Horizon 2020

Project acronym:	**LASH FIRE**
Project full title:	**Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**
Grant Agreement No:	**814975**
Coordinator:	**RISE Research Institutes of Sweden**

Deliverable D08.4

Stowage planning optimization and visualization aid

June 2023

Dissemination level: **Public**

Abstract

The present deliverable relates to one of the Risk Control Option envisaged in LASH FIRE, the so-called Stowage Planning Tool, which is a software solution that includes fire hazard management. One of the core components of the software is the algorithm in charge of distributing the cargo along the decks of a ship in such a way that the overall risk is reduced by means of the implementation of a risk assessment based on historical data.

In way of research, data collection from the ship operators in the LASH FIRE Consortium has made it clear that cargo units classified as dangerous cargo according to the IMO IMDG code are handled entirely in compliance with the code, but also that changes are needed to current, more indiscriminate stowage management practices for non-dangerous goods cargo units, with the perspective of reducing ro-ro space fire risk.

Thus, this document includes how the core development works to achieve the expected objectives and how Human-Centred Design (HCD) has been applied to the visual interface in order to create an effective, efficient and satisfactory software for the end users to interact with.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814975

Document data

Document Title:	LASH FIRE_D08.4_Stowage_planning_optimization_and_visualization_aid_V1.docx		
Work Package:	WP08 – Ignition		
Related Task(s):	T08.5, T08.6, T08.9		
Dissemination level:	Public		
Deliverable type:	R		
Lead beneficiary:	CIM		
Responsible author:	Francisco Rodero		
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Date of delivery:	2023-06-20		
References:	D04.2, D7.11, D08.1, D08.3, D08.4, D08.7, D08.8, D08.13		
Approved by	Erik Styhr Petersen on 2023-06-16	Robert Rylander on 2023-06-05	Maria Hjohlman on 2023-05-29

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Document history

Version	Date	Prepared by	Description
[00]	2021-08-20	Francisco Rodero	Draft of structure
[01]	2023-03-31	Francisco Rodero	Final report
[02]	2023-05-25	Francisco Rodero	Final report reviewed
[03]	2023-06-20	Francisco Rodero	Final report approved

Content

1 Executive summary

Main author of the chapter: Francisco Rodero, CIM

1.1 Problem definition

Today, ro-ro cargo units other than dangerous goods are loaded without consideration to the hazards they involve, leaving room for improving the stowage process from the prevention perspective. In other words, current cargo placement in ro-ro spaces is not optimal against fire hazards.

Since statistics reveal that around 90% of fires are initiated in the carried cargo, above-mentioned improvements should focus on a more effective management of the units based on available information coming from previous incidents. These resources contribute with valuable feedback that can be used to distribute the cargo trying to minimize the overall fire risk before departing.

Therefore, the objective is to develop a stowage planning tool including fire management features powered by the knowledge from the past as a tangible outcome of the lessons learnt.

Safety management and risk mitigation are purposes of LASH FIRE by means of many actions considering a wide variety of risk control options. Careful distribution of cargo units through the Stowage Planning Tool (SPT) drives to a reduced overall risk which means that such a measure potentially contributes to the objectives of the project.

1.2 Technical approach

As briefly introduced in the above section, the approach to solve the problem consists of the development of software implementing features that provide fire management considerations to the stowage process.

Based on conversations with the LASH FIRE partners DFDS and Stena Line and the conclusions after field visits to the terminals of Valencia, Ghent and Gothenburg during 2011, it is clear that the handling of dangerous goods classified by the IMO IMDG code (IMO, 2018) is done carefully and in full compliance to the rules and industrial best practice – but it is also clear that non-IMDG cargo is dealt with rather indiscriminately; such cargo units are usually not subject to planning, but are loaded in the order of arrival or availability in the terminal. Thus, the key element of the software is the risk assessment of the cargo units being loaded to the ship. Dangerous goods will be managed fulfilling existing IMDG regulations. Other units will be distributed along the decks considering the criticality and severity of reported incidents involving the corresponding type of the cargo.

The distribution algorithm working behind the scenes implements the step-by-step process performed for every single cargo unit, from its scoring until its final placement. The score is basically a quantitative representation of the risk and the objective is to get a total value of the risk as lower as possible. The risk assessment, as one of these steps, sets the score based on historical data and provides placement recommendations to reduce overall risk.

The developments are conceived to help supporting risk reduction and a more managed stowage process to directly provide the benefits of more accurate cargo information in case of a fire.

This document builds from D08.1 “Definition and parametrization of critical fire hazards, classification of cargoes, transport units, engines, fuels and vessels and identification methodologies” which contain the initial work performed prior to the risk assessment component of the algorithm and complements deliverables D08.7 “Description of stowage plan visualization aid demonstration” and D8.8 “Stowage plan visualization aid”.

1.3 Results and achievements

This document includes the definition of the sequence of actions taken to obtain a distribution of the cargo that represents a reduced risk in terms of historical data used in the risk assessment of a suggested stowage plan.

Actions are described in a step-by-step basis and are complemented with explanation of inputs and outputs that concern each step together with the potential errors that may arise. Also, when needed to improve understanding, workflow diagrams are used to graphically depict the whole process.

With the objective of being used as the unique baseline during the implementation stage, this document outlines:

- a design dimension concerning how data is structured (by means of the corresponding underlying data model) and the role the component plays from the software architecture point of view.
- specification aspects in terms of requirements that must be fulfilled since they represent feedback with relevant impact on the usefulness of the prototype developed in LASH FIRE.

Also, the document reports one additional aspect of the Stowage Planning Tool, which is the visualization; the Human-Machine Interface (HMI) the system presents to the users identified to use the tool. Their needs are varied and different, and so are their working conditions, and to fulfil their requirements, Human-Centred Design (HCD) has been specified the primary development method of the SPT HMI. HCD is an iterative method involving end-users in the design and test cycles of product development towards a product of good usability, which is the ambition for the SPT – being effective, efficient and to provide in-use satisfaction to the users.

In concrete terms, analysis has been performed to identify actions and workflows, and initial requirements for the SPT HMI have been formulated – in total, six types of users, more than 10 use-cases and more than 80 requirements constitute a part of this document.

1.4 Contribution to LASH FIRE objectives

The development of the LASH FIRE Stowage Planning Tool directly addresses the potential fire safety gains associated with a managed stowage process, where fire risk is mitigated by a safety-optimized usage of deck space, and where the consequences of an eventual fire are reduced by an optimum cargo distribution.

LASH FIRE Action 8-A envisages the development of a "digital management tool featuring risk-based load planning" with this report being the foundation prior to the corresponding software development. At the same time, the software itself helps to achieve the global objective 1 of the project: "strengthen the independent fire protection of ro-ro ships by developing and validating effective operative and design solutions addressing current and future challenges in all stages of a fire". The software has been labelled as "Pre2a" in the list of solutions for the different RCM defined by the project.

Besides this, there is also a clear contribution to the IMO Strategic Plan 2018-2023, where integration of new and advanced technologies in the regulatory framework is strongly recommended.

1.5 Exploitation

As mentioned, results achieved include the specification, design and implementation of the algorithm including fire hazard management. Taking advantage of the fact that the SW has been designed as a plug-in, there is a potential exploitation by operators of the Consortium willing to integrate in their systems the feedback that the SW can provide. In this context, plug-in means that the SW component developed in LASHFIRE can be considered as an external (to the software of the operators) component implementing specific features like the scoring and the cargo distribution. This could be carried out in a short-term if operators develop the corresponding interface to the software as well as modifying their own systems and/or procedures to manage the response sent by the SPT; furthermore, the internal database of the SPT should be modified according the physical layout of every single ship involved other than the generic ones used for testing.

In a long-term, turning the implementation to a more complete stand-alone software could provide other operators without an existing booking system or less advanced proprietary solutions with a tool capable of supporting fire management during the stowage.

Also, the design of the Human-Machine Interface will be exploitable by the entire European ro-ro-community, considering that all data and results will be publicly and freely available.

2 List of symbols and abbreviations

2.1 Abbreviations

AI	Artificial Intelligence
ANT	Actor-Network Theory
CAPEX	Capital expenses
DB	Database
DFDS	Det Forenede Dampskibs-Selskab Seaways
DG	Dangerous Goods
ERD	Entity-relationship diagram
FCHD	Fire Cargo Hazard Database
FRMC	Fire Resource Management Centre
GA	Grant Agreement
HCD	Human Centred Design
HMI	Human-Machine Interface
IMDG	International Maritime Dangerous Goods
IMO	International Maritime Organization
LIFO	Last In, First Out
LSA	Life-saving appliances
MAAG	Maritime Authorities Advisory Group
MOAG	Maritime Operators Advisory Group
OPEX	Operating expenses
RA	Risk Assessment
RCM	Risk Control Measure
RCO	Risk Control Option
RS	Risk Score
SOLAS	International Convention for the Safety of Life at Sea
SPT	Stowage Planning Tool
SW	Software
TEMS	Traffic Enhanced Measurement System
VHD	Vehicle Hot-Spot Detector

2.2 Terms & Definitions

Can	The use of the word 'can' or 'could' indicates that something is possible, see also https://www.iso.org/foreword-supplementary-information.html
Context-of-use	[the] users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used (ISO9241-11, 1998)
May	The use of the word 'may' indicates that something is permitted, see also https://www.iso.org/foreword-supplementary-information.html
Shall	The use of the word 'shall' indicates a requirement, see also https://www.iso.org/foreword-supplementary-information.html
Should	The use of the word 'should' indicates a recommendation, see also https://www.iso.org/foreword-supplementary-information.html
Usability	[the] extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO9241-11, 1998)
ISO9241	Multipart standard, managed by the Technical Committee 159, covering ergonomics of human-computer interaction. As a previous version, Part 11 (1998) examines the quality of how well tasks are fulfilled by the users (usability testing). Part 210, updated in 2019, provides guidance on human-system interaction throughout the life cycle of interactive systems as a revision of ISO 13407 which was withdrawn.

3 Introduction

Main author of the chapter: Francisco Rodero, CIM

One of the Risk Control Measures (RCM) or solutions proposed in this project to help preventing the fire ignition is the automatic screening and management of cargo fire hazards; as one of the Risk Control Options (RCO), this RCM is composed of the Stowage Planning Tool (SPT) with fire hazard management, which is the software whose implementation is described here. The development of the SPT is part of the tasks included in the Action 8-A of LASH FIRE and the SW supports the loading process by suggesting appropriate placement of the cargo based on historical data from the database and, optionally, additional constraints.

This tool is actually a set of applications that work together, aiming to identify and detect the potential risks associated to a loading plan, given a certain ship deck configuration:

- The core component is an algorithm that searches for the combination of cargo placements that avoid high risk and minimizes the risk overall. This will include, for example, not only finding places where certain types of cargo should be placed (i.e., because of the need for certifying the compliance of the special requirements regulated by the SOLAS) but also where it should not (i.e, preventing proximity to other cargo that may drive to potential hazards).
- End users interact with the above-mentioned component using a visual interface that manages external events and user actions as needed. Definition of requirements associated to this visual interface can be found in the corresponding section.

This document aims at reporting all the work carried out during the development of the SPT software: design, coding and testing. The idea behind the software is that it can be used as a plug-in to serve already existing applications of the operators rather than (only) being a stand-alone application.

The image below depicts a general overview on how the software fits with existing SW (external to LASH FIRE project) and what is the main data exchange between the two systems:

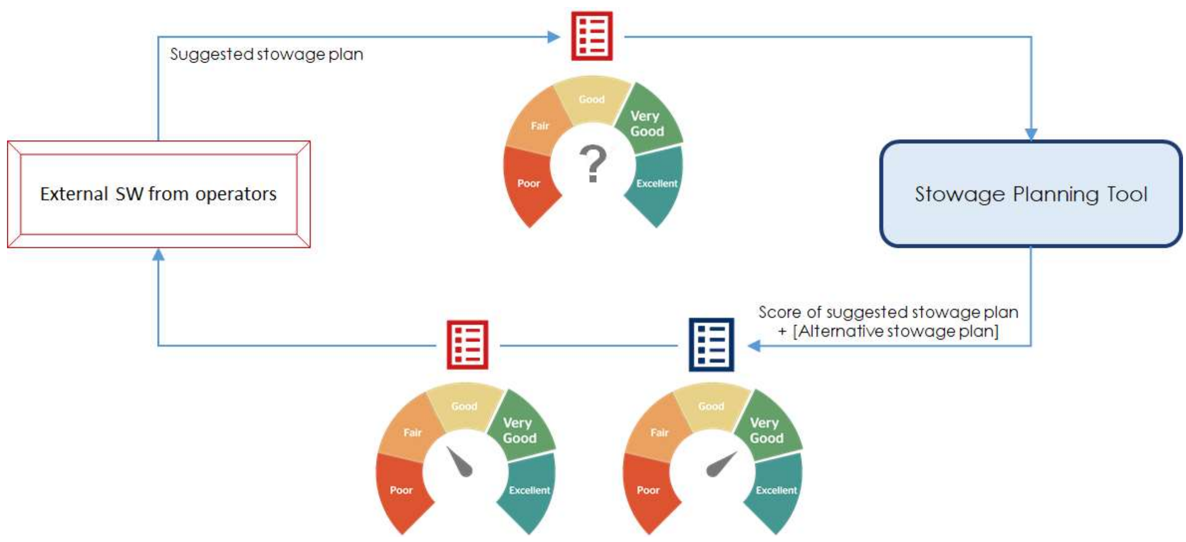

Figure 1 - Overview of the interaction of the Stowage Planning Tool with external SW

The next diagram depicts the whole architecture from the SW perspective and the interface to the external component (as shown before) as well as other internal components, like the Vehicle Hot-Spot Detector (VHD) who is in charge of inspecting every single unit before it is loaded to the ship and is able to trigger an alarm depending on the status of the cargo, which is used to modify its initial score and to decide, during the loading stage, if the suggested placement for the unit must change accordingly this new hazard information.

Other interfaces to the FRMC or the rolling drones (AGV) in charge of patrolling during the voyage are described in D08.13.

Figure 2 - Software components of the Stowage Planning Tool

The algorithm for hazard minimization is the core component in charge of performing all necessary steps that implement both scoring and cargo distribution features. It relies in two databases, one storing risk assessment calculations and the other supporting management related to needed information about units, ship layout, constraints and so on, as described further in this section. Regarding the risk assessment database, it feeds from statistical analysis applied to the data gathered in the cargo fire hazard database, which can also be found in D08.1, " Definition and parametrization of critical fire hazards, classification of cargoes, transport units, engines, fuels and vessels and identification methodologies".

The visualization aid acts as the point where considered end users interact with the stowage planning tool providing them with a graphically user-friendly interface. This component represents an evolution of the fundamentals introduced in D08.3 "Development of fire hazard mapping visualization tool with fire hazard matching integrated".

Operators of the LASH FIRE Consortium have shared information regarding their present-day stowage planning, loading and unloading practices on their ships and in their terminals. The information exchange has partly been through virtual meeting conversations, through field work performed by LASH FIRE partners' staff as well as using remote ethnographical recordings of operations. A consistent picture of the state-of-the-art has emerged, clearly demonstrating that the handling of cargo classified as dangerous goods according to the IMO IMDG code (2018) is well managed throughout the entire value chain, from the booking of space to the unloading of cargo in the destination port. Compliance with the IMDG code is ensured through stowage planning using existing systems and methods, and subsequent to the loading on board the ships, cargo unit parking positions in the ro-ro spaces are noted and made available at the bridge/safety centre from where, in case of an emergency, a fire will be managed, and the firefighting will be directed while the ship is underway.

However, the same level of management does not appear to be in place when it comes to non-IMDG cargo units, where the overall handling reasonably is best described as indiscriminate. From the above-mentioned meetings and field-work, it appears that non-IMDG cargo units are treated uniformly when it comes to stowage planning, loading and unloading. The processes described and observed takes no account of the type of cargo being carried, the type of the cargo unit being used (container, reefer, truck with tarpaulin covers, open flatbed truck etc.), or, in case of self-propelled units, the type of fuel being used, or the volume of fuel brought onboard. This appears also the case when it comes to personal cars and vans, where APVs seems to be handled like conventional petrol or diesel-driven vehicles.

Hence, in case of a fire in a closed ro-ro space or on the weather deck, and barring the well-managed transport of IMDG units to which no adverse remarks are needed, the consequence of the present-day practice for the handling of non-IMDG cargo units are:

- Uncertainty of what is on fire, from the perspective of toxicity, potentially lethal gas emissions as well as the potentially releasable energy and thus the contribution to the development of a fire.
- The prospectively most effective means of fire suppression, in case that choices are available, cannot readily be determined.
- The anticipation and/or predictability of fire spread, considering the nature and combustibility of cargo immediately adjacent to one or more burning cargo units, is either prolonged or even impossible for the lack of (timely) information available to the fire management team.

From a fire risk management perspective, the above demonstrates that there is room for improvement regarding the potentially negative side effects of today's practices. The conceptually simple solution, meant to result in a significant reduction of the risk and consequences of a fire, is to manage each cargo unit through all the steps of booking, terminal operations and loading on board the ship. It is appreciated that a solution of this nature will be far-reaching in terms of practical impact, but by investing in the associated additional processes, the ultimate goal of removing unambiguity and facilitating quick and well-founded decision-making by the fire management team onboard can be reached, in the unfortunate event of a fire in a ro-ro space. In the LASH FIRE project, the method chosen to mitigate the described present-day issues is to integrate accurate, up-to-date cargo stowage information with the 'Digital Fire Central' developed in D7.11 "Firefighting resource management simulator prototype" (see Figure 3), and thus ensuring that the work undertaken in the Fire Resource Management Centre (FRMC) is fully informed of what is burning and what may catch fire next.

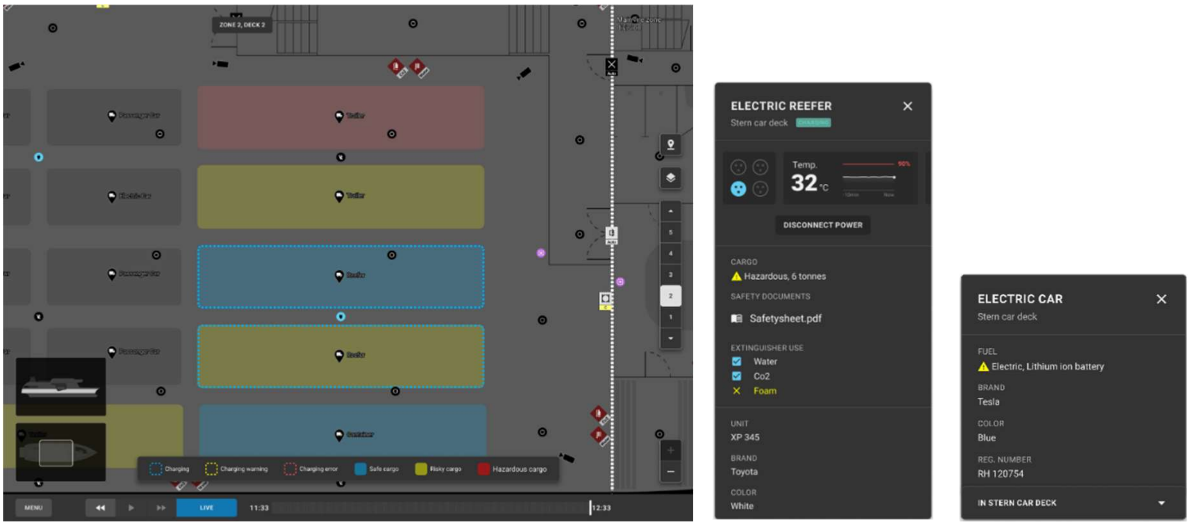

Figure 3 - Example of cargo unit information integration with the Digital Fire Central

The means to provide this functionality, i.e. the collection, management and subsequent export of accurate cargo stowage information to the FRMC, is one of two goals of the LASH FIRE Stowage Planning Tool (SPT). To achieve this, it is foreseen that a number of stakeholders – from personnel working with booking and check-in to the driver eventually unloading the cargo unit from the ship – are to interact with the tool, and to be supported by the tool. Considering their varied functions, the purpose of this internal report is to analyse and specify the design methodology to be applied going forward, as well as to determine the first iteration of stakeholder information needs and visualization requirements. The primary methods being used are a mixture of stakeholder definitions, use-case definitions and the application of the principles of Human-Centred Design.

In terms of constraints, so far only a single issue has been identified which has an impact on the visualization design of the SPT – the need for data integration towards existing stowage planning methods and/or tools. In more detail, the operators consulted in connection with the present work made it clear that existing stowage planning mechanisms are in place, especially when it comes to the management of IMDG cargo units. For this reason, the functionality and design – including the visualization – of the SPT must consider that a stowage plan originating in another system will be imported first into the tool, rather than being created from scratch.

While this document focuses on the technical aspects concerning the back-end of the SPT (design, development and testing), it is important to highlight that D08.7 “Description of stowage plan visualization aid demonstration” concerns the front-end perspective, with a detailed description of the visual interface as well as demonstration of the human-machine interaction.

4 Fire hazard minimization algorithm

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An algorithm is a way to define the steps for solving a specific problem or to perform a task such as data processing or an automated reasoning. Algorithms are described using a finite number of clear instructions that start in an initial state and terminate at a final ending state. Each state can have inputs and/or outputs and transitions between states may be driven by rules.

Minimization is the selection, from a set of different alternatives, of the "best" combination for the distribution of cargo units in the ship. In the context of LASH FIRE, "best" is understood as the distribution that suggests the minimum risk, measured as a score, among all combinations that are tested by the algorithm. The score is calculated after a risk assessment phase as deeply explained further in this document.

4.1 Specification

While other sections in this document describe how things are being done, the contents here define what things have been implemented by means of a list of requirements, each of them uniquely identified, accurately and unambiguously explained. Most of concepts shown in the table, such as layout, route, voyage and so on, are described in the Annex C since they mostly correspond to the possibility of populate the underlying database in a consistent manner. As a matter of fact, requirements REQ1 to REQ15 are directly supported by means of the data model design and with the population of both master and ship-specific tables during the customization of the tool for the three generic ships of the project.

