger to immediately return to their Muster Station
	The Muster Station officer crew (overseeing the area) receive alert message about the incident
	The Bridge EC identifies the passenger who left the Muster Station
	The Bridge/EC selects two crew members positioned around the Muster Station and informs them about the incident (via MCPTT)
	The passenger is located and returned to the Muster Station - The Bridge monitors the evolution of the incident on PIMM
	The Bridge/EC communicates with the Muster Station manager, via MCPTT, to let them know about the end of the incident
End event: Muster Station attendance report re-issued	The SEM platform automatically re-counts the passengers and crew gathered at the Muster Stations

Table 19. Mustering 4

Action	Embark1_314
Start event: Embarkation is initiated	The Bridge/EC changes the “state” of PIMM to “Embarkation”
	The Bridge communicates via MCPTT to the Muster Station manager that they should start the embarkation process
	The SEM platform generates embarkation groups and assigns them to the passengers of the muster stations

	The SEM platform sends notification messages to the passengers informing them about their embarkation group assignments
End event: Muster Station manager reports that embarkation is in progress	Muster Station manager reports via MCPTT to the Bridge/EC of the progress of the embarkation

3.2.2.3 Group C: Issue/Incident Management

The issue/incident management group of exercises will aim to evaluate the ability of the Smart Evacuation Management (SEM) infrastructure in effectively assisting passengers with health conditions that require assistance to evacuate quickly, detecting and resolving passenger health incidents, and providing support to people with special needs to increase the overall efficiency of evacuation. The pilot actions of this group are crucial in determining the system's ability to manage diverse and complex situations, ensuring passenger safety and reducing the risk of delays or complications during the evacuation process.

3.2.3.1 Mustering 2 pilot exercise

The Mustering 2 pilot exercise is designed to handle a range of issues and incidents that may arise during the mustering process. For example, if a passenger becomes trapped and requires assistance, the Palaemon App will be used to handle the situation (Must3_321). Additionally, the SEM system will detect health issues among passengers and crew members and dispatch a medical team to provide necessary assistance (Must_322). In cases where passengers require assistance based on their profile, such as those with special needs or disabilities, the SEM platform will dispatch a medical team (Must1_323). By addressing issues and incidents promptly, the exercise plays a critical role in ensuring the safety of all passengers and crew members during the mustering process, minimising any potential risks or delays.

Previous actions assumed: In this exercise, it is assumed that the SEM system has been activated to initiate the evacuation protocol and alert passengers about the emergency. Crew members have already been informed and instructed to proceed to their designated positions for emergency response. The general fire alarm is sounding continuously, providing additional alert to passengers and crew. Through the SEM system, passengers have received alerts about the emergency and evacuation path instructions, directing them to their designated muster stations.

Pilot exercise starts: The pilot exercise begins when the SEM system receives a request for assistance from a trapped passenger in their cabin (Must3_321).

Pilot exercise steps: A crew member will be dispatched to the cabin to assist the passenger after receiving authorization from the Master. The passenger will eventually reach the muster station, albeit with some delay. Additionally, the SEM platform will detect a health issue with one passenger whose heartbeat drops below acceptable levels (Must4_322). A suitably trained crew member will be dispatched to assist the passenger and safely transfer them to the muster station. Finally, a pregnant passenger will receive instructions on her mobile phone to wait for assistance to evacuate (Must1_323). A crew member will be assigned to assist her in reaching the muster station safely.

Pilot exercise ends: The pilot exercise concludes once all the incidents have been resolved and the Muster verifies that all passengers are accounted for at the muster station.

The detailed actions of the exercise are presented in the following table:

Table 20. Mustering 5

Action	Must3_321	Must_322	Must1_323
Start event: Detection	The Bridge/EC receives an emergency feedback message (sent by the mobile app of passenger A862054 requesting immediate help)	The PIMM alerts automatically the Bridge/EC about a passenger with a health issue - A862053 - (triggered by a SRAP event[10])	The PIMM alerts automatically the Bridge/EC about a passenger with known condition that hinders their evacuation capacity (pregnant passenger A862052)
	The PIMM module displays a notification requesting authorization from the Bridge to dispatch a crew member team to the identified from PaMEAS incident. The SEM platform proposes allocation of the crew member team (via its leader) to the specific incident (based on proximity and capabilities)	The SEM platform receives the notification and transforms it into a suitable passenger assistance request	The PIMM module displays a notification requesting authorization from the Bridge to dispatch a crew member team to the identified from PaMEAS incident
	The Bridge/EC consents (Crew Team: x04)	The Bridge/EC consents - The SEM platform proposes allocation of the crew member team (via its leader) to the specific incident (based on proximity and capabilities)	The Bridge/EC consents - The SEM platform proposes allocation of the crew member team (via its leader) to the specific incident (based on proximity and capabilities)
	The SEM platform notifies the selected crew members (alert message via MCPTT)	The SEM platform notifies the selected crew members (alert message) - The	The SEM platform notifies the selected crew members (alert message) - The

[10] SRAP identifies that a passenger is displaying abnormal health indicators (heartbeat reduced below acceptable limits) and generates an event. The exact way SRAP is functioning is presented in the deliverables D3.9 Development of Risk Assessment Platform (V1) [22] and D3.10 Development of Risk Assessment Platform (V2) [23].