Table 1.List of requirements

Identifier	Description
REQ1	At least two ships shall be available to select. These two ships correspond to the generic ones for Ro-Ro and Ro-Pax types. In other words: Magnolia Seaways from DFDS (Ro-Ro) and Flavia from Stena (Ro-Pax).
REQ2	The system shall allow to define additional ships.
REQ3	At least one physical layout shall be available, for a given ship, corresponding to their configuration during normal operations (no restrictions regarding available space to distribute cargo along the decks and all decks available).
REQ4	The system shall allow to define additional layouts for a given ship.
REQ5	Definition of decks and lanes shall be available for the normal configuration layout of the two generic ships.
REQ6	The system shall allow to define, for a given layout, available decks, lanes and existing electrical connections.
REQ7	At least one route shall be available for a given ship with a valid definition of the voyages the route is composed of.
REQ8	The system shall allow to define new routes for a given ship with their corresponding voyages.
REQ9	The system shall allow to define/load/import/read a list of cargo units with required attributes as needed by the optimization algorithm (as defined in CARGO_UNIT table).
REQ10	The system shall allow to define/load/import/read placement constraints for a given cargo unit.
REQ11	Information about allowed DG cargo for the two generic ships shall be available.
REQ12	The system shall allow to define location constraints concerning DG cargo for a given ship.

REQ13	The system shall allow to define location constraints that could optionally be in a per-unit basis. If the stowage process has been started, before changing location constraints, the system shall use the loading status in order to check if cargo units are already placed in areas that are going to be unavailable.
REQ14	The system shall include built-in values for master tables concerning fire origin, definition of DG, types of decks and types of ships.
REQ15	The algorithm multiple times, storing the outputs in a persistent way together with the timestamp of the execution.
REQ100	The system shall implement an interface to external software in order to retrieve a list of cargo units representing a suggested distribution.
REQ101	The system shall calculate a risk score for a given layout, route and list of cargo units representing a suggested distribution, as a final action of the use case when *Service=Score* is configured.
REQ102	The system could modify the suggested distribution of units based on location constraints defined in a per-unit basis.
REQ200	The system will implement an interface to external software in order to receive alarms triggered for a cargo unit from the VHD system.

4.2 Inputs

4.2.1 Fire Cargo Hazard Database

This database aims at establishing relations between the cargo and the risk of ignition based on historical data coming from several data sources.

The FCHD, fully described in D08.1, is used by the algorithm when trying to minimize the risk during the assessment process of the units. It includes necessary information to calculate the score as described in the corresponding section. From the software architecture perspective of the SPT, a subset of data only focusing on what the algorithm will use has been selected and included in the database as described in 11.3.2.

4.2.2 Information concerning the cargo

Many aspects concerning the cargo units that are expected to be stowed on a given ship: physical characteristics, their type with specific focus in case of DG and, optionally, the location in function of the deck, lane and frame_start/frame_end attributes are considered.

Physical characteristics include height, length and weight. The first two is used to manage in which decks a cargo may fit and, once selected a deck, what is the remaining space in a given lane after placement. Finally, weight is not used during the cargo distribution process but since it is basic information that can be retrieved from external booking system, it has been included to support future features concerning risk assessment in function of this parameter or stability calculation, embedded or through external components.

One of the attributes included here is the type of the cargo for a given unit, which represents an initial filter parameter to select which decks are suitable. Also, for those units not labelled as dangerous goods, type of the cargo is used to retrieve information compiled in the database in order to calculate frequencies and probability of certain risks. For further details on the risk assessment, please refer to the corresponding section in this document.

For DG, they must specify not only their standardized classification but also additional attributes that determine where or where not they can be stowed in a given ship. Depending on the class, if they are liquid or solid state, flammable or not or the flashpoint, there are a set of rules that must be applied in order to select the best location in both the ship's area and respect to other cargo nearby.

Finally, there is information associated to the route; to be more specific, the cargo is linked to the voyage, which is used to know the distance between the origin and destination ports and if the unit must be placed in a special location because it must be loaded or unloaded in an intermediate port call.

So far, these attributes are always used no matter the operating mode of the SW, plug-in or stand-alone. There are, however, additional attributes supporting the algorithm when it runs as a plug-in. In that case, the input concerning the cargo includes a suggested stowage plan, which is represented by the suggested location for each unit and, if needed, the identifier of an electrical connection that the unit will use during the voyage.

Full list of attributes associated to cargo can be found in the section describing CARGO_UNIT table in the Annex C further in this document. Description also includes a detailed explanation about special values for *portOrigin* and *portDestination.*

It is important to remark that as *CARGO_UNIT* table describes; lot of fields are part of relationships with other tables of the data model. Taking that into consideration, values for attributes that reference other tables (foreign keys) need to have valid values.

4.2.3 Cargo constraints

Optionally, the initially proposed cargo distribution can be modified by the algorithm. To do that, it is necessary to define a set of location constraints that can be global, cargo-type based or unit-by-unit.

As briefly introduced in the previous section, location constraints that directly influence the potential areas where a given cargo unit can be stowed can be defined to support a wide variety of scenarios from the ship layout perspective. Type of cargo limits which decks can be used to stow a cargo unit. This is a first level of filtering which just allows a selection of decks but not the exact place in the deck.

For those cargo units that are classified as dangerous goods, there is an additional constraint definition that defines not only the decks where the cargo is allowed to be stowed but also the specific frames that limit the allowed area. Which decks and frames depend on the class, the state of the cargo or the flashpoint. ALLOWED_DG_CARGO table definition in Annex C includes a partial sample of an official document for one of the generic ships of the project showing how DG characteristics are used to limit the allowed areas. Also, please refer to the table definition for further details about involved attributes, which are intended to support the information usually found in documents certifying the compliance of the special requirements regulated by the International Convention for the Safety of Life at Sea (SOLAS).

When the algorithm runs as a plug-in, there is an additional option to define restrictions on how cargo units can change their initial location (suggested stowage plan) in the same way as explained in the previous paragraph. Table LOCATION_CONSTRAINTS is used to achieve this objective (please refer to the corresponding table definition in Annex C for further details). This is a definition that may apply to both DG and non-DG units and it can be fine-tuned in a per-unit-basis, that is, location constraints apply to all units or just the ones specified, giving more power and flexibility to the algorithm.

4.2.4 Ship Layout

The information about the decks of the ship and segmentation of the space can be found in the ANNEX C: .

4.2.5 Detection from sensors

The information received from the arc of thermal sensors will be used to assess the risk of the load in real time, from the thermal markings of the different parts of the scanned unit load. This will result in a real-time assessment of the cargo as output and probably new routines and procedures prior and after loading:

- No alarm: the thermal mark is correct.
- Warning: attention must be paid to some parts of the cargo unit, so it must be inspected before entering the ship, and if it is finally placed on the ship, attention must be paid to its evolution on the ship.
- Alarm: the cargo unit must be inspected and until this alarm is still active, it is not recommended that it be loaded on the ship.

These three alternatives will result in a change of the final Risk score of the cargo unit, if it is finally loaded on the ship.

Real time data from the sensor arc will be obtained through the TEMS interface, a SICK proprietary piece of software that allows communication between the SPT and the information of VHD.

4.2.6 Configuration parameters

As previously mentioned in this document, wherever it is possible and always without adding complexity, the design includes features in order to decouple as much as possible the implementation to a limited specification unable to be easily extended in the future.

Configuration parameters give a mechanism to customize the behaviour of the algorithm (through the corresponding implementation of the associated coding that processes them) avoiding hard-coded parts of the software, which is not a best practice even in prototypes.

The next table includes configuration parameters:

Table 2.List of configuration parameters

Name	Description and valid values
Service	Defines the top-level objective of the algorithm: • *Score*: The system just scores the suggested stowage plan provided by the external software that is calling the stowage planning tool. • *RemoveService*: Removes from the database all the information associated to a specific service or all services, depending on the parameter *IdService*. Even in case of removing all services, the sequence of identifiers is not reset. • *ResetService*: Similar to *RemoveService* but it also resets to 1 the sequence of identifiers assigned to the services executed, • *Distribution*: The system scores the suggested stowage plan and then, it generates a new distribution by modifying cargo unit locations while respecting all constraints that may apply together with the new score. *RemoveService* and *ResetService* are implemented aiming at supporting the vacuum of the database during both the development and the testing stages.
ServiceDescription	Just a string of characters used to set a description of the service.
IdService	Numerical parameter (greater than 1) that identifies one service that has been already executed. This is the identifier stored in the database.
Ship	Defines the selected ship to be considered. Value must match one element in the field *imo* of the table *SHIP.*
Layout	Defines the selected layout to be considered for the given ship when running the algorithm. Value must match one element in the field *uid* of the table *LAYOUT* records that also match with the ship. That is: *LAYOUT.uid == [Provided value for Layout] AND LAYOUT.id_ship == [Provided value for Ship].* By default, only the one regarding normal operation of the ship will be available as built-in element of the implementation but as a requirement, the system will allow to define additional layouts. Selecting a layout determines what configuration parameters will be used: • Available decks and their type • Allowed DG cargo in a per-deck basis • Available lanes and their length and maximum height • Available electrical connections and their connection range in a per-deck basis
Route	Defines the selected layout to be considered for the given ship when running the algorithm. Value must match one element in the field *uid* of the table *ROUTE* records that also match with the ship. That is: *ROUTE.uid == [Provided value for Route] AND ROUTE.id_ship == [Provided value for Ship]*
SlotError	Distance (in meters) of tolerance used when making calculations during the placement of units or when checking the consistency between the length of cargo unit and the frames where it is stowed.
Sep_X (*)	Distance (in meters) ahead and behind a cargo unit which is considered when checking surrounding units in the same deck.
Sep_Y (*)	Distance (in meters) from the sides of the cargo unit which is considered when checking surrounding units in the same deck.

<table>
<tr><td>Timeout (**)</td><td>Stop criteria for the algorithm when generating a cargo distribution to stop after a specific computational time. This value is only checked every time the algorithm has processed all available decks (iteration). In other words, if after one iteration the timeout has expired, the algorithm stops, otherwise it continues.</td></tr>
<tr><td>Improvement (**)</td><td>Expressed as a percentage respect to the initial score, represents the objective reduction for the algorithm to stop searching cargo distributions. For example, having a value of 10, if the initial risk score is 600, the algorithm will stop if it founds a cargo distribution combination scoring 540 or less.</td></tr>
<tr><td>IsTest</td><td>Indicates if the results of the service being run must be compared to the corresponding expected results in the system database.</td></tr>
<tr><td>IdTest</td><td>If IsTest is enabled, then this parameter indicates what are the specific results used to be compared with the outputs of the execution.</td></tr>
<tr><td colspan="2">(*) Sep_X and Sep_Y parameters are used in combination of the information that can be found in LANE and DECK_DEPENDENCY tables when calculating the score (RS value) of each unit.

(**) The stop criteria are used in a way that the search for a better distribution stops if any of them is satisfied, not all of them are necessary to be satisfied for the algorithm to stop.</td></tr>
</table>

The rows of the following table include the existing configuration parameters and it shows which of them are mandatory, optional or not used (N/A) for the implemented features or services:

Table 3.List of parameters per service

<table>
<tr><th rowspan="2">Parameter</th><th colspan="4">Service</th></tr>
<tr><th>RemoveService</th><th>ResetService</th><th>Score</th><th>Distribution</th></tr>
<tr><td>Service</td><td colspan="4">Mandatory</td></tr>
<tr><td>ServiceDescription</td><td colspan="4">Optional</td></tr>
<tr><td>IdService</td><td>Mandatory</td><td rowspan="12">N/A</td><td colspan="2">N/A</td></tr>
<tr><td>Ship</td><td rowspan="11">N/A</td><td colspan="2" rowspan="6">Mandatory</td></tr>
<tr><td>Layout</td></tr>
<tr><td>Route</td></tr>
<tr><td>SlotError</td></tr>
<tr><td>Sep_X</td></tr>
<tr><td>Sep_Y</td></tr>
<tr><td>timeout</td><td>N/A</td><td>Mandatory</td></tr>
<tr><td>Improvement</td><td>N/A</td><td>Optional</td></tr>
<tr><td>IsTest</td><td rowspan="2">Optional</td><td rowspan="2">N/A</td></tr>
<tr><td>IdTest</td></tr>
</table>

4.3 Outputs

4.3.1 Cargo distribution

As previously introduced, the cargo distribution that minimizes the overall risk is one of the possible outcomes of the stowage planning tool as a result of the execution of the algorithm being described in this document.

The data model supporting the algorithm allows multiple runs for a given ship, layout and route (which, at the same time, defines the list of cargo units used as input) but using different configuration parameters (iterations or improvement objective) or different location constraints. Each execution is uniquely identified by a timestamp and eventually may contain a description (i.e., the corresponding field can be automatically filled up with constraints or used parameters). Further details about the attributes associated to the management of this feature can be found in the definition of the table CARGO_DISTRIBUTION in ANNEX C: Table definition.

How cargo units are expected to be stowed along the decks for a given ship (and route) is defined by means of a set of location attributes:

- Cargo unit identifier: Unique identifier of the unit itself.
- Deck, lane, frame_start/frame_end: This triplet defines the exact place in the ship; the deck as stablishes the physical configuration of the ship, the lane as they are numbered by the algorithm (see definition for table LANE in Annex C) and assigned slot, which is the specific spot in the given lane (between frame_start and frame_end). Slots can eventually be numbered from 1 to N , from fore to aft.
- Id_Connection: If the cargo unit requires to be connected during the voyage, this identifier contains the reference to the specific connection assigned by the algorithm (see definition of table ELECTRICAL_CONNECTIONS in "ANNEX C: Table definition" for further details about how this equipment is identified). Otherwise, this field contains a null value.
- Score: This is the main KPI concerning the risk of a cargo unit based on the assessment using historical data (see next section for further details about the calculation).

This is the main information which is shared with the visual interface in order to show results in a more user-friendly way.

4.3.2 Risk assessment

The Risk Score is the value that each cargo unit, deck and ship will have after analysing the intrinsic risk of each cargo unit and everything that surrounds it (other cargoes and elements of the ship).

To start this calculation, the cargo units have been grouped into three main groups

- General Cargo
- Alternative Powered Vehicles (APV)/Alternative fuel vehicles (AFV)
- Dangerous Goods

In order to quantify the risks of each cargo unit in the case of General Cargo and Dangerous Goods, a history of accidents that have occurred in the maritime field (ro-ro ships) where the origin was cargo and a fire occurred was used. In the case of APVs, due to their relatively modern prosperous, we have not obtained a sufficient sample of data on which to base the risk analysis, so it has been carried out using data from accidents in other areas (car parks, roads and tunnels) with the aim of preventing future accidents.

APVs and DG have special considerations as detailed in specific sections that can be found in ANNEX D: Risk Assessment considerations and background

The risk assessment gives the initial risk values for each cargo unit, based on historical fire accident data based on the frequency of fire occurrence in the cargo unit and the severity of the fire.

To perform the calculation, we will first start by explaining which types of cargo are to be considered in this analysis and then carry out calculations of accident frequency of occurrence and severity, resulting in an initial fire risk value.

4.3.2.1 Cargo units

General cargo is any type of cargo that is transported in small quantities and in independent units. The number of packages can be counted and are therefore handled as units unlike bulk or loose cargo.

LASH FIRE addresses the management of general cargo (also known as unitized cargo) and more specifically, vehicles. For car-carrier ships, the cargo are the vehicles their selves and for ro-ro and ro-pax ships, the cargo is always carried on trucks or trailers as well as private vehicles of the passengers.

Among the different types of cargo being transported, dangerous goods deserve special attention since are articles or substances that may pose a significant risk to the health, safety or environment of both persons handling them and other cargo that may share the space within a ship.

Further details about DGs and its classification, stowage and transport can be found in ANNEX E: Risk Assessment considerations and background.

4.3.2.2 Methodology

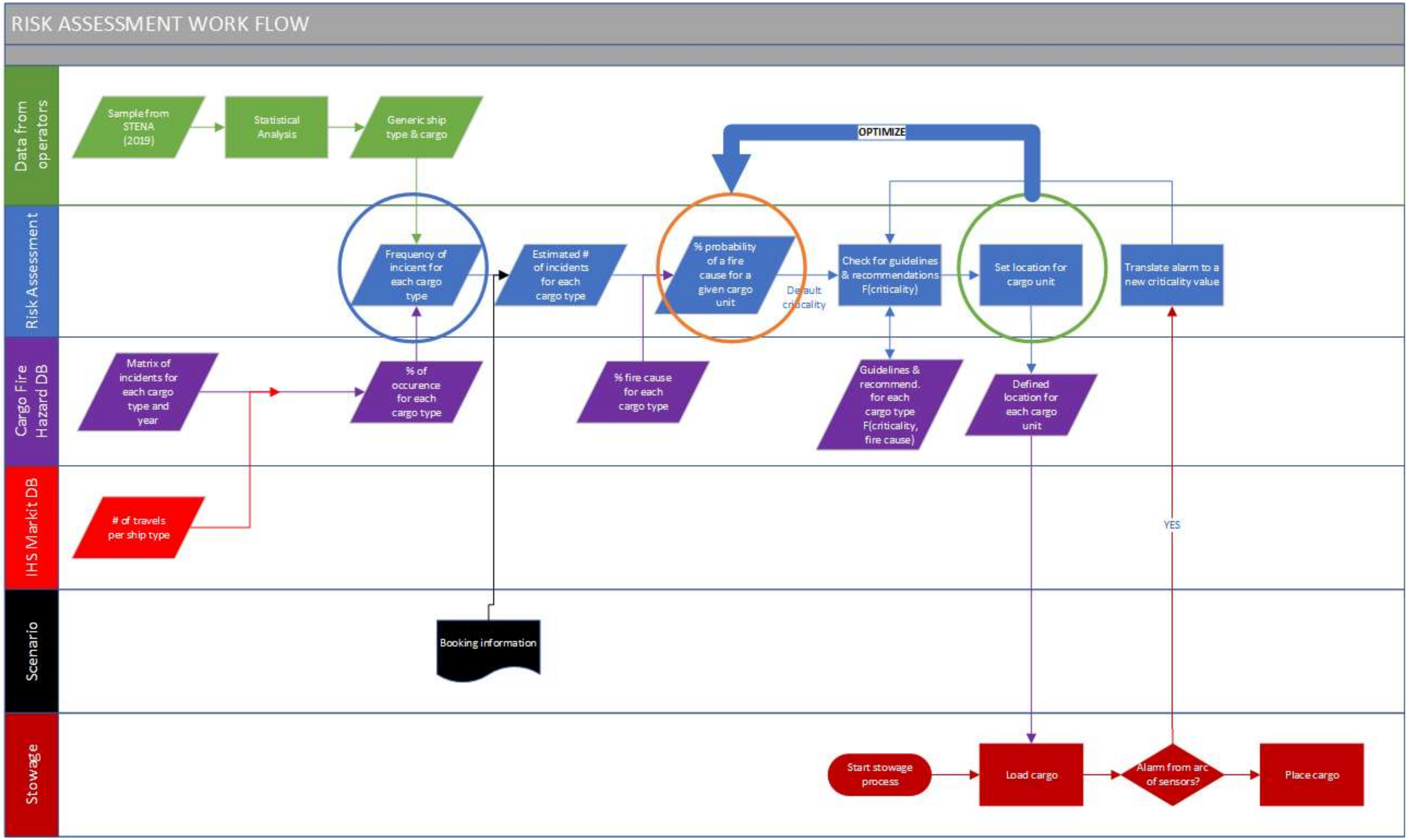


Figure 4 Risk assessment workflow

With the three main data sources: cargo fire hazard database (purple line), number of routes (voyages) and nautical miles travelled by ro-ro, ro-pax and vehicle-carrier ships (red line), and units of that type of cargo are transported (green line). The occurrence frequency (based on historical data) for a cargo unit to start a fire could be calculated. Blue line represents the voyage-specific risk management.

This calculation is made for each single unit from the cargo list to be loaded in a ship, obtaining the most probable causes that may happen in a voyage and therefore, the initial risk level from the theoretical point of view (which has a set of guidelines and recommendations suggesting appropriate placement of the cargo).

The process iterates in a loop for all cargo units, having a suggested cargo distribution minimizing the overall risk.

During the stowage process and just before loading a cargo unit, they pass through a tunnel of sensors that may trigger an alarm. The alarm is received by the stowage planning tool which may reconsider the risk level for that unit. Reconsideration may lead to do not loading the cargo, loading it anyway with no changes respect to the initial placement or loading it with actions that may alter the initial placement.

4.3.2.2.1 Frequency of occurrence

The frequency of occurrence results in the number of times a cargo unit has caught fire, taking into account the total deployed fleet of the years studied (2013/2020) and the amount of such cargo usually loaded on the ships.

$$Frequency\ of\ occurrence\ i = \frac{\sum_{j=0}^{n} Fire\ accidents_i}{Units\ i\ on\ the\ Lash\ Fire\ general\ ship \cdot \sum_{j=0}^{n} routes} \quad (1)$$

i: Type of cargo

j: years (2013/2020)

The following procedure has been followed to carry out these calculations:

- Sample of the deployed ro-ro fleet. (fleet data)
- Fire accident data
- Ship cargo data

4.3.2.2.1.1 Fleet data

In order to quantify the number of routes (voyages) and nautical miles travelled by ro-ro, ro-pax and vehicle-carrier ships. The total population of voyages performed by these ships from 2003 to 2020 has been extracted from the IHS Markit database, for this purpose only ships with the following characteristics have been extracted.

The LASH FIRE ro-pax, ro-ro and vehicle carrier fleets were composed of ships which are (the same considerations were taken as in the LASH FIRE Database developed in D04.2 to ensure consistency of the project results are based on the same ships sampling):

1. Classed as ro-ro passenger ship, ro-ro cargo ship or vehicle carrier in the IHS database;
2. Delivered on or after 01/01/1970,
3. With a Gross Tonnage equal or greater than 5 000 GT;

Thereby, domestic ships, which are not necessarily compliant with the SOLAS Convention, were excluded from the database (except European Domestic Class A, which are SOLAS compliant, based on Article 4 of the Directive 2009/45/EC).

4. With a Froude number less than or equal to 0.5;

The Froude (Fr) number is defined as: $Fr = v\sqrt{g L_{pp}}$

Where:

- v is the maximum speed of the ship (m/s).
- g = 9.81 m/s².
- L_{pp} is the Length between perpendiculars

5. Classed or having been classed by an IACS member during their lifetime.

The list of IACS members was taken at the time of the study:

- American Bureau of Shipping (ABS),
- Bureau Veritas (BV),
- China Classification Society (CC),
- Croatian Register of Shipping (CRS),
- Det Norske Veritas Germanisher Loyds (DNV GL),
- Indian Register of Shipping (IRS),
- Korean Register of Shipping (KR),
- Lloyd’s Register (LR),
- Nippon Kaiji Kyokai (NK),
- Polish Register of Shipping (PRS),
- Registro Italiano Navale (RINA),
- Russian Maritime Register of Shipping (RS).

Summary of extracted data. Y-axis represents the number of routes by selected fleet in a yearly basis:

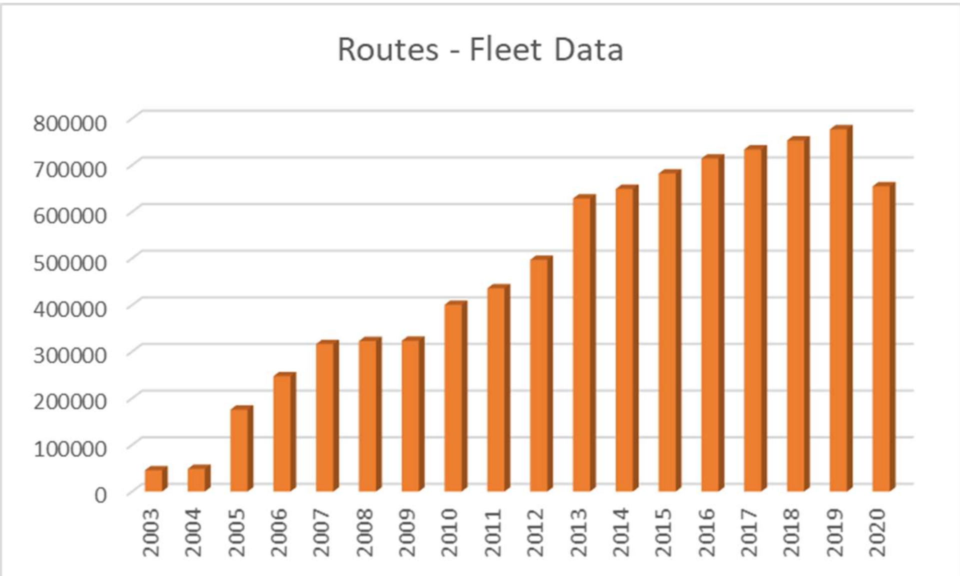


Figure 5. Routes - fleet data

4.3.2.2.1.2 Fire accident data

From the "Fire Hazard Database" developed in D08.1: Cargo fire hazard database, only accidents involving ships were extracted.

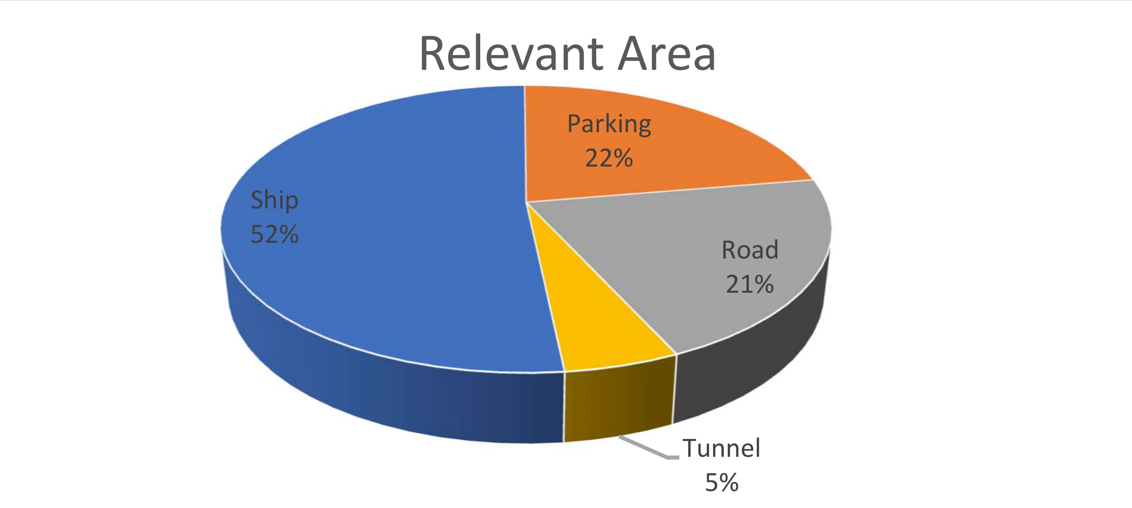


Figure 6. Cargo Fire Hazard Database – Relevant Area Data

Within the population of accidents on ships, the following fields have been selected to support the risk assessment methodology.

Table 4 Attributes of Cargo Fire Hazard Database

Attribute	Description	Risk Assessment
Fire origin 1	Where fire has been originated	Used
Fire origin 2	More detailed information about the fire origin. For example, for conventional vehicles, it is specified if the incident occurred in a truck, bus or car	Used
Fire cause	Which has been the cause of the fire: Electrical fault in the engine, overheating, leakage…	Used
Ships/tunnel/parking/road	In which scenario the incident occurred	Used
Ship/tunnel name	Which is the name of the ships (at the moment of the incident) or the name of the tunnel where the fire occurred	Not relevant for risk assessment
Month	Month when the incident occurred	Not relevant for risk assessment
Year*	Year when the incident occurred	Used

Failure	General description of the incident. This is the wider attribute, and relevant description of the incident is written here such as a more detailed information of the cause of the fire, or the list of events before and after the incident	Used
Severity	Degree of severity of the incident. This information appears just in ships because for the other types of incidents this information was not available.	Used
Type of ship	In which type of ship the incident occurred	Not relevant for risk assessment
Location	Where the incident occurred. If the incident occurred on passage, the name of the sea or ocean will appear. If the incident occurred in port, the name of the port will appear	Not relevant for risk assessment
Occurred when	In which process was the ship when the fire occurred: on passage, in port…	Not relevant for risk assessment
Deck where fire originated	In which deck the fire occurred. Weather deck, deck 1, deck2…	Not relevant for risk assessment
Closed or open	If the deck where the fire occurred was open or closed	Used
More info. About deck location	Other relevant information about the location of the incident in the deck, such as in which zone of the deck the ignition originated	Not relevant for risk assessment
Goods in the fire origin	Which goods was carrying the vehicle where the fire originated	Used
Goods close to the fire origin	Which goods were close to the fire origin, but that were not transported by the vehicle where the fire originated	Used
More info. About close goods and other fuels' intervention	Other relevant information about goods close to the fire origin such as their tonnage, or special factors that could influence the ignition	Not relevant for risk assessment

Dangerous goods	If the good in the fire origin was classified as dangerous	Used
Code dangerous good	In the case that the good is classified as dangerous, which is its code	Not relevant for risk assessment
Continent (for tunnels and parkings)	In which continent the fire occurred	Not relevant for risk assessment
Country (for tunnels and parkings)	In which country the fire occurred	Not relevant for risk assessment
Was charging?	Gives information about if they were charging or not at the moment of the incident	Used
Number of incidents	How many incidents occurred for each record? Usually, this attribute has a value of "1". However, in some specific cases there was not information of each incident individually, and more than one incident was computed	Used
Weight	It defines the credibility of the incident. In some cases, it was not possible to verify if a new incident was already in the data base or not due to a lack of information of the source. In these cases, a weight less than 1 but bigger than 0 was computed	Not relevant for risk assessment
Link	The link where the incident was found	Not relevant for risk assessment
Found in document	In which document the incident was found. In many cases, the incidents recorded in the database come from other data bases so the incidents are extracted from a document, not from a link	Not relevant for risk assessment
IMO Number	These 3 attributes are focused on tracking the identification numbers of the reports depending on the organization the incident comes from. Not all three columns are necessarily filled for a given record. They are used to manage duplicates during compilation but for privacy purposes they are not transferred to the SW database.	Not relevant for risk assessment
Casualty report nr.		Not relevant for risk assessment
ForeSea ID		Not relevant for risk assessment

SOURCE_DB	Indicates which is the source of the record	Not relevant for risk assessment

* Since the sample of routes extracted from the IHS is from 2003, accidents from 2003 to 2020 have been selected. Taking the rest of the sample that has been discarded as references for the recommendations.

Only accidents occurring on ships have been considered for the calculations. The rest of data will be used to analyse them and make recommendations to prevent fires in the marine environment. Once filtered by the accidents occurred on ships, those that have occurred from 2013 to 2020 have been selected, this period was selected because the data of the global fleet deployed obtained IHS Markit, offered the information from 2013. So the rest of the data could not be evaluated against the global fleet, however, the accidents occurred before this period, will be used to evaluate their causes and add value added in the recommendations.

4.3.2.2.1.3 Ship cargo data

In order to properly assess whether fire accidents in each cargo unit are relevant, we must know how many units of that type of cargo are transported in order to evaluate their impact.

For this purpose, information on the cargo transported during one year was requested from the operators and a pattern was obtained of what is the average of each type of cargo transported in a typical ship.

This will help us to develop the frequency of occurrence of an accident per unit of cargo.

The pattern used is the one shown below (the general data of the cargo transported during a year is confidential, that is why only the pattern resulting from the analysis is shown), in order to perform the Risk Assessment, we have only selected from the pattern, the type of cargo where the Fire Hazard Database shows that an accident has occurred in the same. (However, for the totals we have considered the pattern of global cargo of the ship, this means the total number of goods moved by the ship type selected in the project).

General Cargo:

Table 5. General Cargo - Minimum units carried by the LASH FIRE ship

Fire origin 1 and Fire origin 2	Average units carried by type (LASH FIRE ship)
Conventional vehicle Bus	2
Conventional vehicle Car	63
Conventional vehicle Truck	41
New energy carrier Electrical vehicle	4
Reefer unit Value	8
Special vehicle trailer	32
Special vehicle RVs	10
Special vehicle Tractor	4

Dangerous Goods:

Table 6. Dangerous goods - Minimum units carried by the LASH FIRE ship

Dangerous Goods	Minimum units carried by the ship (LASH FIRE ship)
Dangerous goods Corrosive substances	1
Dangerous goods Explosive	1
Dangerous goods Flammable liquid	1
Dangerous goods Flammable solid	1
Dangerous goods Gas	1
Dangerous goods Miscellaneous dangerous substances and articles	1
Dangerous goods Undeclared DG	1

4.3.2.2.1.4 Frequency of occurrence results

Following the equation 1 the results shown in Table 7 have been obtained:

Table 7. General Cargo – Frequency of occurrence

Cargo unit (general cargo)	Frequency of occurrence
Reefer unit Value	8,1577E-07
Conventional vehicle Bus	4,7586E-07
Conventional vehicle Truck	1,5168E-07
Special vehicle RVs	7,9311E-08
Conventional vehicle Car	6,9077E-08
Special vehicle Tractor	3,9655E-08
New energy carrier Electrical vehicle*	2,9741E-08
Special vehicle trailer	3,8376E-09

* Due to the small sample of accidents on ships (since this type of vehicle can be considered an emerging technology, accidents caused in other environments, such as parking lots, tunnels and roads, have been used to create recommendations, since many of the accidents caused in these spaces can be extrapolated to the decks of ships, creating recommendations and safety measures to avoid them. Due to their possible widespread use, it is necessary to identify and quantify the risks related to these alternative fuel vehicles and to quantify, in comparison with traditional vehicles, which are the measures to be taken on board ships.

Table 8. Frequency of occurrence of Dangerous Goods

Cargo unit (dangerous cargo)	Frequency of occurrence
Dangerous goods Flammable solid	5,9483E-07
Dangerous goods Flammable liquid	3,569E-07
Dangerous goods Miscellaneous dangerous substances and articles	2,3793E-07
Dangerous goods Corrosive substances	1,1897E-07
Dangerous goods Explosive	1,1897E-07
Dangerous goods Gas	1,1897E-07
Dangerous goods Undeclared DG	1,1897E-07

4.3.2.2.1.5 Frequency index

Frequency index is used to give a risk magnitude that can be easily assessed by the SPT and subsequently evaluated together with the severity of the accidents. The frequency of occurrence has been converted into frequency indexes, these indexes evaluate the frequency from the least frequent (extremely remote, which has been assigned a frequency index equal to 1) to the most frequent (More probable, which has a frequency index of 4). These evaluations have been based on the results obtained from the loads analysed, and that allows to evaluate those that are more usual to cause fire from those that, although in the history there have been accidents, these are more remote, or that when this unit is loaded more on the ships, due to a question of mass probability, it has had accidents on some occasion, but compared to the loaded units, this frequency is insignificant.

As a result, the results shown in Table 9 were obtained.

Table 9. Frequency Index

Frequency Index	Description	Ranges
1	Extremely remote	$f < 5x10^{-8}$
2	Remote	$5x10^{-8} \geq f < 1x10^{-7}$
3	Reasonably probable	$1x10^{-7} \geq f < 5x10^{-7}$
4	More probable	$f \geq 5x10^{-7}$

4.3.2.2.2 Severity Index

Definition about severity can be found in ANNEX E: Risk Assessment considerations and background

In the Cargo Fire Hazard Database, the level of severity was collected in the levels shown above (Very Serious, Serious, Less Serious, Marine incident and Near miss) these levels were then categorized in the Severity Index which considered the loss or damage to humans and the ship. From a localized loss of a cargo unit (Severity index =1) to a total loss of the ship (Severity index=4). It should be noted that in order to assign an SI (Severity index) to each accident, the accident must comply with at least one of the consequences shown in Table 10, on the side of the damage or human life or the damage or loss of the ship.

Table 10. Severity Index

Severity index		Human	Ship
1	Minor	Single or minor injures	Local equipment and structural damages (10.000-50000€)
2	Significant	1-5 severe or 10-50 minor injures	Non-severe ship damage (100000-500000€)
3	Severe	1-5 fatality or 10-50 severe injures	Severe damages (yard repair required, downtime 1 week) (1-5 M€)
4	Catastrophic	Multiple fatalities	Very severe damage or total loss (10-100M€)

4.3.2.2.3 Risk Cargo Index

The Cargo risk index is the evaluation of the frequency and severity indices of each cargo unit, so that conclusions can be drawn from the comparison of the frequency of occurrence and severity of accidents. Since the recommendations and actions to be taken by the SPT will be based on both indices and how one affects the other.

$$Risk\ Cargo\ Index\ =\ Frequency\ Index\ x\ Severity\ Index\ \ (2)$$

Table 11. Cargo risk index Matrix

		Severity Index			
		1	2	3	4
Frequency Index	1	Low	Medium	Medium	High
	2	Medium	Medium	Medium	High
	3	Medium	Medium	High	High
	4	High	High	High	High

The matrix has been slightly biased towards medium and high risk as a measure to stay in the side of the safety. This is a best practice when the actions to be taken by the software are based in results obtained from a sample which could be not representative enough. In the end, this increases the benefits of having a cargo distribution with an actual lower risk while the impact on the algorithm is not relevant since it will just consider a set of units or another when selecting an appropriate slot.

Using the frequency and severity index analysed in the previous sections, and finally evaluating the accidents for each cargo unit and the average severity of the accidents, the following results have been obtained for the sample analysed.

Table 12. General Cargo units: Frequency and Severity Index

Cargo unit	Frequency index	Severity index	Cargo Risk Index
Reefer unit	4	2	8
Conventional Vehicles – Bus	3	1	3
Conventional Vehicles - Truck	3	2	6
Special Vehicles -RV	2	2	4
Conventional Vehicle – Car	2	2	4
Special Vehicles - Tractor	1	1	1
New energy vehicle – Electrical vehicle	1	1	1
Special Vehicles - Trailer	1	1	1

Table 13. Dangerous goods units: Frequency and Severity Index

Dangerous goods units*	Frequency index	Severity index	Cargo Risk Index
Dangerous goods Flammable solid	4	2	8
Dangerous goods Flammable liquid	3	2	6

Dangerous goods Miscellaneous dangerous substances and articles	3	1	3
Dangerous goods Corrosive substances	3	1	3
Dangerous goods Explosive	3	1	3
Dangerous goods Gas	3	1	3
Dangerous goods Undeclared DG	3	1	3

(*) only the DDGG which have suffered an accident have been considered. As a rule, these cargo units are already stowed with predefined regulations, but based on these data, the need to comply with them correctly and to add recommendations is emphasised.

4.3.2.3 Risk Score

The risk score is the final risk score for each cargo unit, based on the Initial Risk Index, sensor data (data on the actual condition of each cargo unit) and its compatibility with the other cargo surrounding it, as well as its position on the ship.

4.3.2.3.1 Static risk score

The Risk Assessment is based on historical data these gives a static Initial Risk Score, based solely on past accident experience. To make sense within the SPT and easy to understand for all users who have to interact with the tool, the Initial Risk Score will be based on three values, from 1 to 3, depending on the level of risk (low, medium, high). This way, 1 means a low intrinsic risk, 2 a medium risk and 3 high risk.

Table 14. Conversion of initial risk index to initial

Cargo Risk Index	Initial Risk Score
Low	1
Medium	2
High	3

This simplification was done because at the establishment of recommendations there was not enough data to establish 16 levels and to evaluate how the risk moved within these 16 levels. That is why it was simplified to three levels of risk: high, medium or low, since the data extracted from the Fire hazard Database allowed to extract recommendations that allowed to pass the different causalities from lower risk to higher risk and vice versa.

The distribution of the 16 levels into low, medium or high risk was not homogeneous, and the following assumptions were considered for classifying the different combinations of frequency of occurrence and severity.

Assumptions:

a. The risk will only be low if its frequency of occurrence and severity are as low as possible given the sample used. This only happens when the accident cases produced by that unit load have occurred very remotely and, at the same time, the severity of the accident has been very low.
b. For high risk, it has been considered to be those that both its severity is maximum regardless of the frequency, and those that its frequency is maximum regardless of the severity.
   This is because in the case of severity, even if its frequency is not high, if the fire in that unit load is very severe, it implies that when it occurs even if it is not often its consequences can be devastating so special attention must be paid to that unit load.

Likewise, when a cargo unit frequently suffers a fire, it should be considered as high risk regardless of its severity, since it will constantly produce a potential risk to itself and to the rest of the cargo around it. This implies that perhaps its severity is very low if the hazard occurs in that unit load, but if the surrounding load comes in contact with this heat source, the combination of both loads could produce very severe results. This assumption has been directly included at implementation level (coding of the algorithm).

c. High risk has also been assigned to the combination of medium-high frequency and medium-high severity since the combination of both implies an elevated risk to the load.

d. The rest of the severity and frequency combinations were assigned a medium risk, due to their medium, medium-low frequency and severity.

Table 15. Cargo Risk Index as the result of: Frequency Index x Severity Index

		Severity Index			
		1	**2**	**3**	**4**
Frequency Index	**1**	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	4	4	8	12	16

Table 16. General Cargo units: CRI vs Initial Risk Score

Cargo unit	Cargo Risk Index	Initial Risk Score
Reefer unit	8	3
Conventional Vehicles – Bus	3	2
Conventional Vehicles - Truck	6	2
Special Vehicles -RV	4	2
Conventional Vehicle – Car	4	2
Special Vehicles - Tractor	1	1
New energy vehicle – Electrical vehicle	1	1
Special Vehicles - Trailer	1	1

Table 17. Dangerous goods units: CRI vs Initial Risk Score

Dangerous goods units*	Cargo Risk Index	Initial Risk Score
Dangerous goods Flammable solid	8	3
Dangerous goods Flammable liquid	6	2
Dangerous goods Miscellaneous dangerous substances and articles	3	2
Dangerous goods Corrosive substances	3	2
Dangerous goods Explosive	3	2
Dangerous goods Gas	3	2
Dangerous goods Undeclared DG	3	2

* only the DDGG which have suffered an accident have been considered. As a rule, these cargo units are already stowed with predefined regulations, but based on these data, the need to comply with them correctly and to add recommendations is emphasised.

In the case of APVs and AFVs, due to the uncertainty of accidents on ships, this uncertainty, and taking as a reference the accidents in other environments, the initial risk will be medium, the initial risk score will be equal to 2 as a preventive measure. This does not imply that all classes of APVs and AFVs have the same risk, however, as the potential risks of these new fuels are studied, the initial risk score will be modified.

4.3.2.3.2 Dynamic risk score

4.3.2.3.2.1 Pre-loading

The risk analysis of the cargo in the pre-loading phase is carried out before the vessel starts loading, so the factors that will influence the final result will be:

- Intrinsic risk of the cargo, this level of risk will be given by the result of the Risk Assessment.
- Compatibility of the cargo to be analysed with the rest of the cargoes around it, both on the same deck and on the deck immediately above and immediately below.
- Compatibility of the cargo and its location on the vessel.
- Recommendations for both location on the vessel and compatibility between the different cargoes.

It is important to highlight that the risk analysis is made on an existing loading plan; in other words, the algorithm does not suggest a cargo distribution from the scracth (empty ship) but takes an initial distribution (provided by the operator), assess the risk in terms of the score and, optionally, proposes an alternative placement of the units according the methodology.

4.3.2.3.2.1.1 Cargo compatibilities with other cargoes

Compatibilities will only increase the intrinsic risk level of the cargo. These compatibilities refer to how the environment can enhance the fire, which is why to assess the compatibilities between cargoes. This depends on the initial Risk Score of each of the cargoes to be compared. Directly adjacent loads shall be assessed as well as the loading of the deck immediately above and immediately below. So, the compatibility or incompatibility of each cargo unit will be altered or remain the same.

In such a way that when a unit load is evaluated, the adjacent cargoes will be evaluated and its final score will be the most unfavourable of that comparison.