	- The message instructs the crew to move to the location of the passenger	message instructs the crew to move to the location of the passenger	message instructs the crew to move to the location of the passenger
	The Crew team or the Bridge/EC establishes a MCPPT communication with the crew team	The Bridge/EC establishes a MCPPT communication with the crew team	The Bridge/EC establishes a MCPPT communication with the crew team
	The Bridge/EC retrieves the profile of the passenger and forward it to the crew team	The Bridge/EC retrieves the profile of the passenger and forward it to the crew team	The Bridge/EC retrieves the profile of the passenger and forward it to the crew team
	The Bridge/EC monitors the case on PIMM - The crew team arrives at the passenger location (location tracing)	The Bridge/EC monitors the case on PIMM - The crew team arrives at the passenger location (location tracing)	The Bridge/EC monitors the case on PIMM - The crew team arrives at the passenger location (location tracing)
End event: Reporting and/or Monitoring	The Crew Team reports over MCPTT on the successful transfer of the passenger in the designated area (9BG2) - The Bridge/EC verifies on PIMM the successful transfer of this person to the Muster Station	The Crew Team reports over MCPTT on the successful transfer of the passenger in the designated area - The PIMM displays the arrival of the passenger in the designated area	The Crew Team reports over MCPTT on the successful transfer of the passenger in the designated area - The Bridge/EC verifies on PIMM the successful transfer of this person to the Muster Station

4 PALAEMON Smart Evacuation Framework: Performance Evaluation Framework and KPIs

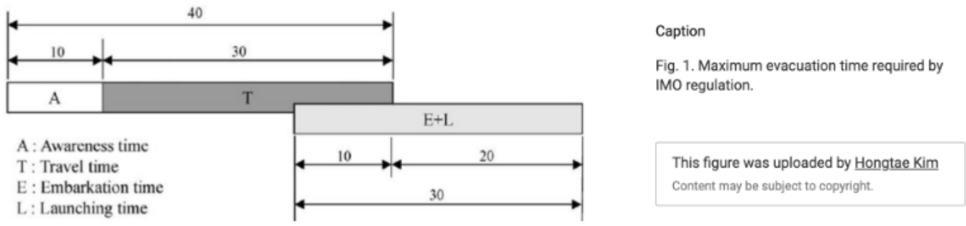
The previous section presented the detailed design of the Pilot plan that was defined to verify the capabilities of the SEM platform and to enable the study of its impact on the ships “evacuability”.

This section presents an “evacuation model” which is then used to define a set of critical **Key Point Indicators** (KPIs) to enable the measuring of the exact effects of the SEM platform on the ships capacity to efficiently evacuate. This evacuation model was defined after a careful review of related literature (presented in this chapter), took existing mustering drills and practices into consideration, and finally used the pilot plan as its basis. Specifically, the evacuation model identifies the following areas in which the contribution of the SEM platform should be evaluated:

1. Response Time
2. Pathway Decision Time
3. Travel Time
4. Embarkation Preparation Time
5. Incident Response Time

We must acknowledge at this point that due to the specific constraints of the piloting actions[11], the effect of the SEM platform with respect to Travel Time and Embarkation Preparation Time will be difficult to accurately evaluate. Nevertheless, the following sections present the derived KPIs for these areas with the intent to gather the necessary measurements and evaluate their accuracy and capacity to extract meaningful results after the conclusion of the piloting efforts.

4.1 Starting point: Evacuation Time according to the IMO regulation



- Total Evacuation Time: 1.25 (A + T) + 2/3 (E + L) < n

Figure 5. Evacuation Time according to IMO

The IMO "Guidelines for a Simplified Evacuation Analysis for New and Existing Passenger Ships" covered by MSC Circ 1033 and its successor MSC Circ 1238 recommend a maximum allowable total passenger ship evacuation time (n) to be in the range of 60 to 80 minutes, as modelled in Figure 3 and based on the following:

- 60 minutes should apply to ships having no more than three main vertical (fire) zones
- 80 minutes applying to ships having more than three main vertical (fire) zones

The IMO model of the Evacuation Time acted as the starting point for the SEM evacuation model presented in the following sections.

4.2. SEM evacuation model

This section describes the **evacuation model** developed in the context of the project that is used to derive a set of integral Key Point Indicators (KPIs) that are designed in such a way that enables the measurement of the SEM platform to the ships "evacuability". Research, technology development and piloting actions conducted in the context of the PALAEMON project have been designed to improve the PEC (Passenger Evacuation Capacity) of RoPax and cruise ships. Essentially, the SEM system aims to improve the traditional evacuation process by adding technology support via a software platform based on a microservices

[11] Piloting had to take palace on a very specific area of Deck 9 and with a limited number of participants to ensure the uninterrupted operational capacity and safety of ELYROS (see D8.1b [2] for more details).

structure, and a complementary network infrastructure providing "sensing" functionality (i.e., people location tracking) and onboard communication services with low latency and high reliability. As a result, an augmented evacuation model is progressively designed which is quantified into **two tiers of indicators** presented below

Table 21. Tier Indicators

Tier Indicator	Description
Tier 1	evacuation process monitoring efficiency
Tier 3	passengers evacuation performance

These indicator tier sets are designed after a review of the related bibliography (references are provided where necessary). Specifically, these tiers have been designed to make the impact of the proposed innovation more comprehensible in terms of the utility passengers and crew *de facto* receive from the (pilot) deployment of the SEM operations onboard a ship, compared with the current performance of the evacuation procedures, measured/evaluated through previous evacuation trials or simulations [3][4][5][6] - we essentially compare between two states of the world, **"before SEM" and "after SEM"**.

Under this model five KPIs were defined, presented in the following table and analysed in the subsequent sections.

Table 22. Key Point Indicators

KPI	Tier
Evacuation Response Time Indicator (EVRTI)	Tier 1
Evacuation Pathway Decision Indicator (EVPDI)	Tier 1
Evacuation Travel Time Indicator (EVTRI)	Tier 1
Embarkation Preparation Time Indicator (LSAEMBI)	Tier 1
Incident Response Time Indicator (IRTI)	Tier 2

4.2.1 Tier 1 KPIs

Tier 1 indicators are conceived on the basis of a model framework construct, similar to those proposed in the context agent-based models designed for assessing the evacuation capabilities of passenger ships, built on the assumption of goal-driven decision-making, path planning, and movement of the passengers [3][7]. The model framework proposed here, considers the passenger behaviour onboard a passenger ship, when the general emergency alarm is sounded to call passengers to assemble to the muster stations until the embarkation to LSAs, in the following terms:

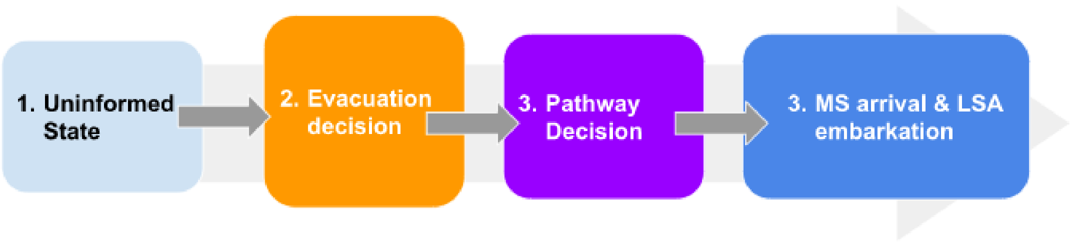


Figure 6. Passenger "Life Cycle"

- Passengers are in an "uninformed state" during the initial phase of an accident that will impose to Bridge the decision to launch the evacuation procedure.
- Once the Bridge has sounded the evacuation alarm, passengers will be alerted through the Public Address System and the Passenger Messaging Service. The behaviour of the passengers during this early stage of evacuation (pre-evacuation) involves a **response time** during which passengers acquire, verify and process the received alert information and, finally, decide to move on.
- After deciding to evacuate, passengers will explore the available information on possible pathways to the muster station, given their current location. Some people may rely on their own understanding of the escape route, others would trust the suggestions of the crew or follow the decision of other passengers. The time between the decision to take action and when passengers start purposeful movement to a muster station is modelled in the related literature as a path-finding process which requires a **(pathway) decision time**.
- Once the decision is made, passengers will move on the selected path with a certain speed, acceleration (if the situation suddenly becomes worsening) or delay (in the case of hindances such as ambient smoke etc., or congestion restrictions along their path). The time from the start of the evacuation movement to the arrival of the passengers at the muster station corresponds to the **travel time** of the IMO evacuation process template.
- Finally, passengers move in groups to the nearest evacuation exit and prepare to embark the LSAs. The time needed for all passengers and crew to organise in groups and become ready for evacuation to suggested LSAs is considered as **embarkation preparation** time.

The following table summarises the model framework and gives additional input to the structure of the different components of the total evacuation time.

Table 23. Model framework summary

Evacuation stage	Time factors	Time components		
Pre-evacuation	Response Time	information dissemination time	information perception time	
Pathway finding	Pathway Decision Time	pathway information reach time	pathway decision time	
Mustering	Travel Time	expected travel time	congestion time	-Δfluidity support policies

Embarkation	Embarkation Preparation Time	embarkation information reach time	embarkation groups time	

Specifically, in the table above the following definitions are used:

- information dissemination time: the time required to effectively alert passengers
- information perception time: the time a passenger needs to perceive/verify the received emergency information
- pathway information reach time: the time of acquiring information about the available escape options
- pathway decision time: the time needed to process that information and decide on the evacuation path
- expected travel time: the (expected) time required by passengers to travel from their original location on the vessel to the muster station
- congestion time: the time needed to travel through congested areas along the escape route
- Δfluidity support policies: the rerouting or evacuation batching policies applied to facilitate seamless passenger flow
- embarkation information reach time: the time required to effectively notify passengers that they should get prepared for embarkation
- embarkation groups time: the time needed for the passengers to move to their exit gates in groups

The KPIs of Tier 1 are the most significant with respect to the capacity of the SEM platform to improve a ship's “evacuability”. Specifically, to define these KPIs an extensive review of related literature was conducted. Tier 1 consists of the following KPIs.

Table 24. Tier 1 KPIs

KPI	Description
Evacuation Response Time Indicator (EVRTI)	ratio of the total response time in the “after” state and the total response time (time for passengers to become aware) in the “after” and “before” state.
Evacuation Pathway Decision Indicator (EVPDI)	ratio of the total evacuation pathway decision time in the “after” state and the total evacuation pathway decision time in the “before” state
Evacuation Travel Time Indicator (EVTRI)	ratio of the total travel time in the “after” state and the total travel time in the “before” state
Embarkation Preparation Time Indicator (LSAEMBI)	ratio of the embarkation preparation time in the “after” state and the embarkation preparation time in the “before” state

Due to their significance in the analysis of the performance of the SEM platform, each such KPI is presented in detail. Specifically, in the following sections the definition of the measurement related to the KPI prior to the SEM platform is presented and an analysis of the related bibliography is provided as background information. Finally, reasoning to the definition of the same KPI measurement after the application of the SEM platform is provided. Finally the KPI is formally defined to enable its calculation after the execution of the piloting exercise.

4.2.1.1 Evacuation Response Time Indicator (EVRTI)

This section provides an analysis of the definition of the **Evacuation Response Time Indicator (EVRTI)** and how this is calculated as the ratio of the total response time in the “after” state and the total response time in the “before” state.

Definition (pre-SEM): The Evacuation Response Time (EVRT) is a measurement that denotes the difference in terms of the time it takes for the passengers to become fully aware of the emergency and react, before the adoption of the SEM approach (the term “before” here refers to data collected from the relevant literature). The total Response Time (RT), which starts counting from the sounding of the alarm, consists of **the time required to effectively alert passengers** [information dissemination time, *idis(t)*] and **the time the passenger needs to perceive/verify the received emergency information** [information perception time, *iper(t)*] [8][5].

$$EVRT(t) = idis(t) + iper(t) \qquad (1)$$

Background information: Previous observational, experimental and simulation studies on passengers’ evacuation [3][9][4] show that during this pre-movement phase (understand/react), passengers might proactively respond to an emergency alarm, but they may also not decide to evacuate until they hear the confirmation on the ship’s Public Address (PA) system (from crew). They rather have the tendency to investigate the situation and look for information that could explain what the alarm signal is about (usually, by asking other passengers). Furthermore, passengers do not react uniformly, because their attitude is affected by individual physical and cognitive characteristics, particularly when the impact of the accident is not yet visible [10][12].

According to the IMO requirements [11], the time that elapses from the sounding of the alarm to the point when a passenger starts to move to the Muster Station (MS) should not exceed 5 min at daytime and 10 min at night-time. Notice that these response time totals include the time required to acquire, verify and understand the evacuation cue (considered in this document as “response time”), as well as the time to search for information about escape options and develop an escape plan, or “(pathway) decision time” (in the terms of this study).