Table 18. Matrix of compatibilities

Initial Risk Score	**1**	**2**	**3**
1	Compatible	Compatible	Compatible
2	Compatible	Compatible but it should be avoided if possible	Incompatible
3	Compatible if recommendations are satisfied	Incompatible	Incompatible

Therefore, the following master table shall be considered when assessing each unit of cargo:

Table 19. Results of cargo unit's compatibilities on deck

Initial Risk Score (RS_0)	RS	
	Compatible	**Incompatible**
1	1	2
2	2	3
3	3	4

Table 20. Results of cargo unit's compatibilities upper deck

Initial Risk Score (RS_0)	RS	
	Compatible	**Incompatible**
1	1	1,25
2	2	2,25
3	3	3,25

Table 21. Results of cargo unit's compatibilities lower deck

Initial Risk Score (RS_0)	RS	
	Compatible	**Incompatible**
1	1	1,5
2	2	2,5
3	3	3,5

- Cargo Compatibilities Assumption

It is considered that if a fire happens on deck X, it will have a more severe impact on deck X+1 due to natural fire spread. That is why the incompatibility comparing deck X with the deck immediately above it acquires a higher value than in the case of incompatibility of a cargo located on deck X with a deck immediately below it (X-1). Influence of cargo in above and below decks is applied regardless of the existing insulating materials.

4.3.2.3.2.1.2 Cargo location in the decks

As far as possible, cargoes with a high Score should be avoided in the proximity of the following elements of the ship, considering the following priority:

1. Near passenger areas
2. Emergency exits
3. Life-saving appliances (LSA):

- Lifebuoys and life-jackets
- Lifeboats
- Life-rafts
- Rescue boats
- Rocket parachute flares
- Launching and embarkation appliances

4. Access
5. Access ramps exits
6. Other security elements

So, two cargo units with the same RS_0 depending on their location on the ship, will be potentially more dangerous depending on the compatibility of what is around them. Not because it makes the fire accident more likely to occur, but because if it does occur, it is potentially more dangerous to the ship and to human life.

Table 22. Results of cargo unit's – ship location compatibilities

	Compatible	**No compatible**
1	1	N/A
1,25	1,25	2,25
1,5	1,5	2,5
2	2	3
2,25	2,25	3,25
2,5	2,5	3,5
3	3	4
3,25	3,25	4,25
3,5	3,5	4,5
4	4	5

4.3.2.3.2.1.3 Pre-loading Assumptions

The RS valuations with a risk level of 4 or above will not be admitted in the initial distribution of the ship's cargo, unless actions are taken to decrease the score, if possible. Therefore, the maximum admissible RS value for a cargo unit once it has been placed in its location will be equal to a risk 3.

4.3.2.3.2.2 Loading

The risk analysis of the cargo in the loading phase is carried out when the ship is being loaded, so the factors that will influence the final result are:

- Intrinsic risk of the cargo, this level of risk will be given by the result of the Risk Assessment.
- Result of the cargo status after being analysed by the VHD.
- Compatibility of the cargo to be analysed with the rest of the cargoes around it, both on the same deck and on the deck immediately above and immediately below.
- Compatibility of the cargo and its location on the vessel.
- Recommendations for both location on the vessel and compatibility between the different cargoes.

4.3.2.3.2.2.1 Sensors data

The information of the real state of the cargo unit, will be given by the arc/tunnel of sensors, this will give an information of the state of the cargo unit that will complement the original Risk Score (RS), the result of adding the valuation of the real state of the cargo unit will alter the Risk Score of the cargo, so that the following variations of the RS can be given depending on the static RS of the cargo unit.

Table 23. Risk Score modification by VHD

Initial Risk Score	**Risk Score (Initial risk score modified by VHD)**		
	No alarm	**Warning**	**Alarm ***
1	1	4	4
2	2	4	4
3	3	4	4

* Upon alarm and inspection, it is decided that the cargo unit enters the vessel.

The above table shows the different situations that can be found when a cargo unit is scanned before being loaded to the ship:

- If no alarm is received from VHD, initial risk score remains unchanged.
- In case of receiving a warning, then the initial risk score is 3.
- If an alarm is triggered, cargo units must always be inspected if, after inspection, it is decided that it should enter the vessel, its risk level will be 4.

Therefore, the value 4 of risk level before placing the cargo in its location in the ship will be given by the negative result of its initial state when passing through the VHD.

In case of false alarm, the cargo unit will have the initial risk value, derived from its intrinsic value (RS_0).

4.3.2.3.2.2.2 Cargo compatibilities with other cargoes

Once verified if an alarm has been triggered, the compatibility between cargoes should be evaluated.

Compatibilities will only increase the intrinsic risk level of the cargo. These compatibilities refer to how the environment can influence the progress of a fire, which is why to assess the compatibilities between cargoes. This depends on the initial Risk Score of each of the cargoes to be compared. Directly adjacent loads shall be assessed as well as the loading of the deck immediately above and immediately below. So, the compatibility or incompatibility of each cargo unit will be altered or remain the same.

In such a way that when a unit load is evaluated, the adjacent cargoes will be evaluated and its final score will be the most unfavourable of that comparison.

Table 24. Matrix of compatibilities

Initial Risk Score	**1**	**2**	**3**
1	Compatible	Compatible	Compatible
2	Compatible	Compatible but it should be avoided if possible	Incompatible
3	Compatible if recommendations are satisfied	Incompatible	Incompatible

Therefore, the following master table shall be considered when assessing each unit of cargo:

Table 25. Results of cargo unit's compatibilities on deck

Initial Risk Score (RS_0)	RS	
	Compatible	Incompatible
1	1	2
2	2	3
3	3	4
4	4	5

Table 26. Results of cargo unit's compatibilities uper deck

Initial Risk Score (RS_0)	RS	
	Compatible	Incompatible
1	1	1,25
2	2	2,25
3	3	3,25
4	4	4,25

Table 27. Results of cargo unit's compatibilities lower deck

Initial Risk Score (RS_0)	RS	
	Compatible	Incompatible
1	1	1,5
2	2	2,5
3	3	3,5
4	4	4,5

4.3.2.3.2.2.3 Cargo location on the decks

As far as possible, cargoes with a high Score should be avoided in the proximity of the following elements of the ship, considering the following priority:

1. Near passenger areas
2. Emergency exits
3. Life-saving appliances (LSA):
    - Lifebuoys and life-jackets
    - Lifeboats

- Life-rafts
- Rescue boats
- Rocket parachute flares
- Launching and embarkation appliances

4. Access
5. Access ramps exits
6. Other security elements

So, two cargo units with the same RS0 depending on their location on the ship, will be potentially more dangerous depending on the compatibility of what is around them. Not because it makes the fire accident more likely to occur, but because if it does occur, it is potentially more dangerous to the ship and to human life.

Table 28. Results of cargo unit's – ship location compatibilities

	Compatible	No compatible
1	1	N/A
1,25	1,25	2,25
1,5	1,5	2,5
2	2	3
2,25	2,25	3,25
2,5	2,5	3,5
3	3	4
3,25	3,25	4,25
3,5	3,5	4,5
4	4	5
4,25	**4,25**	**5,25**
4,5	**4,5**	**5,5**
5	**5**	**6**

4.3.2.3.2.2.4 Loading Assumptions

The RS valuations with a risk level of 5 or 6 will not be admitted in the initial distribution of the ship's cargo, so it will be mandatory to take recommendations at the level of the rest of the cargo or its location on the ship so that the risk level is lower. Therefore, the maximum admissible RS value for a cargo unit once it has been placed in its location will be equal to a risk 4.

4.3.2.3.3 Cargo distribution recommendations

The only way to reduce cargo risk is through cargo placement recommendations.

There are several types of recommendations, some that are considered primary recommendations, and others that are stated as additional recommendations.

In such a way that depending on the starting RI these measures should be more or less critical, all the cargoes with an RI of 3 or higher will be prioritized when it comes to place them in a safer way.

Table 29. Recommendations to decrease Risk Score

Risk Score (RS)	RS with recommendations
1	1
2	1
3	2
4	3
5	4-3
6	5-4

Application of recommendations is focused to achieve the following objectives:

1. Protection of lives
2. Keeping the propulsion machinery safe
3. Structural integrity of the ship
4. Fire prevention
5. Facilitating firefighting
6. Facilitate evacuation

Recommendations enumerated in ANNEX F Cargo distribution recommendations are a compilation and adaptation of best practices from operators and DG rules.

4.3.2.4 Global Score

The global risk value can be calculated from the global risk of a cargo unit, which consider its intrinsic risk, its location with respect to the rest of the cargoes and its location within the ship, the global risk of a deck, which consider all the cargoes located on the deck, their interaction between the cargo units and their locations within the ship, and finally the global risk of the ship, which takes into account all the decks and the interaction between them (as it affects the cargoes immediately above and below decks to a cargo unit).

4.3.2.4.1 Global score of cargo unit

$$GRS_i = Rso_i + Max.Rcc_{ik} + Max.Rcs_{ix} + \sum Rr_{ij} \quad (2)$$

Where:

i: cargo unit

The cargo units can be:

- Reefer unit Value

- Conventional vehicle Bus

- Conventional vehicle Truck

- Special vehicle RVs

- Conventional vehicle Car

- Special vehicle Tractor

- New energy carrier Electrical vehicle

- Special vehicle trailer

- Dangerous goods Flammable solid

- Dangerous goods Flammable liquid

- Dangerous goods Miscellaneous dangerous substances and articles

- Dangerous goods Corrosive substances

- Dangerous goods Explosive

- Dangerous goods Gas

Rcc= Cargo Compatibility

Compatibility: 0

Incompatibility: k

k= type of deck

k: same deck: 1

k: deck immediately above: 0.25

k: deck immediately below: 0.5

When evaluated with all cagoes, the maximum value will be selected.

Rcs= Ship compatibility

Compatible: 0

Incompatible: 1

x: place on deck

1. *Near passenger areas*
2. *Emergency exits*
3. *Life-saving appliances (LSA):*
    - *Lifebuoys and life-jackets*
    - *Lifeboats*
    - *Life-rafts*
    - *Rescue boats*
    - *Rocket parachute flares*
    - *Launching and embarkation appliances*
4. *Access*
5. *Access ramps exits*
6. *Other security elements*

Rr=recommendations

j: the types of recommendations

Without recommendations:0

With recommendations by location on the vessel: -1

With recommendations by location with respect to the rest of the cargo units: -1

4.3.2.4.2 Global score on a deck

$$GRS_D = \sum_{i=1}^{n} GRS_i \quad (3)$$

$GRS_D: Global\ Risk\ Score\ on\ deck$

4.3.2.4.3 Global score on the ship

$$GRS_S = \sum_{i=1}^{n} GRS_D \quad (4)$$

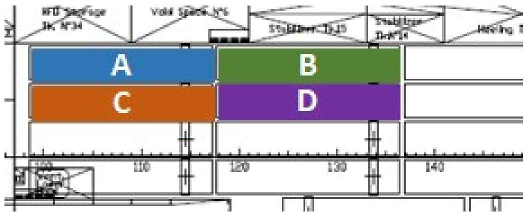
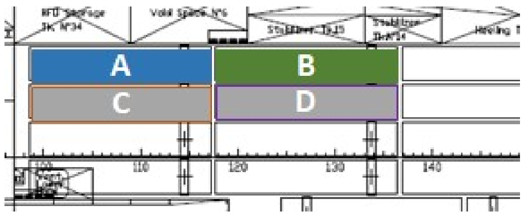
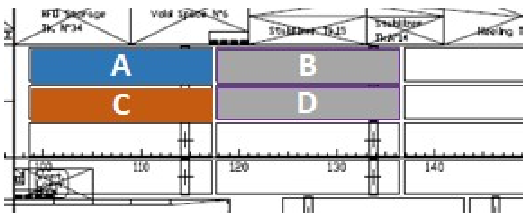
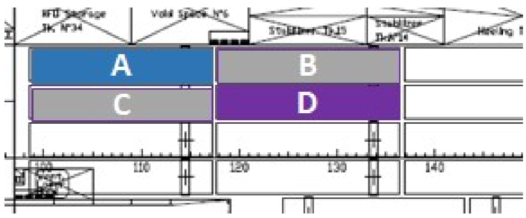
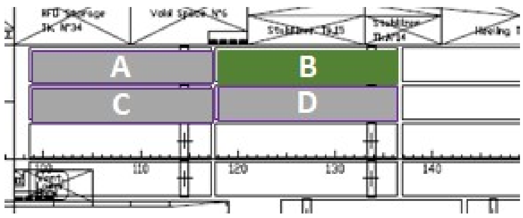
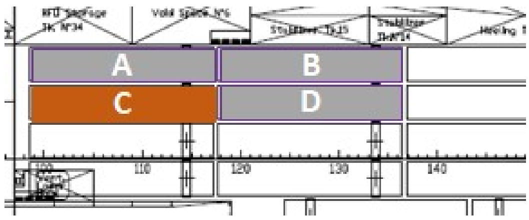
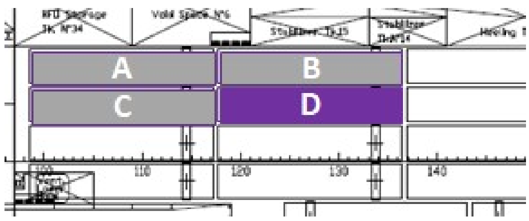
$GRS_S: Global\ Risk\ Score\ on\ ship$

4.3.2.5 Application example

The below table illustrates how the risk assessment calculations are applied to a reduced set of cargo units, first setting the initial risk score (RS_0) based on their cargo type and then, calculating the risk score based on the adjacent units as previously described.

These are the actions that take place during scoring of a suggested stowage plan. The process is more or less the same during cargo distribution but instead of just scoring, the calculated RS value is used to select the best location, understanding best as the one that results on a lower RS value.

Table 30. Application example

Situation	Description
	Initial situation where RS_0 is calculated: A. Conventional vehicle, bus: 2 B. Reefer Unit: 3 C. Tractor: 1 D. Trailer: 1 Values for RS_0 are obtained from tables in section Static risk score.
	Starting with unit A, the process sets RS based on nearby cargo and using Tables 20 and 21. Analysing A with B → $RS_A = 3$
	Analysing A with C → $RS_A = 2$
	Analysing A with D → $RS_A = 2$ After checking all adjacent units, RS for A finally gets the maximum number, which is 3.
	The same process with the unit B results on: • B with A → $RS_B = 4$ (maximum) • B with C → $RS_B = 3$ • B with D → $RS_B = 3$
	The same process with the unit C results on: • C with A → $RS_c = 1$ • C with B → $RS_c = 1$ • C with D → $RS_c = 1$
	The same process with the unit D results on: • D with A → $RS_D = 1$ • D with B → $RS_D = 1$ • D with C → $RS_D = 1$

After the analysis of nearby units, RS for units A and B has increased from 2 to 3 and from 3 to 4 respectively, while RS for unit's C and D does not change.

Similar strategy takes place in a later stage when analysing compatibility with equipment of the ship. Assuming all units are in compatible locations, then RS will not change. Otherwise, RS for units A and B will still increase from 3 to 4 and from 4 to 5 respectively, while RS for units A and D will remain the same.

4.4 Design

The software implementing the SPT requires read and/or write access to data concerning the ship (physical layout and infrastructure elements), the cargo (management of the units and the distribution along the decks) and the information used to assess the risk based on historical data.

In that sense, databases are a powerful software component supporting the abovementioned read and write operations in a fast and reliable way and therefore, providing with enough performance to the whole solution. Section 4.4.1 include the definition of the databases used in the development.

How these databases are used by the software as well as the actions that compose the main features of scoring and cargo distribution are detailed in Section 4.4.2 by means of workflow diagrams.

The following sections describe how the software is composed of and what are the actions and decisions made from a design perspective. Both data models and workflow diagrams are key elements before starting the development stage, which is described in Section 6.

4.4.1 Data model

Data models can be described as one or more entity-relationship diagrams (ERD), which directly provide a helpful tool to design databases. An ERD shows the relationships of entity sets stored in a database. An entity in this context is an object (a component of data). An entity set is a collection of similar entities. These entities can have attributes that define its properties. By defining the entities, their attributes, and showing the relationships between them, an ER diagram illustrates the logical structure of databases, helping to sketch the design.

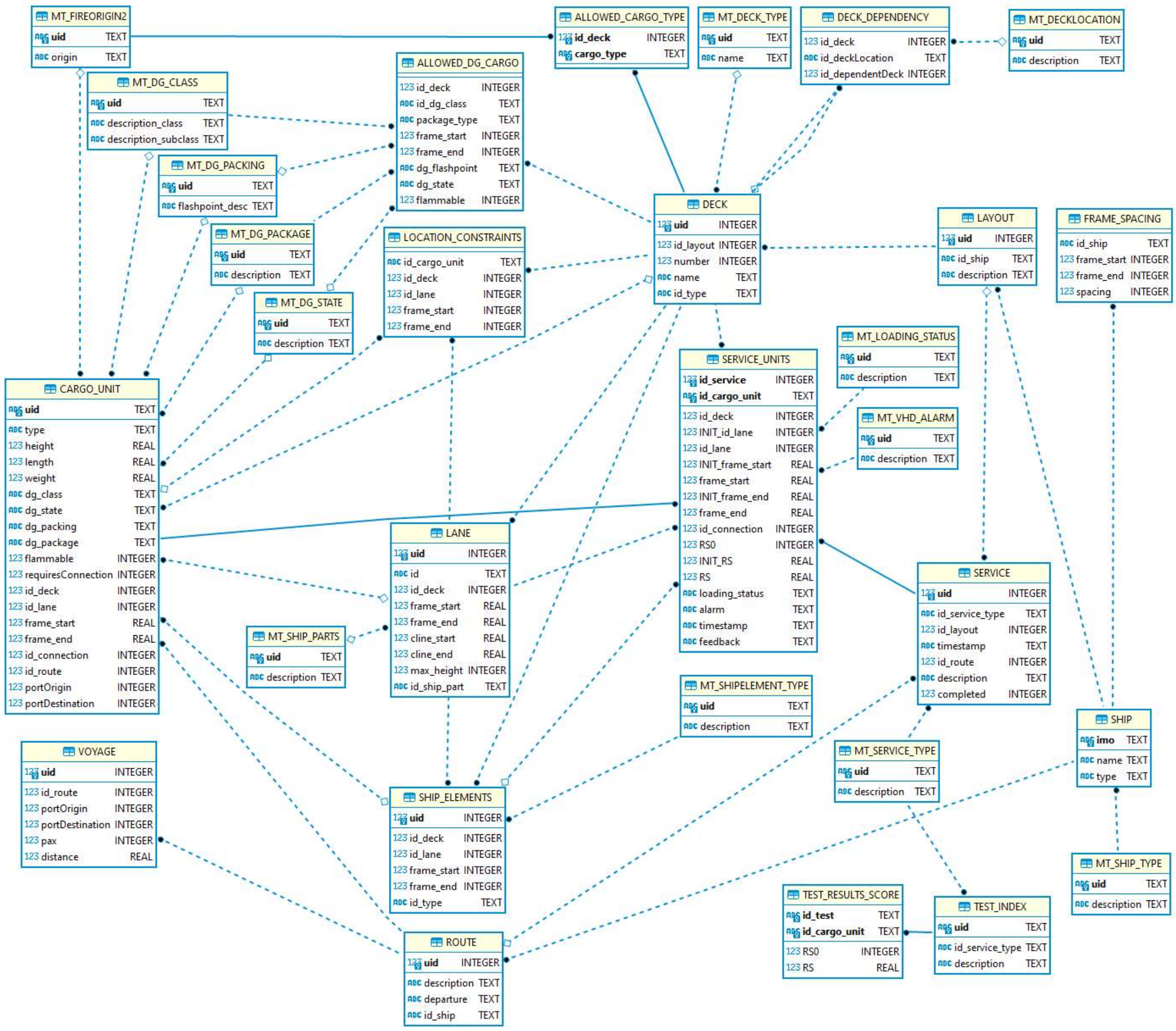


Figure 7. Data model of the Cargo Distribution database

This model takes advantage of some of the definitions previously introduced during the design of the Fire Cargo Hazard Database (see D08.1 for more details) where some of them have been extended to include, among others:

- Frame spacing for each deck to manage space allocation
- Numbering for identification of non-linear lanes
- Management of electrical connections

Other main features are:

- Supports both plug-in and stand-alone running modes.
- Implements definition about ship-specific constraints concerning DG.

As shown in the architecture diagram, there is another database supporting parameters and information needed for calculations made during the Risk Assessment. The below image shows the corresponding data model:

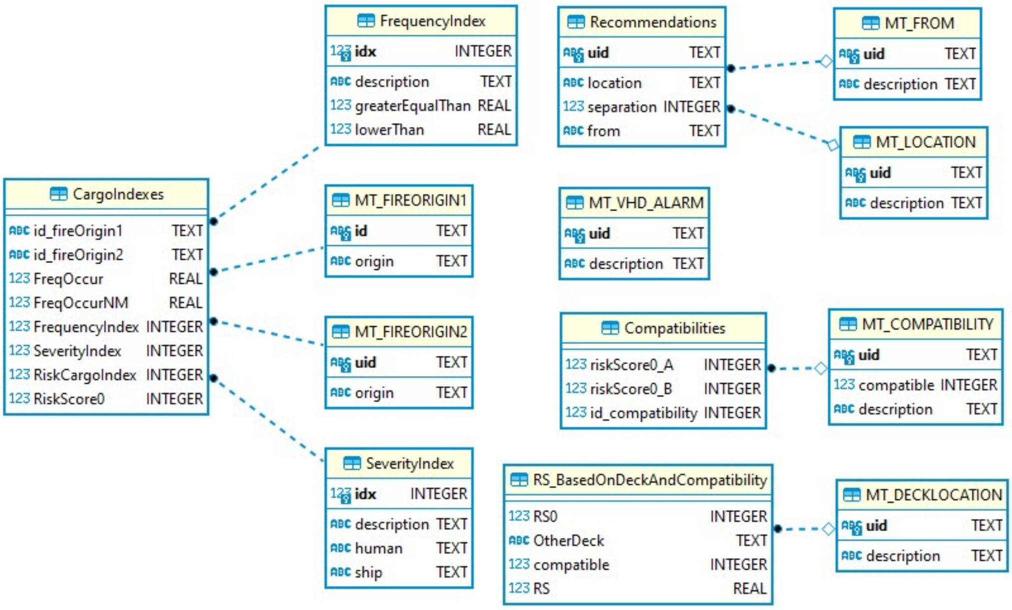


Figure 8. Data model of the Risk Assessment database

4.4.2 Workflow

Algorithms may be described in many ways, being flowcharts or high-level programming languages examples of the most popular ones. The next diagrams show the different workflow being implemented in the algorithm.