Yue et al [12] use simulation experiments to evaluate passengers’ "perception time" -- they use the term "perception time" to describe what in the present study is defined as Response

[12] The personal identity attributes and cognitive features of passengers, their psychological quality after the emergency launch, the perception they have about the type of danger, their attachment to the opinion and reaction of other passengers etc., are naturally different, therefore they follow a non-uniform distribution within a given population (ibid).

Time (see Eq. 1)[13]. They have estimated that the perception time is 40 sec when the information “initial dissemination rate” is 25% -- the term in quotation marks refers to the percentage of passengers who immediately understand the meaning of the evacuation cue, and immediately shift to the evacuation decision state. As the initial dissemination rate increases, the perception time becomes shorter. Particularly when the initial information dissemination rate is equal to or greater than 75%, the perception time reaches its minimum value at 25 sec as shown in Figure 5 (Figure 8 of the cited paper [12]).

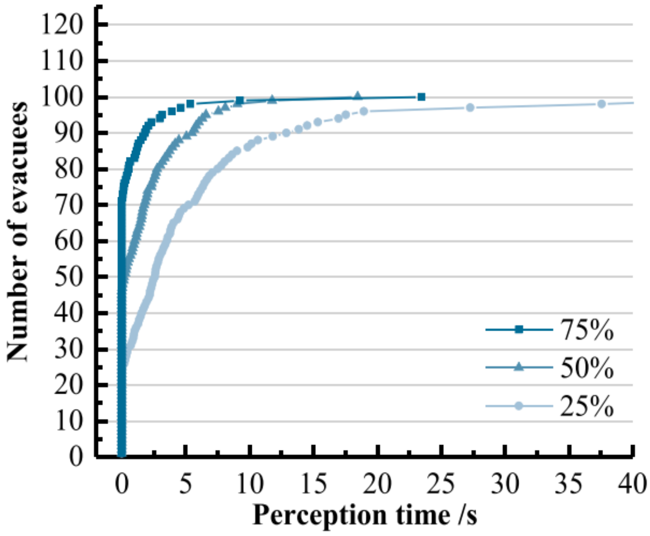


Figure 7. Perception times of evacuees under different initial “dissemination rates” (Y. Yue et al, 2022)

In their experiments, Yue et al. used cut-off values of 25%, 50% and 75% initial dissemination rate as the purpose was to show the effects of information dissemination on the total perception time. In fact, 25% and higher initial dissemination rates are quite optimistic without some kind of technological enabling as other relevant research suggests. In particular, Casareale et al [7] have found -- using a random sample of 100 passengers boarding various cruise ships at the port of Ancona (Italy) -- that the main response of 83% of the passengers, after the first alarm, was to verify the veracity of the signal received, meaning that a mere 17% of the passengers immediately understood the emergency cue and started evacuating with no delay. Hence the use of a 17% initial dissemination rate in the "before SEM" state can be considered a safe assumption.

By adjusting the 25% initial dissemination rate curve of Fig. 5 to correspond to an initial rate of 17%, while maintaining the same distribution, it follows that 90% of the passengers[14] will have an average perception/response time of 27 sec. Of this time, 10 sec is considered as the time required for information dissemination (*idis(t)* of Eq. 1), which in the “before” state is taken as equal to the duration of the continuous blast of the vessel's whistle in case of fire[15]. The remaining 17 sec correspond to the time required for information perception (*iper(t)*) in

[13] In the terms of Y Yue et al, the perception time is the initial delay before evacuation and depends on the information dissemination process by which passengers acquire, verify, and disseminate information during pre-evacuation.

[14] The reason why time values for people accounting for 90% of rated passenger capacity were chosen is to exclude the interference of individual passengers under exceptional circumstances, such as excessively long time to reach their mobile phone, extremely long perception times, etc.

[15] Source: https://www.marineinsight.com/marine-safety/different-types-of-alarms-on-ship/

the same state (as the terms defined by [12]). Fig. 2 illustrates the above considerations in relation to the different stages of the pre-evacuation phase.

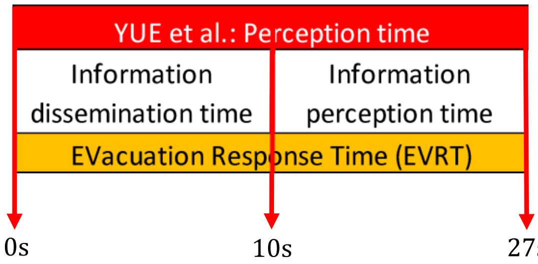


Fig. 6: idis(t) and iper(t) reference values in the "before SEM state" (simulation-based estimations)

With this analysis in mind we were ready to define the EVRT after the deployment of the SEM platform.

Definition (after-SEM): The **Evacuation Response Time Indicator "after SEM" state,** i.e., after the implementation of the SEM approach, the EVRT is defined as follows:

$$EVRT_{AftSEM}(t) = idis_{AftSEM}(t) + iper_{AftSEM}(t) \quad (2)$$

The information dissemination time [$idis(t)$] is the time needed by the SEM system to send all the alert messages:

$$idis_{AftSEM}(t) = t_{SysMsgTravel} \quad (3)$$

Where $t_{SysMsgTravel}$ is the time needed by the system to generate the messages plus the time needed by the network to deliver them to the passengers' devices.

The (individual) information perception time in the "after SEM state" i.e., after the implementation of the SEM approach, $iper(t)$ is defined as the passenger's reading time of all the received messages in order to understand them:

$$iper_{AftSEM}(j) = \sum_{i=1}^{n}(t_{read}(j,i) \quad (4)$$

Where j denotes the passenger and i the message.

The total perception time, $iper(t)$, is defined as the maximum of the individual perception times of 90% of the passengers participating in the pilot action.

$$iper_{AftSEM}(t) = max(iper_{AftSEM}(j)), j = 1, \dots, k \quad (5)$$

Combining Eq. 2 through Eq. 5 yields Eq. 6 from which the total response time can be calculated for the "after" state:

$$EVRT_{AftSEM}(t) = t_{SysMsgTravel} + max[\sum_{i=1}^{n}(t_{read}(j,i)] \quad (6)$$

Where $i = 1, \ldots, n$ the number of received alert messages, $j = 1, \ldots k$ the number of passengers and $EVRTI_{AftSEM}(t)$ the evacuation response time after the adoption of the SEM approach.

EVRTI Definition: Finally, the Evacuation Response Time Indicator (EVRTI) can be calculated as the ratio of the total response time in the “after” state and the total response time in the “before” state

$$EVRTI = \frac{EVRT_{AftSEM}(t)}{EVRT_{BefSEM}(t)} \times 100\% \quad (7)$$

Note: The crew response time to the emergency can be assessed similarly, with the difference that their perception time is zero as they immediately shift to the evacuation state and thus only the information dissemination time needs to be calculated.

4.2.1.2 Evacuation Pathway Decision Indicator (EVPDI)

This section provides an analysis of the definition of the **Evacuation Pathway Decision Indicator (EVPDI)** and how this is calculated as the ratio of the total evacuation pathway decision time in the “after” state and the total evacuation pathway decision time in the “before” state.

Definition (pre-SEM): The Evacuation Pathway Decision (EVPD) is a measurement that denotes thethe time required for passengers to search for information about escape options and develop an escape plan (choose a pathway) that would lead them to the muster station, before the adoption of the SEM approach (the term “before” here refers to data collected from the relevant literature). The time to complete this process encompasses **the time of acquiring information about the available escape options** [pathway information reach time, *pireach(t)*] and **the time needed to process that information and decide on the evacuation path** [pathway decision time, *pdecide(t)*].

$$EVPDI(t) = pireach(t) + pdecide(t) \quad (8)$$

Background information: Generally, modern ships provide passengers with wayfinding information and signage tools such as evacuation maps and exit signs (posted on visible places) which can strongly support the passengers’ pathway decisions [13] [14][15]. As in the case of the emergency awareness indicator (EVRTI), the process a passenger uses to make a decision on how to reach the muster station depends on several factors, such as their personal characteristics, the surrounding environment, the presence of crew that provides instructions and, in the absence of such instructions, the behaviour of neighbouring passengers [5][6].

Observations from evacuation drills conducted in real conditions and different types of vessels [4] reveal that the passengers’ response time – the time which is considered in these results as “response time”, includes what is defined in this document as “response time” plus the “(pathway) decision time” – depends on the vessel type (Ro-Pax and cruise ship) and on the initial location of the passengers when the alarm is sounded (public spaces or cabins).

The difference in response behaviour between passengers on the Ro-Pax vessels and cruise ships, may be due to the differences in the nature of the voyage and the impact this has on passenger perceptions of their connection to the vessel. Ro-Pax vessels are considered by passengers as a means of transport from one location to another, whereas voyages on cruise ships are considered an integral part of the vacation experience. Voyages on Ro-Pax vessels are typically short, passengers generally have their belongings with them and they are anticipating making a speedy departure as soon as the vessel arrives. In effect, the passengers are primed to leave, whereas passengers on cruise ships expect to stay on the ship for several days – they effectively make the ship their home and have a greater expectation of permanency. In a similar vein, passengers in cabins take considerably longer to respond than passengers in the public areas. The longer response times for passengers in cabins as compared to passengers in public spaces could be due to longer notification times and a different range of action and information tasks undertaken during the response phase. For instance, passengers in cabins could be asleep or in the process of dressing, leading to longer notification times and a different range of action and information tasks compared to passengers in public spaces. To give an indication, the average time between the sounding of the alarm and when passengers start moving to an assembly station—for 90% of the passengers, in public spaces or cabins, on a RO-PAX vessel—is 158 sec, while in cruise ships 90% of the passengers in public spaces respond in 242 sec and in 704 sec when in cabins [4] (thus exceeding the maximum suggested time by IMO).

Apparently, the time between the sounding of the alarm and the start of the movement to the muster station, besides pathway decision time, also includes the passenger Response Time (RT) which was estimated in the previous section at 27 sec. In the absence of more data, we can only assume that the total pathway decision time (for the "before" state) is equal to the difference between the 158 sec found by Brown et al and the 27 sec RT time found in section 3.3.1; that is 131 sec. Of these 131 secs, 23% correspond to the pathway information reach time (i.e. 31 sec), while the remaining 100 sec is the pathway decision time.

The above 23% quota was derived from the work of Casareale et al, who have found that the time between the first arrivals, at the exit gate, of passengers who had no prior information about escape routes and the first pick of passengers who had such information, is approximately 70 sec. Considering that both groups of passengers arrived at the exit gate in about 5 min (300 sec) and that the only factor that could differentiate their arrival times is the knowledge of the escape routes (no evidence exist in the original study that suggest otherwise), we have estimated the pathway information reach time (as a percentage of the total pathway travel time) by dividing the 70 sec lead-time, of passengers with prior knowledge of the escape routes, by the total travel time of 300 sec. The obtained result was 23%. Fig. 5 illustrates the above considerations in relation to the different stages of the pathway decision phase.

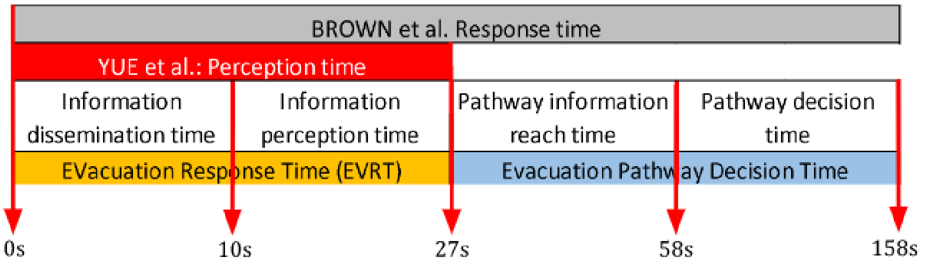


Figure 8. pireach(t) and pdecide(t) reference values in the "before SEM state" (simulation-based estimations)

Following the analysis presented above, the definition of the EVPD after the application of the SEM platform is presented.

EVPD Definition (after-SEM): The **evacuation pathway decision time in the "after SEM" state,** is defined as follows:

$$EVPD_{AftSEM}(t) = pireach_{AftSEM}(t) + pdecide_{AftSEM}(t) \quad (9)$$

The pathway information reach time [$pireach(t)$] is the time needed by the SEM system to send all the notification messages:

$$pireach_{AftSEM}(t) = t_{SysMsgTravel} \quad (10)$$

Where $t_{SysMsgTravel}$ is the time needed by the system to generate the messages plus the time needed by the network to deliver them to the passengers' devices.