The next subsections will help to understand the diagrams since they contain narrative and verbose descriptions of the involved steps and potential errors and/or warnings may appear. An error is an event that stops the process while a warning triggers a notice about something potentially wrong but not sufficient to stop the process.

Table showing errors and warnings uses as identifiers the string in the format {E|W}{N}.{X}[.{Y}]. That is, first letter E (error) or W (warning), then a number which corresponds with the step of the algorithm, a dot and the number of error or warning. Finally, an optional number to specify a sub category. In the description field of the table may appear dynamic parts of the description represented with the symbol %, representing that the error/warning appeared in a context where this dynamic element can change between different executions of the algorithm.

4.4.2.1 Initialization

Before performing any action for any user case implemented there are a set of initialization steps that need to be completed. This way, this diagram represents a common procedure shared between the top-level features of the stowage planning tool: scoring and cargo distribution. Other secondary implemented use cases like *RemoveService* and *ResetService* are not included here but they work in the same way.

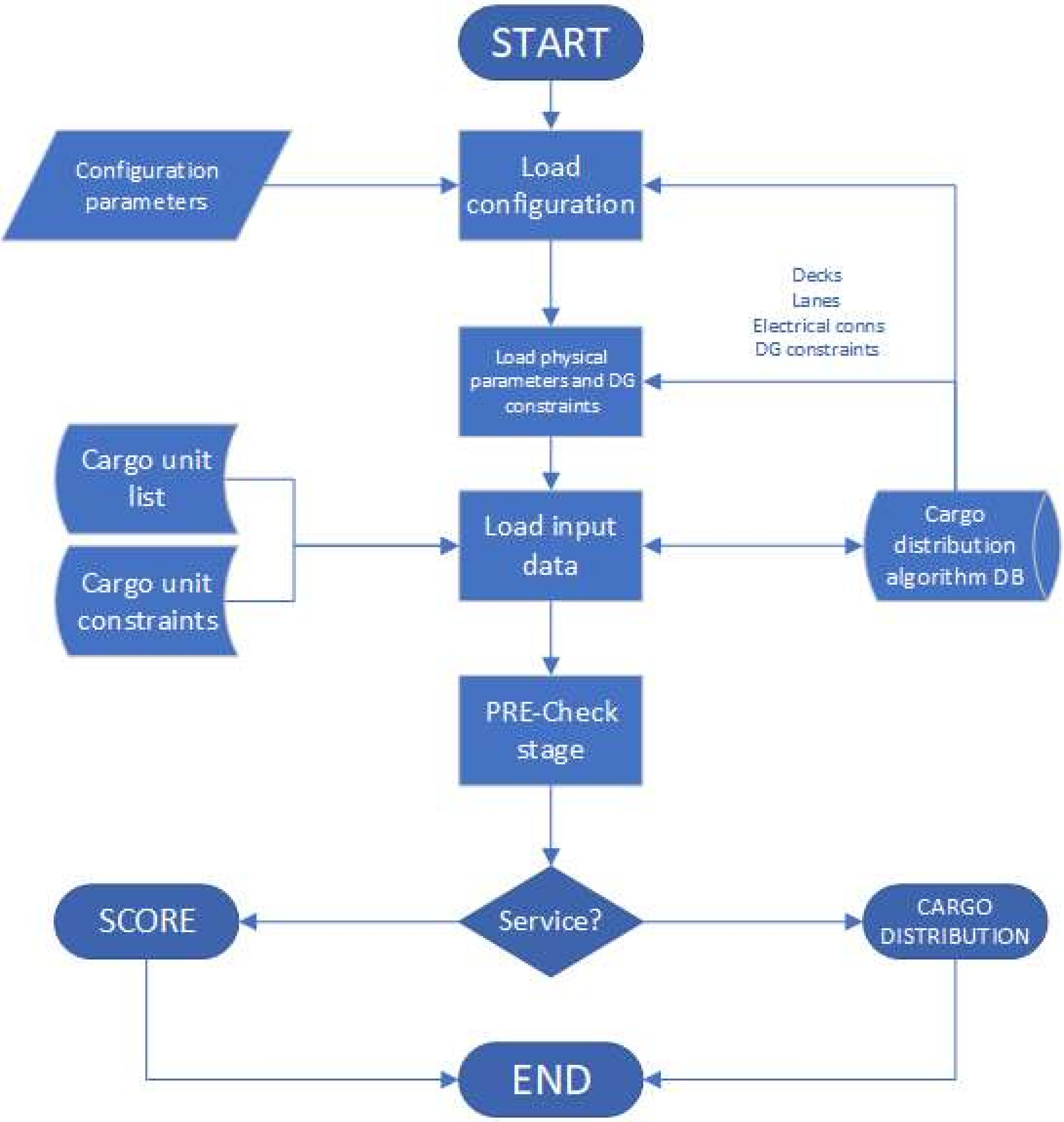


Figure 9. Workflow of initialization stage

4.4.2.1.1 Load configuration

It basically represents the first step after the entry point to the software development and from the algorithm perspective it includes initialization of the mandatory configuration parameters needed to run the algorithm and to check if input data is valid in the next step.

4.4.2.1.2 Load physical parameters and DG constraints

Once the ship and the layout have been checked (and also deck and lanes), all physical parameters needed to run the algorithm are retrieved from the database.

4.4.2.1.3 Load input data

After previous step, the algorithm is aware of not only what is the procedure it must run (score or cargo distribution) but also which are the ship, the layout and the route that must be considered from now on. In this step, these values are used to check if the list of cargo units are consistent of not. That is, if values for deck/lane/connection/route/DG match with the existing ones in the database; otherwise, the corresponding errors will arise. Valid values for the other fields are checked as well.

4.4.2.1.4 PRE-Check stage

Once all needed inputs regarding ship, route and cargo have been loaded and just before starting the optimization process, a set of verifications is performed to avoid problems in a later stage and to ensure consistency of the data:

1. Cargo unit height lower than the maximum height of all available decks (for all cargo units).
2. Cargo unit type not allowed in any available deck (for all decks).
3. Check if the ship has room for each DG unit (DG constraints)
4. Number of electrical connections required versus existing ones
5. Total lane length is greater than the sum of all lengths of cargo units

4.4.2.2 Score

Top level use case of the algorithm in charge of analysing a suggested stowage plan and returning the corresponding score.

The next image depicts the high-level workflow of the scoring process:

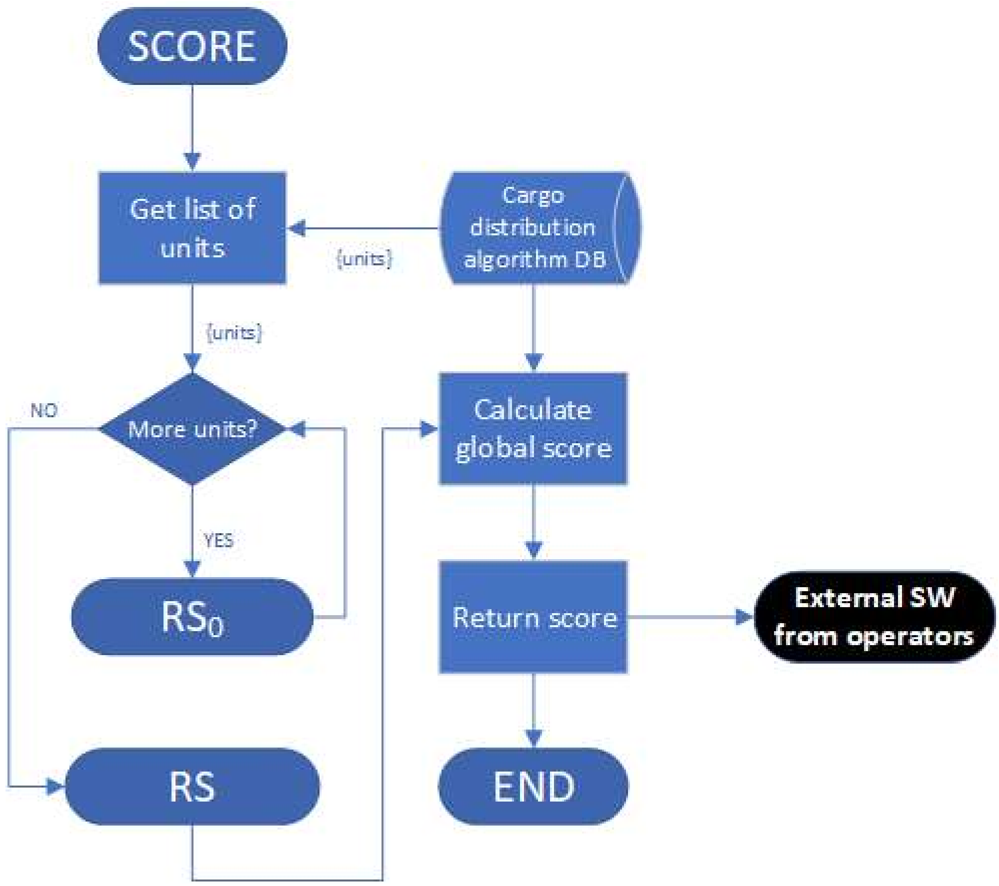


Figure 10. Score process workflow (Start)

After initialization, the algorithm starts a loop that iterates all over the existing cargo units, where, for each element actions described in the next two workflows take place. These diagrams directly depict what is described in a verbose way in the section 4.3.2.

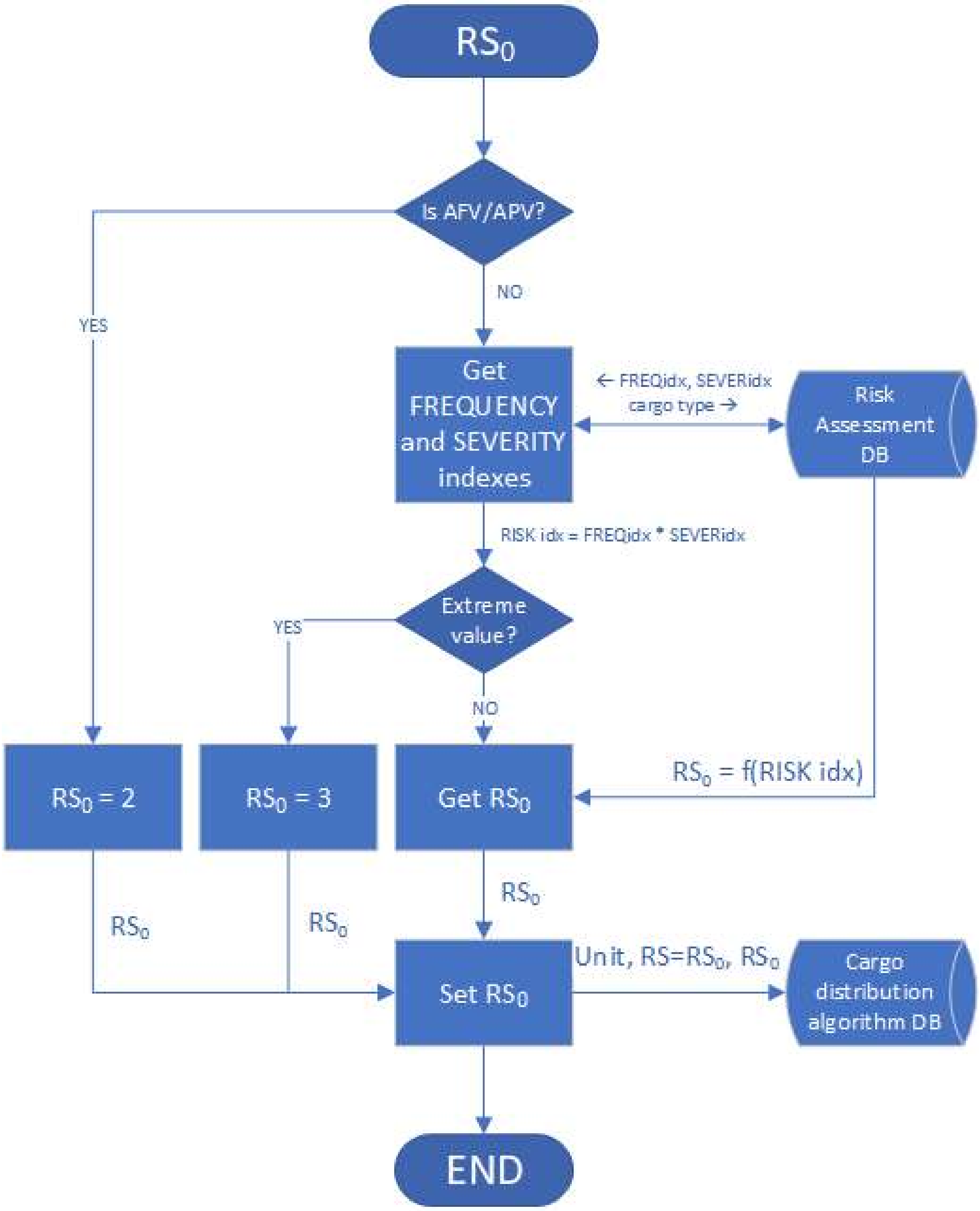


Figure 11. Score process workflow (Initial Risk Score or RS_0)

The first checking determines if the current cargo unit is whether an AFV or not. If it is the case, the initial risk score takes a specific value. Otherwise, from the specific database that stores RA information, both frequency and severity indexes are calculated based on the cargo type of the unit. Once these values are defined, the risk index of the unit is then calculated and compared to extreme values. Again, if it is the case, specific value is set, otherwise initial risk score is calculated based on the risk index. Finally, the value is stored in the main database.

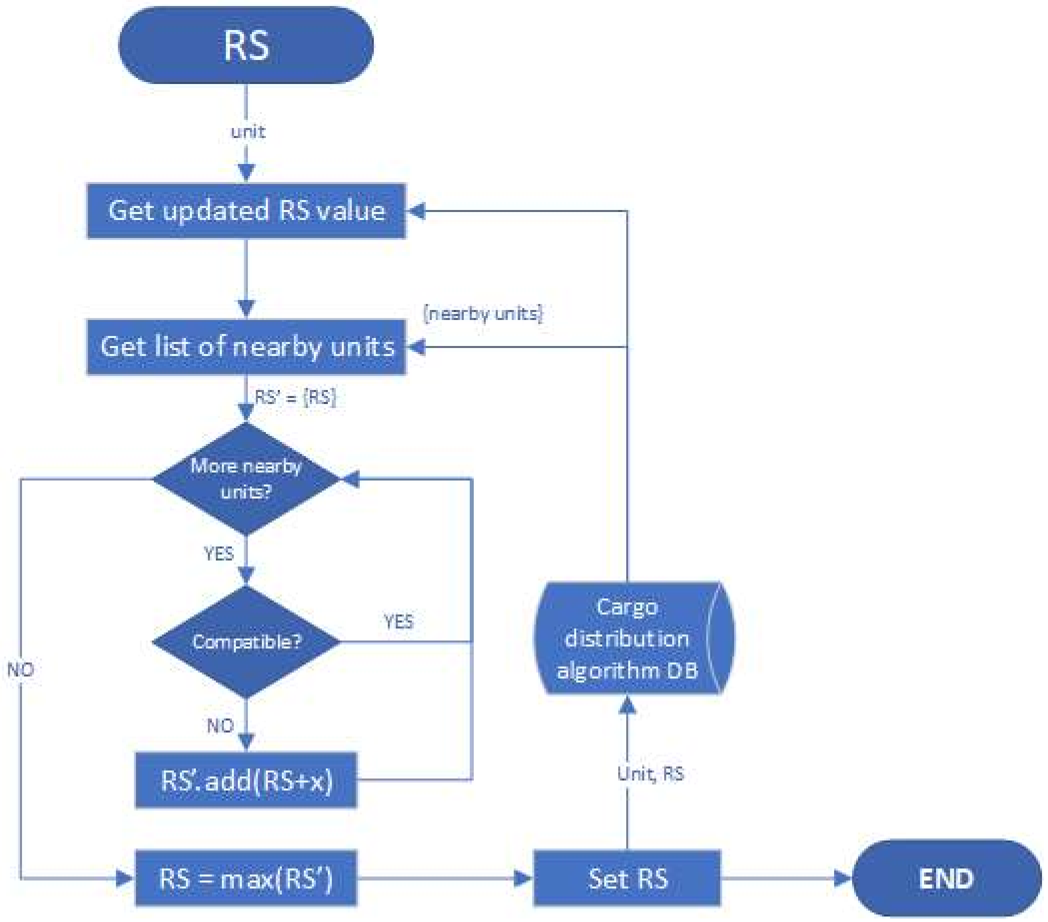


Figure 12. Score process workflow (Adjustment of Risk Score after stowage)

Initial risk score or RS_0 can be adjusted in a later stage depending on the adjacent units and some nearby equipment of the ship. The above image shows these two additional steps that, based on the risk assessment descriptions, may increase accuracy of the level of risk for a given unit.

Diagrams so far depict how risk score for a given unit can be adjusted before the loading process. However, as previously shown by the software architecture, the Stowage Planning Tool interfaces, directly or indirectly through the visualization aid, the VHD System in order to get additional information about potential risk of a cargo unit. The VHD scans units before entering the ship and may trigger alarms that, depending on the level of severity, can modify the risk score.

The next diagram depicts in a high level, how the interaction between VHD and Stowage Planning Tool in terms of the risk score adjustment is carried out. Dotted squares in black colour represent an access to the main database of the software through a specific use case (confirm location, update RS value or get location for a given unit).

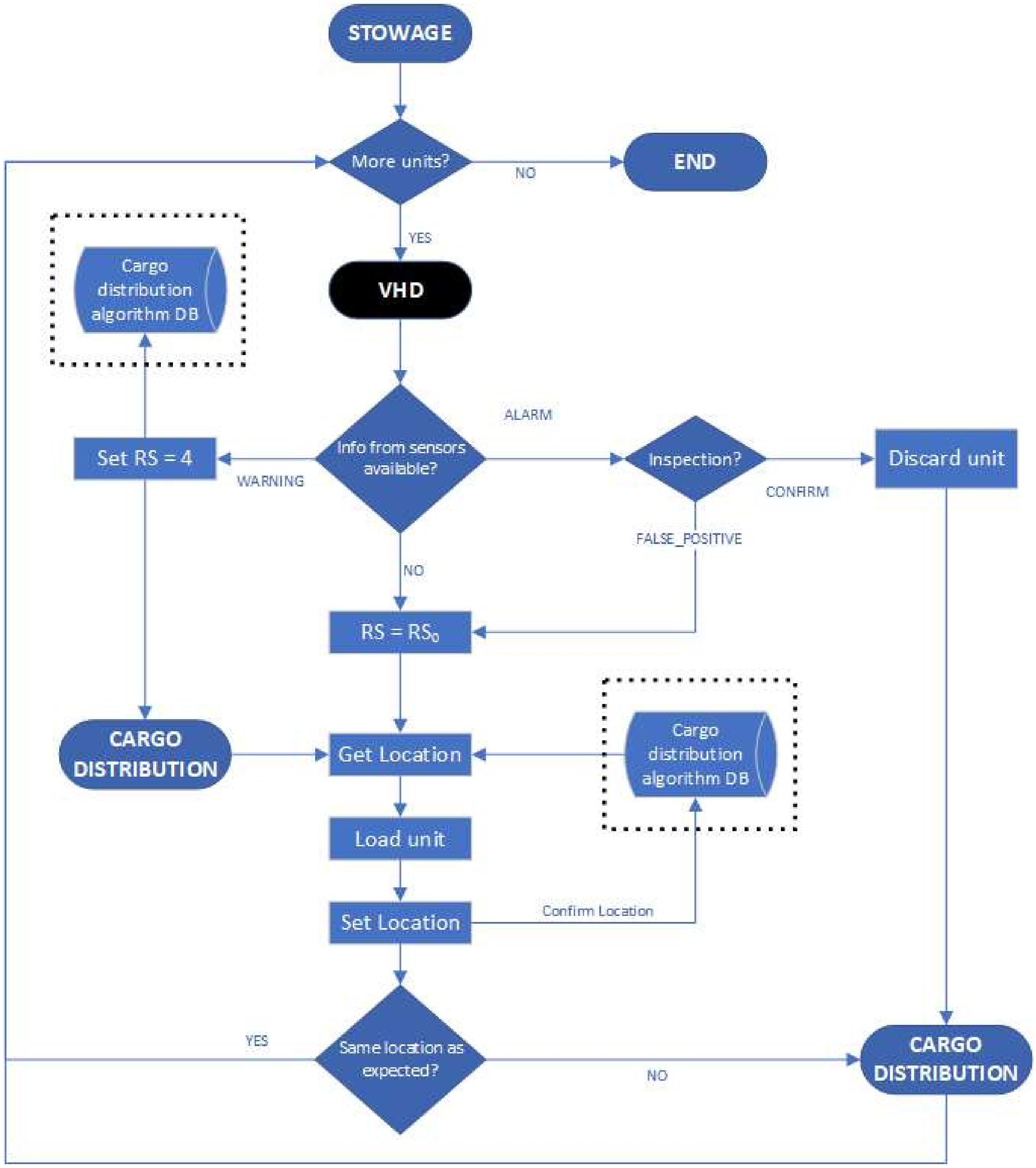


Figure 13. Score process workflow (Adjustment of Risk Score during stowage)

4.4.2.3 Cargo distribution

Once all necessary checking has been done, units are processed in order to get the distribution that minimizes the overall risk. The below diagrams depict the steps carried out to achieve the objective:

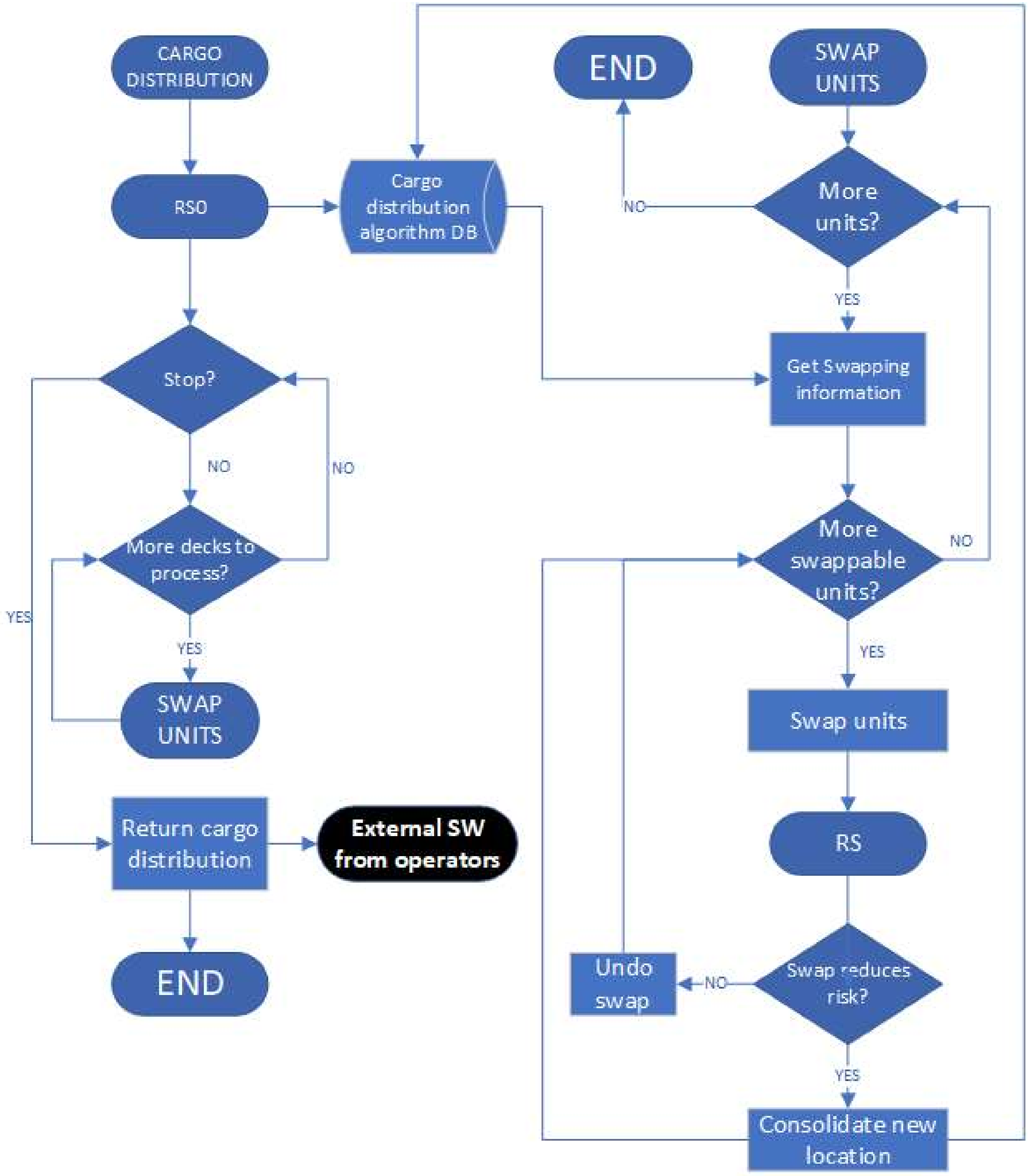


Figure 14. Workflow of cargo distribution process

Distribution of cargo units is executed using the suggested stowage plan as input. The first step calculates the RS_0 values for all units since it will be used afterwards as one of the criteria to select which units can be exchanged, from their placement perspective, with others.