The (individual) evacuation pathway decision time in the "after SEM state" i.e., after the implementation of the SEM approach, $pdecide(t)$ is defined as the passenger's reading time of the received messages in order to understand them.

$$pdecide_{AftSEM}(j) = \sum_{i=1}^{n-1}(t_{read}(j,i) \quad (11)$$

Where j denotes the passenger and i the message.

The total pathway decision time, *pdecide(t)*, is defined as the maximum of the individual pathway decision times of 90% of the passengers participating in the pilot action.

$$pdecide_{AftSEM}(t) = max(pdecide_{AftSEM}(j)), j = 1, \dots, k \qquad (12)$$

Combining Eq. 9 through Eq. 12 yields Eq. 13 from which the total evacuation pathway decision time can be calculated for the "after" state:

$$\boxed{EVPD_{AftSEM}(t) = t_{SysMsgTravel} + max \sum_{i=1}^{n-1}(t_{read}(j,i) \quad (13)}$$

Where $i = 1, \ldots, n$ the number of received notifications, $j = 1, \ldots k$ the number of the passengers and $EVPDI(t)$ the evacuation pathway decision time after the adoption of the SEM approach.

Definition EVPDI: Finally, the Evacuation Pathway Decision Indicator (EVPDI) can be calculated as the ratio of the total evacuation pathway decision time in the "after" state and the total evacuation pathway decision time in the "before" state:

$$EVPDI = \frac{EVRPD_{AftSEM}(t)}{EVPD_{BefSEM}(t)} \times 100\% \quad (14)$$

4.2.1.3 Evacuation Travel Time Indicator (EVTRI)

This section provides an analysis of the definition of the Evacuation Travel Time Indicator (EVTRI) and how this is calculated as the ratio of the total travel time in the "after" state and the total travel time in the "before" state

Definition (pre-SEM& after-SEM): The Evacuation Travel Time is a measurement that denotes the difference the time required for the passengers to reach the muster station once they have decided on which pathway to follow, before and after the adoption of the SEM approach (the term "before" here refers to data collected both from the relevant literature and the pilot trials). The travel time as defined by IMO is **the time required by passengers to travel from their original location on the vessel to the muster station** [expected travel time, *ETrav(t)*]. **The expected travel time can be increased,** if needed, **by setting a congestion penalty** [*Cong(t)*] if the status of the evacuation routes becomes congested **and can be decreased by a Δfluidsupport factor** [*Δfluidsupport(t)*] if passenger rerouting or evacuation batching policies are applied to facilitate seamless passenger flow.

$$EVTR(t) = ETrav(t) + Cong(t) - \Delta fluidsupport(t) \quad (15)$$

Background information: The travel time of the passengers during the evacuation depends on several factors, including the vessel's layout, the distribution of the passengers at the time of the sounding of the initial alarm, the evolution of the emergency as well as the passengers' characteristics (e.g. age, gender, weight, and physical ability) which further influence the passengers' travel speed.

The International Maritime Organization (IMO) provides regulations on ship evacuation analysis, through the IMO MSC.1/Circ.1533 which defines two evacuation analysis methods. In particular, the simplified evacuation analysis method manually calculates the travel duration of the targeted escape route, by considering several parameters such as the clear width, initial density of persons, speed and flow but assumes that all the passengers have the same predefined characteristics (response duration, age, and gender). On the other hand, advanced evacuation analysis uses computer simulation to consider the characteristics of each passenger, making realistic predictions possible. By combining the two methods (simplified and advanced), **the expected travel speed** of the passengers can be estimated as the weighted average of the group's expected travel speed, using the data of the following table (used for the Advanced evacuation analysis) [16]:

Table 25. Walking Speed according to IMO

Population groups – passengers	Walking speed on flat terrain (e.g. corridors)	
	Minimum (m/s)	Maximum (m/s)
Females younger than 30 years	0.93	1.55
Females 30-50 years old	0.71	1.19
Females older than 50 years	0.56	0.94
Females older than 50, mobility impaired (1)	0.43	0.71
Females older than 50, mobility impaired (2)	0.37	0.61
Males younger than 30 years	1.11	1.85
Males 30-50 years old	0.97	1.62
Males older than 50 years	0.84	1.4
Males older than 50, mobility impaired (1)	0.64	1.06
Males older than 50, mobility impaired (2)	0.55	0.91
Population groups – crew	**Walking speed on flat terrain (e.g. corridors)**	
	Minimum (m/s)	**Maximum (m/s)**
Crew females	0.93	1.55
Crew males	1.11	1.85

Specifically, by considering a group of passengers with the composition of the following table [17], the group's average expected travel speed is equal to (0.07 x 0.93) + (0.07 x 0.71) + (0.16 x 0.56) + (0.10 x 0.43) + (0.10 x 0.37) + (0.07 x 1.11) + (0.07 x 0.97) + (0.16 x 0.84) + (0.10 x 0.64) + (0.10 x 0.55) = **0.68 m/s**. One may notice that we use minimum speeds in order to be on the safe side of calculations.

Table 26. Population's composition

Population groups – passengers	Percentage of passengers (%)
Females younger than 30 years	7
Females 30-50 years old	7
Females older than 50 years	16
Females older than 50, mobility impaired (1)	10
Females older than 50, mobility impaired (2)	10
Males younger than 30 years	7
Males 30-50 years old	7
Males older than 50 years	16
Males older than 50, mobility impaired (1)	10
Males older than 50, mobility impaired (2)	10
Population groups – crew	**Percentage of crew (%)**
Crew females	50
Crew males	50

Definition (after-SEM): The **(individual) expected travel time** is defined as the distance from the passenger's initial location i to the Muster Station (MS) divided by the passengers' travel speed.

$$ETrav(j) = \frac{d^j}{v^j} \quad (16)$$

This time however is only applicable in ideal conditions, i.e. when the evacuation progresses with no incidents and there is no congestion in the evacuation routes. In cases of congestion, which occurs according to IMO when the density is more than 3.5 persons/m2 or if there is an accumulation of less than 1.5 persons/s between ingress and exit from a point in the queue [18], the average speed of the passengers needs to be reduced and increased again when the conditions are clear.