The process stops if any of the stop conditions is true: timeout has expired or, optionally, a certain improvement respect to the initial RS total value has been achieved.

The algorithm basically selects, for each unit, a list of swappable units (in terms of the slot they are placed) and calculates the resulting RS value of the combination which is a result of swapping every single pair. When a combination that results on a lower risk, the exchange is consolidated in the database and the process continues.

Finally, the new cargo distribution is sent back to the external SW from the operators.

5 Visual Interface

Main author of the chapter: Erik Styhr Petersen, NTNU

Understanding the relationships and interaction between humans, organizational processes and technologies in complex systems is an essential component in socio-technical ventures and mechanisms such as the SPT, and for that purpose, the principles of systems engineering (Kossiakoff, Sweet, Seymour, & Biemer, 2011) as well as the method of human-centred design (ISO9241-210, 2019) are both complementary and directly useful. The former argues that '…the identification of customer needs, the system operational environment, interfacing systems, logistics support requirements, the capabilities of operating personnel, and such other factors must be correctly reflected in system requirements…' (Kossiakoff et al., 2011, p. 831), while the latter makes the same point by stating that 'the characteristics of the users, tasks and the organizational, technical and physical environment define the context in which the system is used' and continues that the analysis of the context-of-use can 'provide information on a whole range of context issues including deficiencies and baseline levels of performance and satisfaction. It can reveal needs, problems and constraints that might otherwise be overlooked but which must be met by the future system' (ISO9241-210, 2019, p. 11).

In the development of the SPT, the advice provided by both schools of thought are being followed, and the definition of requirements – also for visualization – are rooted in the context-of-use, and the tasks and functions users are going to perform with the tool. To further help the analysis and the definition of system requirements, yet another method have been used, which is the Actor-Network Theory (ANT) (Booth, Andrusyszyn, Iwasiw, Donelle, & Compeau, 2016; Sage, Dainty, & Brookes, 2011), and especially how visualization of an actor-network – an ANT map – can help a broad discussion between many stakeholder classes to derive needed functionalities (see also (Payne, 2017)).

Figure 15 constitutes an Ant-network map inspired visualization of the identified stakeholders working with the SPT, and the functions they are going to perform, guiding the development/description of the use-cases (see ANNEX B Context-of-use) for the tool and the visualization needs each use situation needs. As a reference table complementing the above-mentioned annex, the below table summarizes the relation between users and use cases.

									Use-cases						
ID	User Description	UC 1	UC 2	UC 3	UC 4	UC 5	UC 6	UC 7	UC 8	UC 9	UC 10	UC 11	UC 12	UC 13	UC 14
U1	Shore-based stowage planner	**x**	**x**		**x**					**X**					**x**
U2	Deck Crew			**x**					**(X)**	**X**		**x**			
U3	Cargo officer/ Loading officer	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**(X)**	**X**	**x**	**x**	**x**		**x**
U4	Tug/tractor driver			**x**					**(X)**	**X**	**x**	**x**	**x**		
U5	Bridge officer					**x**	**x**	**x**		**X**		**x**		**x**	
U6	Terminal gate keeper								**x**	**X**					

Table 31 - Mapping of users to use-cases

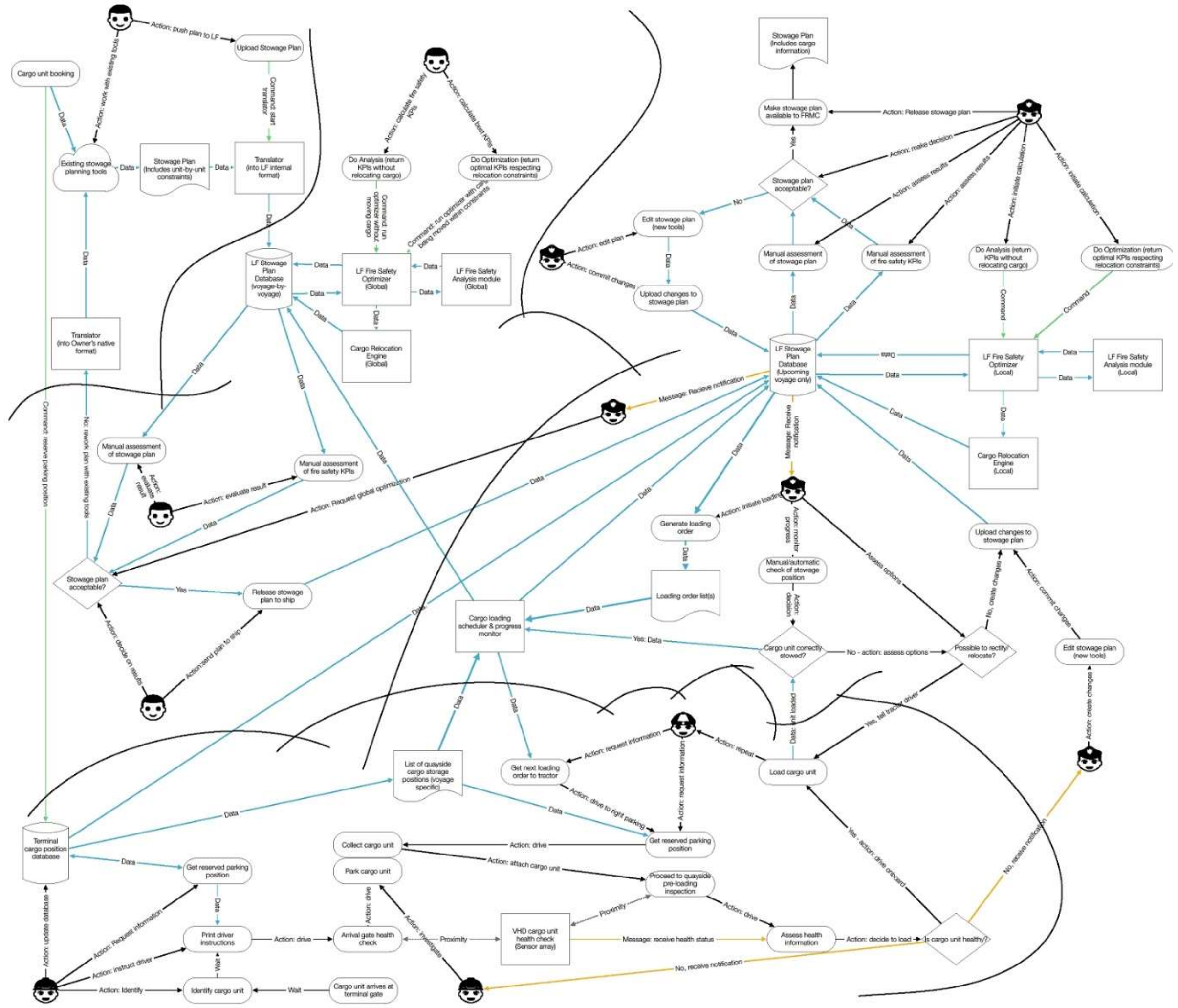


Figure 15 - Stowage Planning Tool actor-activity diagram

5.1 Human-centred Design

5.1.1 Human-centred Design Fundamentals

According to ISO 9241-210 (2019), the usage of Human-Centred Design (HCD) leads to significant benefits for all the stakeholders involved with a particular product, the reasoning being that systems with good usability presumably will be more successful in the market. In the maritime domain, the development of navigation systems is one such example, where the usage of HCD believably led to a beneficial market position (Petersen, 2010).

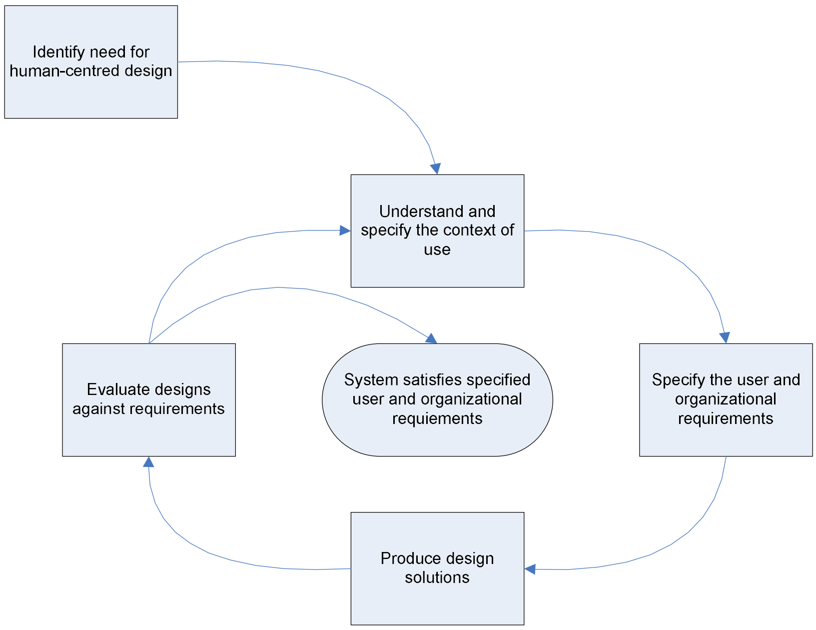


Figure 16 - Human-centred Actions according to (ISO9241-210, 2019)

Considering the end-users, which are the focus of the application of HCD to the development of the LASH FIRE Stowage Planning Tool (SPT), the aim is to enhance the overview of the critical situation of having a fire onboard a ro-ro ship. This is partly achieved through integration of information, expectedly leading to reduced cognitive load and improved situation awareness (Endsley, Bolté, & Jones, 2003); indeed, designing for situational awareness is seen as one possible approach to HCD. Irrespectively, ISO 9241-210 (2019) is considered to be the most recent formalization of a substantial amount of usability-related work undertaken in the last three decades, notably including the original thinking of distinguished human factors writers like Norman (1988) and Nielsen (1993, 1994), and could be seen as design-methods agnostic framework, supplementing other practices, existing or novel by explicitly including or requiring that

a. The design is based upon an explicit understanding of users, tasks and environments;
b. Users are involved throughout design and development;
c. The design is driven and refined by user-centred evaluation;
d. The process is iterative;
e. The design addresses the whole user experience;
f. The design team includes multi-disciplinary skills and perspectives.’ (ISO9241-210, 2019, p. 5).

Each of the above key points of HCD are further elaborated and explained in the standard mentioned, to which reference is made, as well as in numerous publications, journal papers and books.

Common to the practice of HCD is to iteratively cycle through four activities, until the required usability objective is achieved:

- Understand and specify the context-of-use;
- Specify the user requirements;
- Produce design solutions;
- Evaluate

5.1.1.1 Context-of-use

The context-of-use relates to the characteristics of the users of a system and the tasks they are going to perform with usage and/or support of the system. Furthermore, the context-of-use includes the environment in which they work – environment to be understood widely, covering not only physical aspects and locations, but also, where relevant, the organizational and technical aspects of the work situation. In the present case the SPT context-of-use is that of cargo stowage and operations, and spans from work undertaken in an office-like environment (the shore-based stowage planner), via driving tasks (the tractor/tug-master driver(s)) to work and supervision tasks on the ro-ro decks (the deck crew and the cargo/loading officer) and in the wheelhouse of the ship (the bridge officer).

5.1.1.2 User and Organizational Requirements

Identification and description of user and organizational requirements do not differ fundamentally between other established design practices and HCD; however, in HCD it is expected that user needs and user requirements shall be made explicit in relation to the context-of-use. In the present case, this is done by examining 14 defined use cases, in which specific forms of system use are driving the definition of requirements beyond the generic, system-wide user requirements.

5.1.1.3 Design

In HCD, it is a particular defining character that users are to be involved in the multidisciplinary design process throughout the product development phase, contributing their expertise and knowledge, and thus guiding the design towards a usable goal. Iterating and evolving a design in this fashion moreover reduces the risk associated with the design and development of a novel product, since the end-user acceptance is much more likely – in other words, the risk of developing a product which turns out to address a non-existent market need, or which is deemed unusable by the market, is to a significant extent mitigated through HCD.

5.1.1.4 Evaluation & Testing

Product and/or design evaluation by end-users is another defining characteristic in HCD. In the present case, user testing should be undertaken in parallel with the requirements' compliance methods also specified in this document.

5.1.2 Test Methods

Inspired by the methodology adopted by IEC 62288 (IEC, 2008), which governs navigational displays to be used on ship bridges, each requirement in the following includes the test methods that shall be applied during the evaluation of the finished design. However, in addition to the IEC-like inspection methods, iterative testing with users is also required.

5.2 Context-of-Use

For the SPT, the context-of-use consists of the description of users in terms of duties, skills and background, the functions they will be performing with the tool and the characteristics of the physical location where they interact with the tool.

To further synthesize knowledge generated earlier in the LASH FIRE project, D08.3 related to and formulated 26 requirements which are seen as a subset of the visualization requirements for the SPT. All of these requirements are repeated below, keeping the original numbering for consistency (*in italics, see* below). Out of the 26 D08.3 requirements, 21 are directly mapped to the use-cases described

Two of the remaining requirements in D08.3:

- *D08.3 #19: The system shall be an interactive system.*

- *D08.3 #25: The software must show different screens/functions depending on the user who uses it.*

are seen as direct expressions of the need to consider the information needs of individual contexts-of-use, which is performed through the application of HCD, and which is documented in the present deliverable. The finally three remaining are not immediately relevant from a visualization perspective, but are seen as more relevant to implementation:

- *D08.3 #21: The system shall be capable of running on mobile devices, adapting its visualization and navigability accordingly.*
- *D08.3 #23: The system must include an incident log.*
- *D08.3 #26: When loading a new load configuration, any previously loaded configuration shall be stored in the log, informing the user beforehand.*

A complete enumeration of the use-cases and their description, together with a high-level description of the end users can be found in ANNEX B Context-of-use.

5.3 Visualization Requirements

5.3.1 High-level Visualization Support/Guideline

To support the visual design of the SPT, a number of design studies of increasing fidelity have been undertaken and shared with the relevant LASH FIRE partners, partly to inspire those who eventually will have to make the final design and implementation, partly to communicate good design practices in terms of sketching/developing iteratively, and partly to serve as a visual guideline/style guide for the tool.

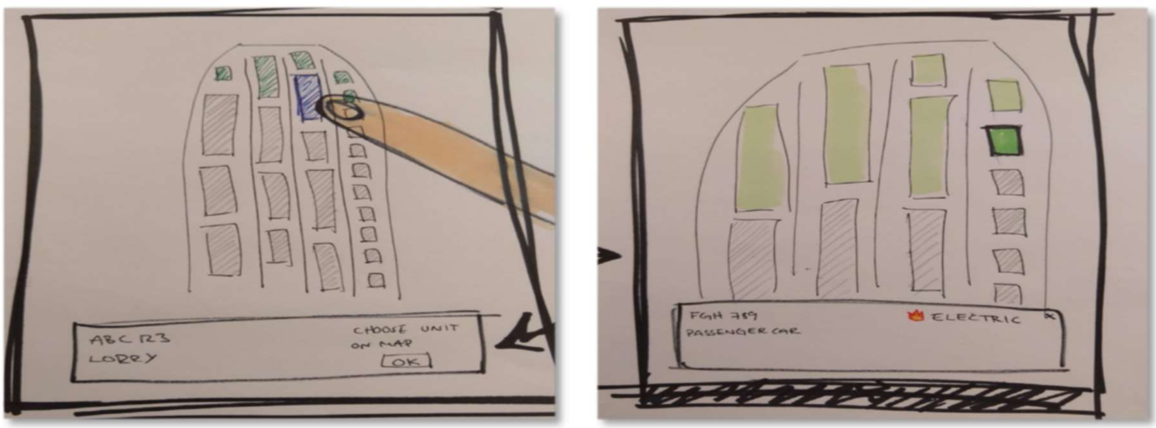


Figure 17 - Early design study of placing loads on the deck as well as status indication

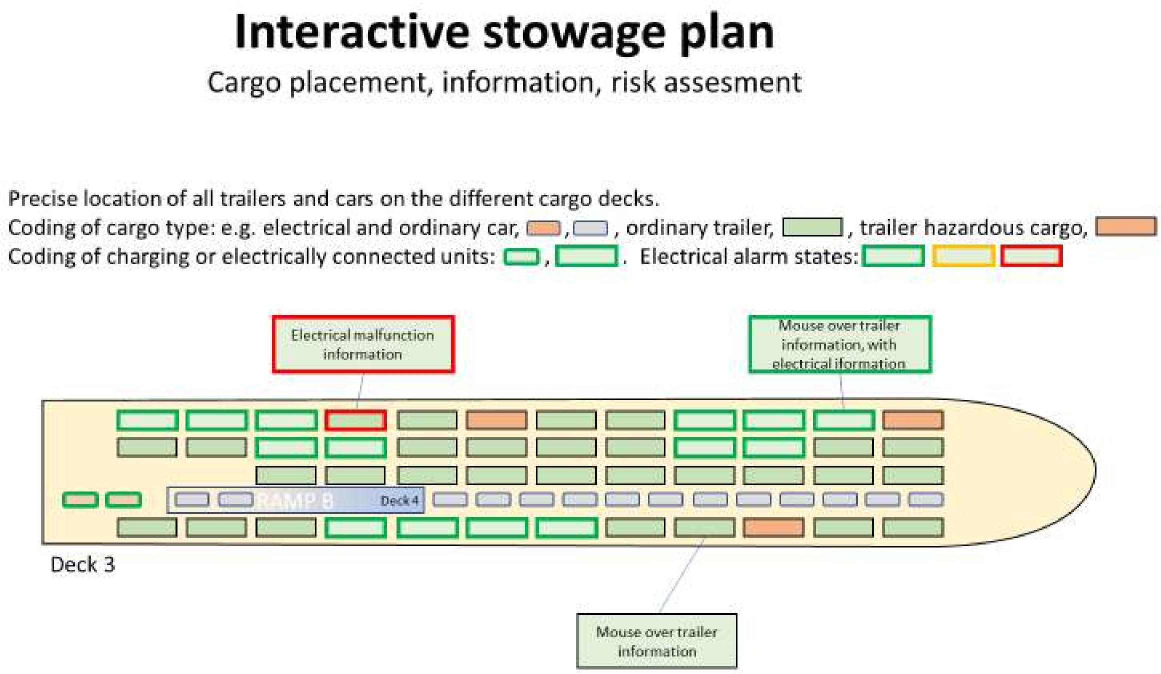
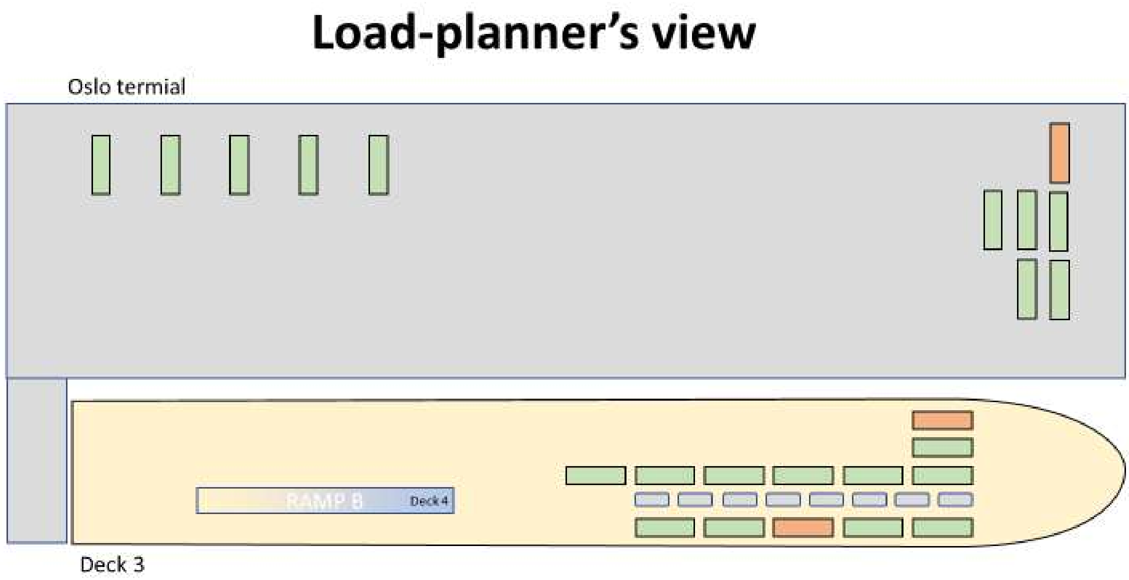