The (individual) congestion penalty is then defined as follows:

$$Cong(j) = \frac{\mathrm{d}^{\mathrm{j}}_{\mathrm{cong}}}{v^{j}{}_{cong}} \ (17)$$

Where d_cong is the distance of the congested evacuation route and v_cong the reduced speed of the passenger due to the congestion.

Regarding the Δfluidsupport factor *Δfluidsupport(t)* of Eq. 15, this can be estimated as the travel time-savings (in sec) for passengers generated by the SEM platform, which applies passenger rerouting policies to facilitate seamless passenger flow when the risk of delay of the completion of the evacuation becomes medium or high due to the congestion conditions and is applicable only to the “after SEM” state.

The (individual) Δfluidsupport time is defined as the travel time-saving for passenger j by using the alternative path suggested by the SEM system instead of the primary evacuation route.

$$\Delta fluidsupport(j) = [ETrav(j) + Cong(j)] - [ETrav_a(j) + Cong_a(j)] \ (18)$$

Where $ETrav_a(j)$ and $Cong_a(j)$ denotes the individual expected travel of the passenger *j* using the alternative path *a* and the individual congestion time of the passenger *j* using the alternative path, respectively. Also, $ETrav(j) + Cong(j) > ETrav_a(j) + Cong_a(j)$.

Combining Eq. 17 through Eq. 18 yields Eq. 19 from which **the individual travel time** can be calculated:

$$EVTR(j) = \frac{d^j}{v^j} + \frac{\mathrm{d}^{\mathrm{j}}_{\mathrm{cong}}}{v^{j}{}_{cong}} - [(ETrav(j) + Cong(j)) - (ETrav_a(j) + Cong_a(j))], j = 1, \ldots, k \ (19)$$

The total travel time is defined as the maximum of the individual travel times for 90% of the passengers participating in the pilot action.

$$\boxed{EVTR(t) = max(EVTR(j)), j = 1, \ldots, k \ (20)}$$

EVTRI Definition: The Evacuation Travel Time Indicator (EVTRI) can be calculated as the ratio of the total travel time in the “after” state and the total travel time in the “before” state:

4.2.1.4 LSA Embarkation Preparation Time Indicator (LSAEMBI)

This section provides an analysis of the definition of the LSA Embarkation Preparation Time Indicator (LSAEMBI) and how this is calculated as the ratio of the embarkation preparation time in the “after” state and the embarkation preparation time in the “before” state

Definition (pre-SEM): This is a measurement that denotes the time required for the passengers to prepare for embarkation to the LSAs, before the adoption of the SEM approach (the term "before" here refers to data collected from the literature). The embarkation preparation consists of **the time required to effectively notify passengers that they should get prepared for embarkation** [embarkation information reach time, *embireach(t)*] plus the time **to form embarkation groups** [embarkation group time, *embgrp(t)*].

$$LSAEMB(t) \ = \ embireach(t) + embgrp(t) \ (22)$$

Background information: When passengers arrive at the embarkation station, they embark on lifeboats under the guidance of the crew. In cruise ships, families or friends are travelling together and they usually act in a group. The group passengers tend to preferentially select the same queue or enter the same lifeboat, while individual passengers directly choose the nearest or shortest queue [19]. This implies that the passengers (individual or groups) may transfer between queues, in order to be with their family members, to move to a shorter queue or when the lifeboat is full[16], a process which may delay the embarkation time.

Forming evacuation groups and assigning lifeboats to each group before the embarkation, **based on the passengers' characteristics, location and the capacity of the lifeboats**, could reduce the time needed to form queues and the transferring between them.

In addition, in cases of rapidly evolving emergencies (such as fire), or when the time runs short and the guidance from the crew is limited, it is important for passengers to know in advance which lifeboat gate should be used for embarkation. Specifically, previous simulation studies on passengers' evacuation [6] have shown that the passengers who had no prior knowledge of the location of their exits either missed their lifeboat gates or reached them very late.

Previous simulation studies on passengers' lifeboat embarkation in cruise ships [19], which divide the embarkation process into queuing and seat selection stages, show that in scenarios of group passengers the total embarkation time[17] is **1199 seconds** (~20 minutes) when the passengers transfer between the queues of all lifeboats and they randomly selects seats and **891 seconds** (~15 minutes) when the passengers transfer between queues that belong to the same lifeboat based on their seat availability and select seats from outboard row to inboard row.

From the above times[18], it follows that the group passengers will have an average total embarkation time of **1045 seconds** during which the passengers a) form queues, b) transfer between queues and c) take their seats in the lifeboat.

[16] Passengers outside the lifeboat cannot verify the number of the remaining seats left inside the lifeboat.
[17] The total embarkation time includes the time for passengers to arrive at the queue, the waiting time in the queue, and the time for selecting seats in the lifeboat.
[18] Those times are the longest and shortest time respectively, observed during the simulations.

Of this time, **200 sec** is considered as the time required for the passengers to form queues, as before 200 sec the embarkation completion rate has small distinction under the transfer rules of the experiment which corresponds to the **embarkation preparation time for the "before SEM " state.** It is important to mention here that the cited paper of M. Hu et al. refers to an embarkation area consisting of three lifeboats. Also, each lifeboat has two entrances, and a queue is distributed in front of each entrance.

Definition (after-SEM): The **embarkation preparation time** after the implementation of the SEM approach is defined as follows:

$$LSAEMB_{AftSEM}(t) \; = \; PreEmb_{AftSEM}(t) + EmbGrp_{AftSEM}(t) \text{ (23)}$$

The embarkation information reach time [*embireach(t)*] is defined as the time needed by the system to send the embarkation messages to the passengers, which indicate their lifeboat number and location.

$$PreEmb_{AftSEM}(t) \; = \; t_{SysMsgTravel} \; (24)$$

Where $t_{SysMsgTravel}$ is the time needed by the system to generate the messages plus the time needed by the network to deliver them to the passengers' devices.