Figure 18 – Overall interaction principles/guideline to indicate cargo types and to extract cargo information by hovering/selecting cargo units



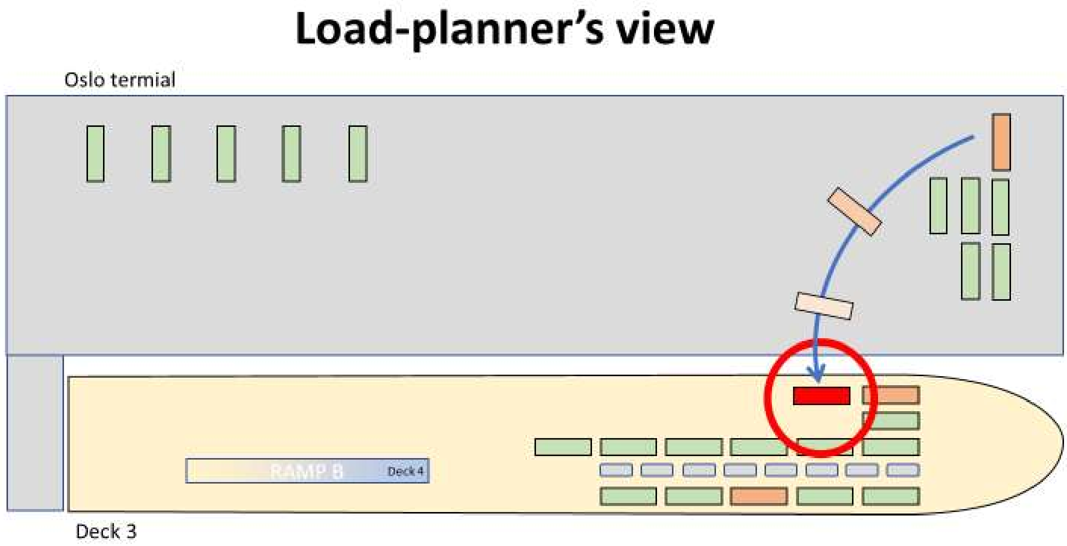


Figure 19 - Considerations relating to stowage planning, placing cargo units on the ship from a pool of cargo booked for the voyage – see also Figure 17.

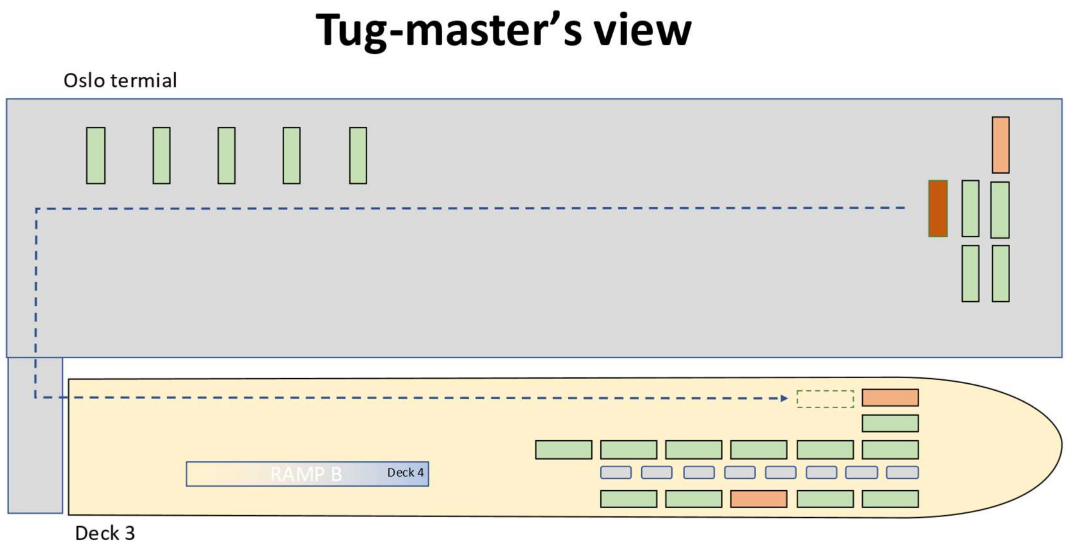


Figure 20 - Considerations of visualizing loading sequences for tug-masters – such representations could be 2D or 3D

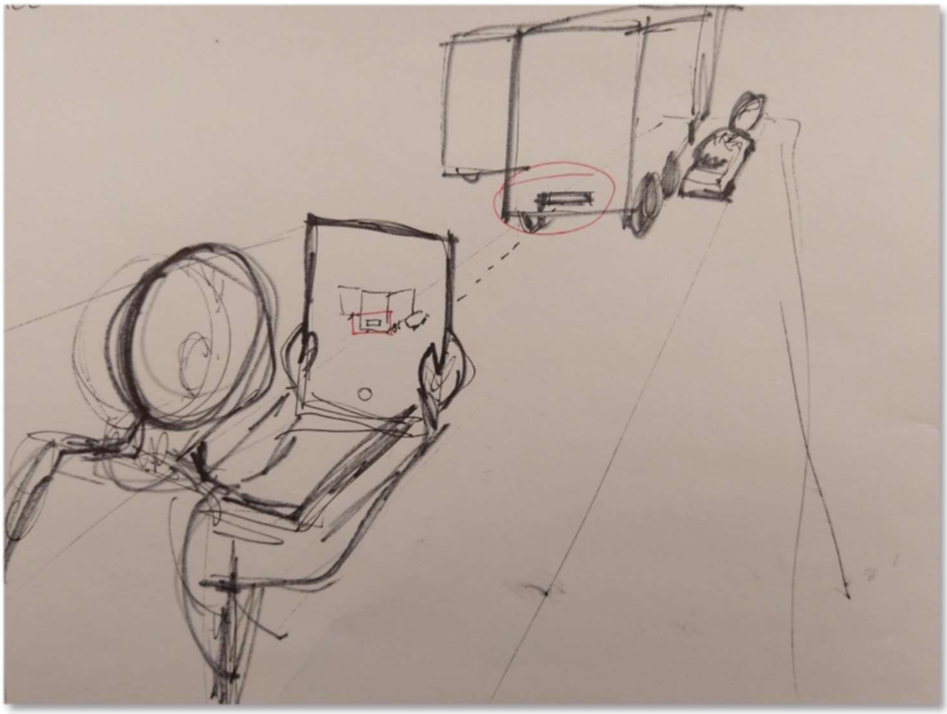


Figure 21 - Early considerations relating to the validation of cargo stowed onboard (manual process using a handheld device)

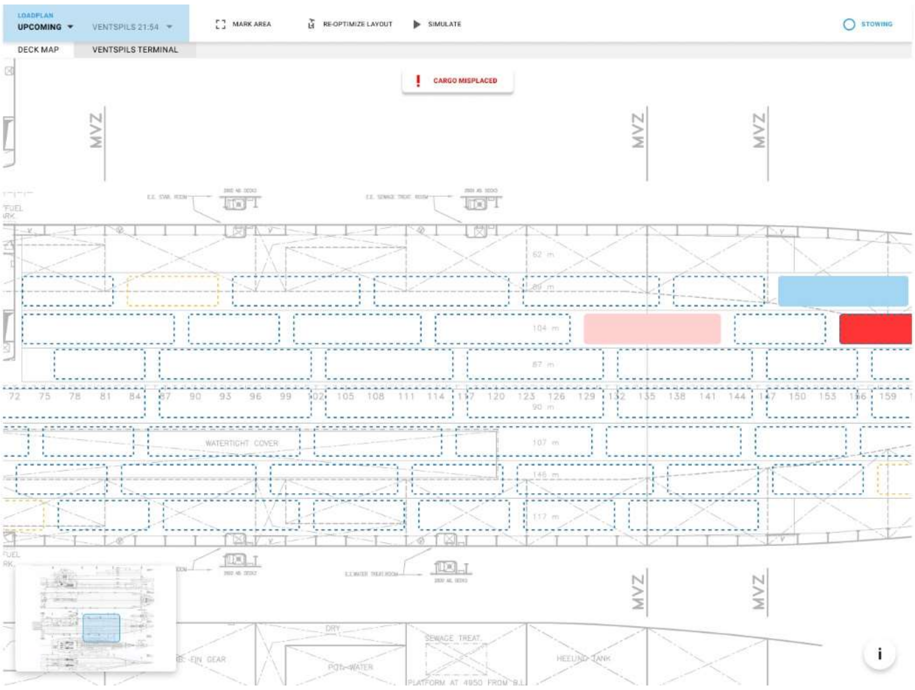


Figure 22 - Considerations regarding mis-placed cargo (automated process) - higher fidelity

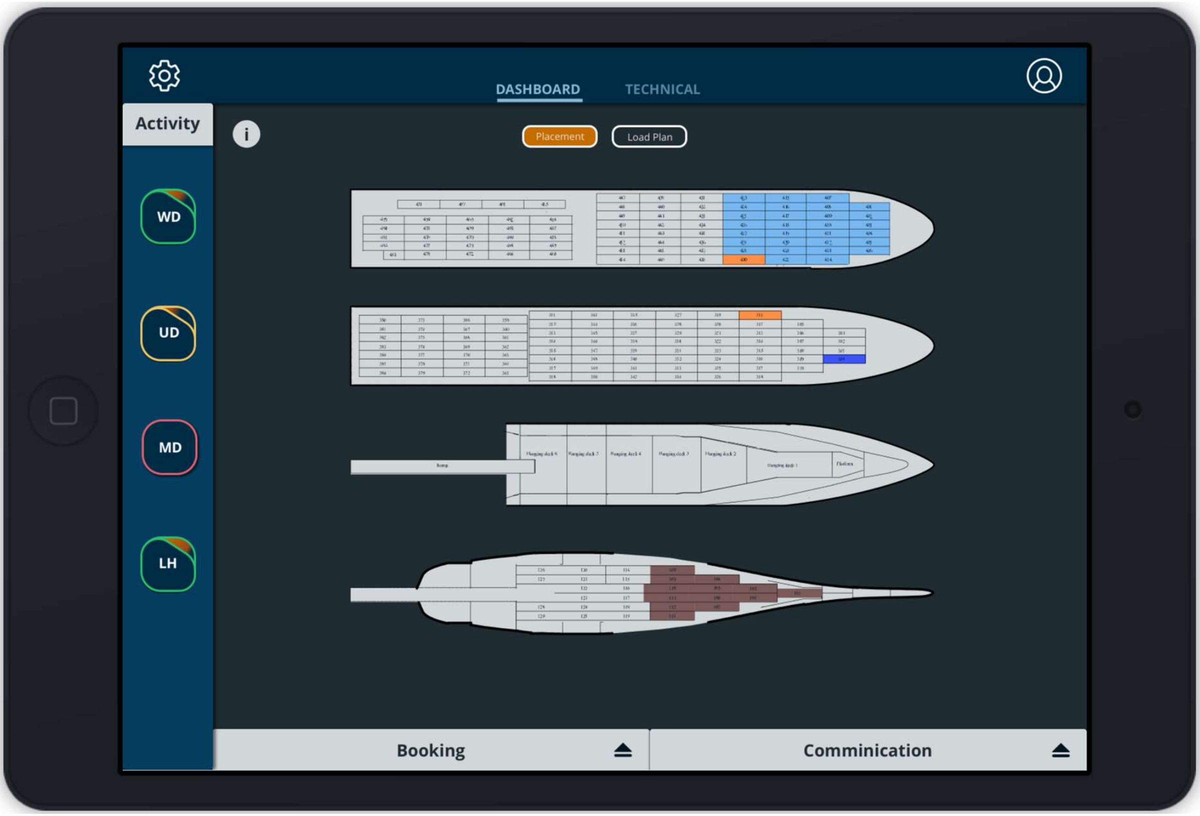


Figure 23 - LASH FIRE SPT Clickable demo, developed to support a future real implementation of the SPT

The LASH FIRE SPT Clickable demonstrator can be found at https://projects.invisionapp.com/share/THHNGHCGJZC#/screens/292891686

5.3.2 Generic Visualization Requirements

It is the nature, and indeed the aim, of an iterative development method like HCD that the understanding of the system being developed will evolve during the process, from an initial, sketchy level to the product release candidate. This also means that at each iteration, based on testing and evaluation with users, new requirements will emerge, and existing requirements either may change, or may be deemed obsolete. In way of maturity, the present internal report is early in the development cycles but is believed to have moved beyond the very first levels, being the result of foregoing analysis and consultations with the LASH FIRE partners DFDS and Stena, representing the target end-users. However, it is to be expected that the continued development will result in significant changes to the requirements to the SPT visual system stated in §1 - §83.

This section will list the requirements that are universal to the Stowage Planning Tool independently of the individual use cases, or overlapping use cases.

§1. The STP visualization shall be designed in conformance to ISO 9241-210. Confirm this by inspection of documented evidence.

Guidance: Attention should be given to the implicit requirement of end-user involvement in the design, as well as frequent testing/assessment by end-users.

§2. The STP visualization shall continue to follow the design language depicted in Figure 17 - Figure 23, and should not deviate from the current implementation (see D08.3 for fuller information) unless this is demonstrated to be non-conformant to one or more requirements mentioned in this internal report. Confirm this by analytical evaluation.

§3. The STP visualization shall be designed to support the different scenarios and contexts-of-use. Confirm this by analytical evaluation.

Guidance: This requirement is in line with the D08.3 requirements #25 (*The software must show different screens/functions depending on the user who uses it)* and, implicitly, with #21 (*The system shall be capable of running on mobile devices, adapting its visualization and navigability accordingly)*. It is recommended to give special attention to light conditions ranging from dark night to bright day, including electrical lights, as well as the freedom of movement and usage of hands during usage of the tool. It is also recommended to use a high-contrast colour scheme, and to have at least two colour schemes suitable for day and night operation, respectively.

§4. The SPT visualization shall be designed in accordance with recognized usability heuristics. Confirm this by analytical evaluation.

Guidance: Table 32 lists 12 main usability heuristics, that should guide the detailed design of the SPT HMI. Reference is made to the underlying literature in case points should be clarified or elaborated.

	MSC.191(79) (IMO, 2004)	Nielsen (Nielsen, 1994)	Shneiderman (Shneiderman & Plaisant, 2005, pp. 74-75)
1	Consistency of information and operations	Consistency and standards Match between system and real world	Strive for consistency
2	Preference to information based on importance	Aesthetic and minimalist design Recognition rather than recall	Reduce short-term memory load
3	Logical grouping of information	Match between system and real world Recognition rather than recall	Reduce short term memory load
4	Clarity of language	Match between system and real world	
5	Readability of information	Aesthetic and minimalist design	
6	Intuitiveness of interaction	Match between system and real world Flexibility and ease of use	Cater to universal usability (novices and experts)
7		Visibility of system status (feedback)	Offer informative feedback
8			Design dialogues to yield closure
9		Error prevention	Prevent errors
10		Help users recognize, diagnose and recover from errors	Permit easy reversal of actions
11		User control and freedom	Support internal locus of control
12		Help and documentation	

Table 32 - Overview of Usability Heuristics/Recommended design principles (from (Petersen, Porathe, & Lützhöft, 2011)

§5. The visualization system shall be designed for learning-by-exploration by an end-user.

Guidance: Exploration is best supported by providing options to cancel operations as well as stepping backwards in the interaction, both to previous dialogues, and to dialogues higher in the interaction hierarchy.

§6. The stowage planner HMI shall support operation by touch as well as by mouse or other pointing devices. Confirm this by inspection of documented evidence.

Guidance: This requirement is in line with D08.3 #19 (*The system shall be an interactive system)*. When selecting actual technological solutions, it is recommended to consider the usage of gloves, as well as operation under damp/wet conditions, which may hinder or disable touch operation.

5.3.3 Use-case Specific Visualization Requirements

5.3.3.1 UC1: Evaluate stowage plan fire safety

This use case relates to the situation where either the shore-based stowage planner or the cargo/loading officer wishes to evaluate the overall risk level of a particular stowage plan, irrespectively of whether it is originating a) from an external system or b) from within the SPT itself, and irrespectively of whether it is c) prospective or d) carried out.

§7. The visual system shall provide the means/dialogue of importing and managing (store/load/delete) stowage plan from an external system. Confirm this by inspection of documented evidence.

§8. The visual system shall provide the means of creating and managing (store/load/delete) a stowage plan from a pool of cargo units booked on a particular trip (see also Figure 19). Confirm this by inspection of documented evidence.

§9. The visual system shall provide the means/dialogue to manage the fire safety evaluation (start/stop/cancel). Confirm this by inspection of documented evidence.

§10. D08.3 #7: The system shall provide the user with the visualization of the risk level of cargo located on each deck. Confirm this by observation.

§11. D08.3 #8: The system shall provide the user with the visualization of the overall risk level of the ship's cargo. Confirm this by observation.

§12. D08.3 #12: The system shall offer the user the possibility to display deck plans of all the predefined ships[1]. Confirm this by observation.

§13. D08.3 #13: The system shall offer the user the possibility to visualize the voyage history of a given ship[2]. Confirm this by observation.

§14. D08.3 #18: The system shall visually identify dangerous goods from other non-dangerous goods by colour coding. Confirm this by inspection of documented evidence.

5.3.3.2 UC2: Optimize stowage plan

This use case relates to the situation where either the shore-based stowage planner or the cargo/loading officer wishes to optimize a stowage plan which is already loaded into the SPT, taking full account of stowage constraints including but not limited to those given by the individual cargo unit, the layout of the ship, and/or the loading/discharging order.

§15. The visual system shall provide the means/dialogue to manage the optimization process (start/cancel). Confirm this by observation.

§16. The system shall indicate optimization progress if the duration exceeds 1 second. Confirm this by observation.

§17. Once optimization is completed, the visual system shall provide a graphical overview indicating the changes to cargo unit positions undertaken. Dialogue/means to accept/reject all the changes shall be provided. Confirm this by observation.

§18. It shall be possible to accept/or reject suggested changes to cargo unit location unit-by-unit. Confirm this by observation.

[1] This requirement is only relevant to the shore-based stowage planner, and does not need to be supported for the cargo/loading officer

[2] See footnote 1.

§19. Once the operator has decided on all changes, it shall be possible to manage (store/delete) the changed stowage plan, the revision of which shall be logged and be clearly visible to the operator. Confirm this by observation.

§20. Cargo units already loaded onboard shall not be subject to optimization. Confirm this by inspection of documented evidence.

§21. Deck areas exempt from usage on a particular voyage (see UC4) shall not be taken into account during optimization. Confirm this by inspection of documented evidence.

5.3.3.3 UC3: Confirmation of cargo unit location

Relevant to the deck crew and the tractor/tug-master(s), and being a logical sequence to UC8, this use case relates to confirming the position on the cargo deck where a cargo unit is stowed for an upcoming voyage. Requirements are split into three sets, depending on whether the cargo unit in question is self-propelled or not. In the latter case, the tractor/tug-master is the user who will report/confirm the cargo unit position, and thus update the SPT system with information; in the former, the same function will be fulfilled by the deck crew.

Generic requirements

§22. D08.3 #3: The system shall offer the user the possibility to confirm the location of a loading unit on a parking slot of a deck. Confirm this by observation.

§23. The system shall provide a menu/dialogue to indicate if a cargo unit has been connected to an onboard electrical connection. The connection ID shall be part of the menu/dialogue. Confirm this by observation.

§24. On passing the VHD (see UC10), an indication shall be given to the vehicle driver that it is safe to proceed loading. Confirm this by observation.

Specific requirements when cargo units are self-propelled

Self-propelled cargo units will be driven onboard by the truck-driver, or, in the case of cars and vans, by the owner/driver. Such cargo units will not have facilities to interact with the SPT, for which reason their parking positions must be recorded by the deck crew in order to provided up-to-date information for loading monitoring (UC5). The assumption is that they will use a hand-held device for this purpose, see Figure 21 for an early-stage impression/example of this process.

§25. D08.3 #21: The system shall be capable of running on mobile devices, adapting its visualization and navigability accordingly. Confirm this by observation.

§26. The visual system shall provide a facility/dialogue to enter cargo unit ID together with cargo unit position. Confirm this by observation.

§27. The visual system may use picture recognition to enter cargo unit ID. No testing of this requirement is needed.

§28. The visual system may use AI tools/software to detect the cargo unit stowage position. No testing of this requirement is needed.

Specific requirements for non-self-propelled cargo units

Loading of non-self-propelled cargo units is undertaken by tractors/tug-master's picking up the correct cargo unit at a designated parking spot in the terminal, and, having passed the VHD (Vehicle Hot Spot Detector) (see UC10) without any problem being detected, proceeds onboard the ship, to park the cargo unit in the parking position allocated by the SPT.

§29. D08.3 #11: The system shall provide the user with an incident table if the load cannot be located where expected. Confirm this by inspection of documented evidence.

§30. Upon commencement of operations, the tractor/tug-master shall issue a 'ready-for-loading' command through a dialogue/facility in the visual system. Confirm this by observation.