The (individual) embarkation group time [$embgrp(t)$] is defined as the time needed by the passengers to read the embarkation messages plus the time needed to move to their assigned lifeboats in queues.

$$EmbGrp_{AftSEM}(j) = \sum_{i=1}^{n}(t_{read}(j,i) + t_{queue}^{j} \text{ (25)}$$

Where j denotes the passenger and i the message.

The total embarkation group time is defined as the maximum of the individual embarkation group time of 90% of the passengers participating in the pilot action.

$$EmbGrp_{AftSEM}(t) = \; max(\sum_{i=1}^{n}\big(t_{read}(j,i) + t_{queue}^{j}\big), j \; = \; 1, \ldots, k \text{ (26)}$$

Combining Eq. 23 through Eq. 26 yields Eq. 27 from which the total embarkation preparation time can be calculated for the "after SEM" state:

$$\boxed{LSAEMBI_{AftSEM}(t) \; = \; t_{SysMsgTravel} + max(\sum_{i=1}^{n}(t_{read}(j,i) + t_{queue}^{j}) \text{ (27)}}$$

EVEMBI Definition: The LSA Embarkation Preparation Time Indicator (EVEMBI) can be calculated as the ratio of the embarkation preparation time in the "after" state and the embarkation preparation time in the "before" state:

$$LSAEMBI = \frac{LSAEMB_{AftSEM}(t)}{LSAEMB_{BefSEM}(t)} \times 100\% \quad (28)$$

4.2.2 Tier 2 KPIs

Tier 2 indicators shift the focus from the performance of the evacuation process from the passengers perspective, to the performance of the crew regarding the **handling of unexpected incidents** during the evacuation as well as to the effective use of mission-critical push-to-talk (MCPTT) service for crew coordination in the “after SEM” state, compared to the legacy push-to-talk (PTT) systems of the “before SEM” state.
The following table summarises the factors used to assess the performance of the crew coordination as well as the components of the total evacuation time.

Table 27. Factors used to assess crew coordination

Evacuation stage	Time factors	Time components		
Incident Management	Incident Response Time	incident detection time	incident assignment time	incident travel time

In the table above the following definitions are used:

- information dissemination time: the time required to effectively inform crew about the emergency
- incident detection time: the time needed by the Bridge to detect the incident
- incident assignment time: the time needed to assign the incident to an appropriate crew member team
- incident travel time: the time needed by the assigned crew members to arrive at the incident’s location

Tier 2 consists of the following KPIs:

Table 28. Tier 2 KPIs

KPI	Description
Incident Response Time Indicator (IRTI)	ratio of the incident response time in the “after” state and the incident response time in the “before” state

4.2.2.1 Incident Response Time Indicator (IRTI)

Definition: This is an element that denotes the time it takes for the crew to respond to an unexpected incident[19] during the evacuation. The Incident Response Time (IRT), consists of **the time needed to detect the incident and inform the Bridge** [incident detection time, *idetect(t)*], **the time needed to assign the incident to an appropriate crew member team**

[19] For the purposes of this document, an “incident” is a real-world event that occurs during an evacuation which might hinder the evacuation process or cause serious delays. An incident could range from something as routine as a crew helping a passenger to evacuate, or as major as a fire or an explosion.

[incident assignment time, *iasgmt(t)*] and **the time needed by the crew to travel to the incident location** [incident travel time, *itrav(t)*].

$$IRTI(t) = idetect(t) + iasgmt(t) + itrav(t) \quad (29)$$

Background information: Effective incident management during an ongoing evacuation is critical to ensuring the safe and orderly evacuation of all individuals. Timely detection of an incident is essential for achieving this goal, as it allows for the rapid deployment of the appropriate resources and personnel. Typically, each incident type has a designated response plan that outlines the necessary resources and personnel required for mitigation. However, in certain situations, the designated crew members may not be available or other crew members may be better suited to handle the incident based on factors such as their location, expertise, and other factors. Therefore, it is important to quickly assign the incident to the most appropriate crew teams and ensure their prompt arrival at the incident location to save valuable time and resources.

Definition (after-SEM): The **incident response time** after the implementation of the SEM approach is defined as follows:

$$IRT_{AftSEM}(t) = idetect_{AftSEM}(t) + iasgmt_{AftSEM}(t) + itrav_{AftSEM}(t) \quad (30)$$

The incident detection time [$idetect(t)$], for a specific incident, is defined as the time needed by the system to detect the incident, based on the data received by the SEM ICT components, plus the time needed by the system to generate an incident issue.

$$idetect_{AftSEM}(t) = t_{SysReadData} + t_{SysProcessData} \quad (31)$$

Where $t_{SysReadData}$ is the time needed by the system to read the received data and $t_{SysProcessData}$ is the time needed by the system to process them and generate an incident issue.

The incident assignment time [$iasgmt(t)$], for a specific incident, is defined as the time needed by the system to create a crew team assignment recommendation, for the specific incident, and the time needed for the crew member(s) to accept their task assignment.

$$iasgmt_{AftSEM}(t) = t_{Rec} + t_{Accept} \quad (32)$$

Where t_{Rec} includes the time needed to display the crew team assignment recommendation to the Bridge. Also, the task acceptance time is the time needed by the crew member to read the message with the incident assignment plus the time to communicate (via MCPPT) with the Bridge in order to acknowledge. The incident travel time, *itravel(t)*, can be assessed as the total time (in sec) between the incident assignment time and the time needed by the crew member to arrive at the incident location.

Combining Eq. 30 through Eq. 32 yields Eq. 33 from which the total incident management time can be calculated for the “after” state:

$$IRTI_{AftSEM}(t) = t_{SysReadData} + t_{SysProcessData} + t_{Rec} + t_{read} + t_{Ack} + itravel(t) \quad (33)$$

Where $IRTI_{AftSEM}(t)$ the evacuation response time after the adoption of the SEM approach.

IRTI Definition: Finally, the Incident Response Time Indicator (IRTI) can be calculated as the ratio of the incident response time in the "after" state and the incident response time in the "before" state:

$$\boxed{IRTI = \frac{IRT_{AftSEM}(t)}{IRT_{BefSEM}(t)} \times 100\% \quad (33)}$$

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