§31. The tractor/tug-master visual interface to the SPT shall indicate the ID and the pick-up position of the cargo unit to be loaded (automatically retrieved from the process described in UC8). Confirm this by inspection of documented evidence.

Guidance: In case all cargo units have been loaded and an 'End-of-Loading' status has been set by UC8, loading will continue uninterrupted from a systems perspective.

§32. The tractor/tug-master visual interface to the SPT shall provide a facility/dialogue to enter the ID of a unit being picked up, prior to driving towards the VHD. This function may require a manual action by the driver, or it may use be an automated function using picture recognition. Confirm this by inspection of documented evidence.

§33. Once the ID of the cargo unit being picked up has been entered into the SPT, the visual system shall indicate that the cargo unit ID has been validated to be the correct unit to load. Confirm this by inspection of documented evidence.

§34. Upon entering the ship, the visual system shall indicate the path/route to the correct parking position designated by the SPT. Confirm this by inspection of documented evidence.

§35. When the cargo unit has been placed in the correct parking position, the visual system shall provide a facility for the tractor/tug-master driver to report the 'end-of-loading' of the particular cargo unit, thus providing updated information to monitor deck loading status, see UC5. Confirm this by inspection of documented evidence.

§36. The visual system should automatically revert to §31 once the tractor/tug-master has issued the 'end-of-loading' command described in §35 and a 'ready-to-next-load' command to initiate a new loading cycle. Confirm by observation that the SPT contains facilities/dialogues for both purposes.

§37. If the cargo unit has been loaded incorrectly, the visual system shall provide a warning to the tractor/tug-master driver as well as to the cargo/loading officer SPT visual system. Confirm this by confirmation of documented evidence.

§38. In case of a cargo unit being positioned in an incorrect stowage position, UC10 shall be invoked to manage deck space. This shall be indicated on the cargo/loading officer SPT visual system. Confirm this by documented evidence.

Guidance: During unloading, the loading process is reversed. Tractors/tug-master's pick up the correct cargo unit in the designated parking position and proceeds off ship to park the cargo unit in a designated parking position in the terminal. In terms of requirements to the unloading process, §22 - §38 apply as well, however without considering input from the VHD.

5.3.3.4 UC4: Disable area for loading

This use case is relevant to voyage-specific requirements necessitating that certain deck areas cannot be utilized for stowage, the end users involved being the shore-based stowage planner and the cargo/loading officer.

§39. The visual system shall provide a facility/dialogue enabling that a designated deck area of rectangular or triangular shape is exempt from the stowage planning process. Confirm this by observation.

§40. The visual system shall support input to exempt a deck area to be given in global ship coordinates (deck number, distance from AP or frame number and distance from CL for two corner points). Confirm this by observation.

§41. The visual system shall support that a deck area is made exempt for a series of voyages (1-n) through the provision of voyage ID numbers. Confirm this by observation.

§42. The visual system shall support management (delete/change/store/load) of exempt deck areas. Confirm this by observation.

5.3.3.5 UC5: Monitoring of loading process

Relevant to the bridge officer and the cargo/loading officer, this use case relates to the continuous monitoring of loading and unloading status of the ship. The information to be provided includes a list of already loaded units with their corresponding up-to-date stowage position and status (data from UC3), raised alarm for each unit if an anomaly has been detected by the VHD as well as deviation from the stowage plan.

§43. D08.3 #4: The system shall always offer the visualization of the current status of the cargo unit. Confirm this by observation.

§44. D08.3 #5: The system shall offer the user the possibility to extract the current cargo manifest. Confirm this by inspection of documented evidence.

§45. D08.3 #6: The system shall offer the user the visualization of a unit load and its individual risk level. Confirm this by inspection of documented evidence

Guidance: The relevant data sets shall be made available to the SPT visual system from the Cargo Fire Hazard database.

§46. D08.3 #14: The system shall offer in real status the % of the loading process (Cargo currently confirmed and loaded on ship/total cargo to be loaded on ship), at deck and ship level. Confirm this by observation.

§47. D08.3 #20: The system shall allow marking of the unit load being loaded and unloaded. Confirm this by observation.

§48. D08.3 #22: The system must be able to display information of a cargo unit in such a way that all users can identify the cargo. The means to do this shall be through a pop-up/hovering mechanism, see Figure 18 for guidance. Confirm this feature by observation.

5.3.3.6 UC6: Stowage information supporting fire management

The primary users for this use case are the bridge officer (including the fire chief) and the cargo/loading officer, the purpose being to provide up-to-date information and fire-related recommendations which will support more effective and efficient firefighting.

§49. D08.3 #2: The system shall provide the user with fire-relevant information on the selected cargo unit. See also §48. Confirm this by observation.

§50. D08.3 #10: The system shall provide cargo location safety recommendations for each cargo unit. Confirm this by observation.

§51. D08.3 #24: The system shall allow searches within the loads. Confirm this by observation.

Guidance: This search shall provide options to search for a) Dangerous Goods codes, b) Cargo unit contents and c) cargo unit combustible load/risk level.

Guidance: See also UC13 for functionality and visual indication supporting this use case.

5.3.3.7 UC7: Validate distribution

This use case serves to provide input to/update the cargo distribution used in the Stowage Planning Tool in the cases where an external function/system is used to modify the stowage plan. Since the algorithm supporting fire hazard management in such cases operates as a plug-in, that is, the external software system calls this LASH FIRE component in order to score or modify a given cargo distribution, a mismatch can result in cases where the LASH FIRE component performs optimization. By invoking UC7, a user can ensure a match between the systems, also safeguarding that a consistent dataset is feed external calculations of ship stability as well as hull girder strength.

Guidance: From a logic perspective, this use case is a subset of UC11, and assumes that the 'End-of-loading' notification has been given.

§52. The SPT shall include means/dialogue to import a stowage plan from an external system, in the format native to the SPT. Confirm this by observation.

§53. The SPT shall provide feedback to the user about a) the status of importing a stowage plan, as well as b) a clear indication of success/failure to import. Confirm this by analytical evaluation.

§54. When using an external system to generate an initial stowage plan (§52), the SPT shall notify/warn the user if a change in the original cargo distribution has been performed, either due to fire risk optimization, or due to cargo being misplaced on the ro-ro deck (see §37). Confirm this by inspection of documented evidence.

§55. The SPT shall include means/dialogue to export a stowage plan to an external system, in the format native to the SPT. Confirm this by observation.

§56. The SPT shall provide feedback to the user about a) the status of exporting a stowage plan, as well as b) a clear indication of success/failure to export. Confirm this by analytical evaluation.

5.3.3.8 UC8: Get location for unit

Relevant for the deck crew, the cargo/loading officer and the tractor/tug-masters, the purpose of this use case is to query the SPT validated stowage plan to retrieve the sequence/loading order for cargo units, as well as the terminal parking position for the unit in question. Alternatively, in case of unloading, this function shall provide information about the sequence/unloading order for onboard cargo units, as well as providing the terminal stowage position to which cargo units are to be directed. All these functions are without direct user interfaces, since the visualization of relevant information is covered by the requirements in UC3.

UC8 is also relevant for the terminal gate keeper, who will use the information to direct incoming self-propelled units to their designated terminal parking prior to loading, as well as incoming self-propelled units to the pick-up spots for outgoing cargo.

§57. D08.3 #1: The system will provide the user with information on the selected load unit. Confirm this by observation.

§58. For incoming self-propelled cargo units, the SPT visual system shall provide facilities/dialogues to validate/match booking orders/reservations with the ID of the incoming cargo unit. Confirm this by observation.

§59. Once a booking has been confirmed, the SPT visual system shall provide the location of the designated parking spot to be used by the cargo unit. Confirm this by observation.

§60. The location of the designated parking spot shall be made available in a form suitable to handle to the driver of the self-propelled cargo unit and shall be unambiguous in way of showing the route from the terminal entrance/gate to the parking lot to be used. Confirm this by analytical evaluation.

Guidance: It is assumed that check-in data will be utilized by the SPT to keep the stowage plan for a particular voyage current. Once deviations from the bookings for a particular voyage are detected, it is moreover assumed that a rerun of the business logic generating stowage plans is performed. See also UC14.

5.3.3.9 UC10: Reject loading of unit

Relevant for the cargo/loading officer as well as the tractor/tug-masters (and drivers of self-propelled cargo units), cargo units will pass a sensor gate to detect heat anomalies (VHD), whether within the cargo unit (in case of a trailer) or relating to the vehicle system (engine, brakes, wheels, reefer unit if present). In case of temperatures being above a trigger level, a notification should be raised, and the cargo unit in question should be detained for further examination rather than being loaded onto the ship without inspection.

- §61. D08.3 #9: The system shall offer the user the possibility to visualize the information provided by external systems such as sensors and drones, for a cargo unit. Confirm this by observation.
- §62. In case of a cargo unit abnormal heat signature, an alert shall be shown on the cargo/loading officer SPT HMI. To be observed by observation.
- §63. In case of a cargo unit being detained for inspection due to an abnormal heat signature, the alert received by the SPT shall trigger UC14 to rearrange the stowage plan to match. To be confirmed by observation.
- §64. All running instances of the SPT cargo/loading officer HMI as well as all running instances of the tractor/tug-master visual system shall post an alert regarding rearrangement, for the acknowledgement of the individual operator(s). To be confirmed by observation.

Guidance: For the sake of this visualization requirement specification, it is assumed that the VHD will issue a digital alert to the SPT in cases of detecting abnormal heat signatures. It is moreover assumed that the VHD will include an external traffic-light device that will turn red (for stop/detainment) in such cases. These visualization features are not part of the scope for this document, which focuses solely on the visualization of the SPT features.

5.3.3.10 UC11: End of loading/discharging

This use-case notifies the overall end of the stowage process for a particular voyage and informs all the stakeholders actively involved in loading (or discharging) that operations are completed (deck crew, cargo/loading officer, tractor/tug-master and bridge officer). From a business logic perspective, the full information for each cargo unit is generated, is being merged with the last loading status and additional data from risk assessment and the VHD, to provide a complete, consolidated and up-to-date stowage plan and cargo manifest. Upon completion, the final stowage plan is transferred digitally to the Digital Fire Central, see also §79. The functionality of this use case results in the following visualization requirements:

- §65. On the visual system of the cargo/loading officer, the SPT shall provide functionality/dialogues to issue the overall 'End-of-loading' status message. Confirm this by observation.
- §66. On all other running instances of the visual system (tractors/tug-masters, deck crew, bridge officer) the 'End-of-loading' should be posted, requiring acknowledgement. Confirm this by observation.
- §67. Issuing of the 'End-of-loading' notification by the cargo/loading officer shall trigger the necessary business logic processes and shall provide visual feedback that these processes are a) running and b) completed. Confirm this by observation.
- §68. Internal errors in the business logic process layer shall provide a visual warning/alert to the cargo/loading officer, to be acknowledged. Confirm this by observation.

§69. If required by operations, the issuing of the 'End-of-loading' notification shall initiate the digital transfer of the final stowage plan to subsystems for stability calculation and hull girder strength calculation. The SPT visual interface shall provide feedback of this/these processes a) running and b) completed. To be confirmed by observation.

5.3.3.11 UC12: Cargo unit feedback

UC12 is relevant to the tractor/tug-master as well as the cargo/loading officer, the intent being to be able to record observations made with respect to a particular cargo unit. At the systems level, such observations are to be propagated to all running instances of the SPT.

§70. D08.3 #15: The system shall offer users the possibility to do manual annotations on each loading unit. Confirm this by observation.

§71. D08.3 #16: The system shall provide users with the possibility to do manual annotations on each deck. Confirm this by observation.

§72. D08.3 #17: The system shall provide users with the ability to do manual annotations on the overall ship's view. Confirm this by observation.

§73. Once a user makes a manual annotation regarding a) a specific cargo unit, b) a ro-ro deck/space and c) the ship/voyage, this shall be announced on all running instances of the SPT. Confirm this by observation.

§74. The system shall support editing of information by the originator only. Confirm this by observation.

§75. Any note shall be visually indicated on the unit/deck/ship they relate to, using an unambiguous symbol. Confirm this by analytical evaluation.

§76. Two different indicators shall be used for marking annotation indicators, showing a) an unread annotation and b) a read annotation. Confirm this by observation.

Guidance: This requirement calls for symbology similar to the practice in many systems, e.g. email, where a closed envelope symbol is used for unread messages, and an open envelope indicated that a message has already been read by the user.

§77. The annotation indicators shall persist until the condition under which they were made becomes irrelevant. Confirm this by observation.

Guidance: Annotation symbols shall persist until the cargo unit they belong to has left the destination terminal, or, in the case of decks or the entire ship, a voyage has been completed and the entire cargo unit load has been discharged.

§78. The visual system shall support displaying an entire list of currently active annotations. Confirm this by observation.

Guidance: At the systems level, facilities should be provided which will save annotations together with other relevant information, to be used for post-voyage claim handling.

5.3.3.12 UC13: Fire Patrol Report

The target user being the bridge officer (and thus including the fire chief), this use case will generate the data needed by an external system to prepare a specific report for fire patrol purposes, containing fire safety recommendations based on the final cargo distribution at/after departure.

§79. Concurrent with cargo monitoring updates, the SPT shall continuously export fire-related cargo information to the Digital Fire Central, see also §49-§50. Updates performed shall be visibly indicated in all running instances of the SPT visual system using unambiguous symbols. Confirm this by analytical evaluation.

§80. Failure in digital data transfer shall result in a warning on the bridge officer and cargo/loading officer SPT displays. Confirm this by observation.

Guidance: UC13 provides functionality described/assumed in UC6.

5.3.3.13 UC14: No-show/rearrange cargo

Relating to UC10, the primary purpose of this use case is to manage on-the-fly changes to the SPT caused by no-show cargo units (UC8), by cargo units which are detained for inspection due to anomalies detected by the VHD (UC10) as well as errors in the execution of the final stowage plan (UC3).

§81. Business logic status (Idle, Optimizing), including confirmation of stowage plan validity (Valid, Invalid), shall be unambiguously indicated on all running instances of the SPT visual system. Confirm this by analytical evaluation.

§82. For the shore-based stowage planner as well as for the cargo/loading officer, the SPT visual system shall provide facilities/dialogues for manual (forced) updating of the stowage plan. A manual (forced) update shall be indicated on all running instances using the symbols required by §81. Confirm this by observation.

§83. Reruns of the business logic shall ignore redistribution of cargo units already loaded onboard or having already been picked up/initiated their loading. During reruns, the status of these units shall be clearly indicated on the SPT visual system. Confirm this by analytical observation.

5.4 Usability Inspection & Test Methods

One of the most important aspects of Human-Centred Design is how a design – future product – is evolved, refined, amended and corrected through continuous user feedback, obtained through inspection and testing with end-user representatives and human factors/usability experts. These actions inform the designers and the relevant management and technical staff as early in the process as possible, when the potentially negative side effects of new or altered requirements are few, and when suggestions to improved functionality or workflow are implementable at minimum cost and effort.

With respect to the LASH FIRE Stowage Planning Tool, three inspection methods and one user test method are specified, and for each requirement (§1 - §83) in section 5.3.2, it is detailed which of the three inspection methods the design shall pass. However, and while it is specified that end-users are also participating in 'observation' and 'analytical evaluation', suitable testing with representative end users shall be performed as part of the iterative HCD cycle, see section 5.4.4 below.

5.4.1 Observation

The below text is a slightly edited version of the IEC 62288 (IEC, 2008) description of the 'observation' inspection method, to which credit is given. Editing is undertaken to make the clause relevant to the inspection of the LASH FIRE SPT.

> *The test method "observation" refers to simple examination of the presentation of information to confirm that a particular observable condition has been met. The phrase "confirm by observation" is used.*
>
> *Observations shall be made by a person with the necessary skill to understand the presentation of information to determine if a statement concerning an observable property has been correctly applied. It is used when suitably trained individuals with a broad range of education and/or*

experience can be confidently expected to reach the same conclusion about a property of presented information or the performance of display equipment.

Compliance is determined by comparing the observed property to the requirement. Some observations may be made directly from the presentation. Other observations may require simulation of input from sensors or other sources. Typical confirmations by observation include:

- *existence of functions or features;*
- *use of symbols or a defined range of words;*
- *a system output in response to a defined input.*

Guidance: care should be exercised when selecting personnel to perform observations; ideally, such persons should have a background similar to the typical end-user background. Reference is made to the description of users in section 11.2.1

5.4.2 Inspection of documented evidence

The below text is a slightly edited version of the IEC 62288 (IEC, 2008) description of the 'inspection of documented evidence' inspection method, to which credit is given. Editing is undertaken to make the clause relevant to the inspection of the LASH FIRE SPT.

The test method "inspection of documented evidence" refers to examination of relevant documents to confirm that a particular presentation or display requirement has been met. The phrase "confirm by inspection of documented evidence" is used.

Documented evidence may include manuals, system requirements, design justification, industry conventions, etc. Inspections shall be made by a suitably qualified person who has the necessary education, skill and/or experience to apply the documentation to the system's presentation or display equipment. It is used when performance of a system's presentation or display equipment is not directly observable or measurable. It may also be used when observation would be excessively repetitious, time consuming, or expensive.

Compliance is determined by comparing the documented property to the requirement. Typical confirmations by inspection of documented evidence include:

- *conformance to a standard or other documented evidence;*
- *existence of optional features or functions;*
- *design and/or operation of algorithms.*

5.4.3 Analytical evaluation

The below text is a slightly edited version of the IEC 62288 (IEC, 2008) description of the 'analytical evaluation' inspection method, to which credit is given. Editing is undertaken to make the clause relevant to the inspection of the LASH FIRE SPT.

The test method "analytical evaluation" refers to detailed examination of the presentation of information to confirm that a particular condition has been met. The phrase "confirm by analytical evaluation" is used.

Analytical evaluations shall be made by a relevant expert with the necessary education, skills and/or experience to make an informed and reliable judgement concerning the presentation of information, its appropriateness and usability. It is used for the evaluation of properties which can be judged only in the context of other information or knowledge which requires the tester to make an informed assessment of the likely performance of a typical user of the presentation.

Compliance is determined by comparing the observed property to the requirement. Typical confirmations by analytical evaluation include:

- *the largest amount of information that can be presented to a user on a single display;*
- *the smallest difference in size, colour or line thickness that will be distinguished by a user on a particular display;*
- *consistency and clarity in presentation of information.*

Guidance: Especially in the case of 'analytical evaluation', care should be exercised when selecting personnel to perform the evaluation; ideally, such persons should have a background similar to the typical end-user background, but as a rule, persons undertaking analytical evaluation should also have formal qualifications and practical experience in maritime human factors, maritime usability and visualization design.

5.4.4 User testing

In HCD, user testing is a cornerstone, providing the development staff with input about needed design changes and other remedial actions. Stanton, Salmon, Walker, Baber & Jenkins (2005) describe user testing – or user trials – as 'a simplistic and flexible means of evaluating a new product or design' (p. 475), and moving on from their opening remarks, they state that 'User trials are perhaps most appalling as they provide an indication of how the end users will use the operational product or device'. To support practitioners, these authors also includes a short recipe for conducting user trials (pp. 475-477), something, however, which other authors like Dumas & Redish (1999) spends an entire volume on. In terms of practical application, this indicates not only that one should expect a learning curve associated with conducting user tests and utilizing the results arising from testing, but also that a detailed, declarative section on the subject is beyond the scope of the present document.

However, in the case of the SPT development in the LASH FIRE project and in slightly more concrete terms, it is recommended that test scenarios matching each of the use cases are prepared, and that testing is undertaken at three design stages:

- Initial (sketches of new functions, outline of workflow and functions),
- Medium-fidelity (when basic software functionality permits operation of the most important functions) and
- Prototype-fidelity, which should coincide with the demonstrations planned for the SPT late summer/early autumn 2022.

6 Implementation details

Main author of the chapter: Francisco Rodero, CIM

The software has been developed using the framework composed of *Visual Studio Code 1.76.2, Python 3.10.4,* as programming language, and *Sqlite* as database management system, on a 64bits platform with *Windows 10 Pro 22H2 (19045.2728)*. From the hardware perspective, the equipment used was a *Dell Precision Tower 3420* with 16 Gigabytes of memory and one *Intel Xeon E3-1270 v6 @ 3.8Ghz* processor.

The next table includes a description of the folders and files that compose the software:

Table 33. Folders and files of the software development

Path	File name	Description
/	clean.bat	Batch file to clean cached bytecode generated by the *Python* interpreter
/	lashfire_spt.py	Main entry point of the software. After checking that there are no errors during the initialization of required modules, it forwards the thread to the specific implementation of the requested service.
/api	api.py	Application programming interface that allows the software to be executed remotely by the visual interface component. The API file is using a *Python Virtual Environment* where *Flask* is running and used to attend the remote requests.
/cfg	__init__.py	Special *Python* file that marks the folder as a *Python* package (configuration package), meaning that it contains code that is able to be imported by other parts of the code. It acts, essentially, as the constructor of the package, that is, it can also contain specific code which is executed the first time the package is called by someone else. It basically checks the consistency of the configuration file by opening it using the *json* library and parsing the parameters while checking that required parameters are correct (for example, *Service* must be present and containing valid value or *Sep_X* is present and is a valid numerical value).
/cfg	parameters.json	File where configuration parameters are taken from when the software requires them. In case of attending a remote request, the API is in charge of creating this file using the parameters of the remote call.
/db	__init__.py	Database package. It just checks that required databases are available and a connection can be made to them.
/db	lashfire_spt.sqlite	SQLITE file implementing the database defined in the Cargo Distribution Database annex.
/db	lashfire_ra.sqlite	SQLITE file implementing the database defined in the Risk Assessment Database annex.
/db	lashfire_spt_db.py	Implements functions that need access to lashfire_spt.sqlite database file: queries for selecting, inserting or updating, transactions and so on.

/db	lashfire_spt_db_ra.py	Implements functions that need access to lashfire_ra.sqlite database file: queries.
/error	__init__.py	Package for error management. It basically checks that the corresponding *json* file with error messages is available.
/error	messages.json	Messages for the defined errors.
/error	lashfire_spt_error.py	Implements all the functions that check the consistency of every single parameter that is used in the configuration file and also that the input file with the units to be processed only contains valid information.
/input	__init__.py	Package for management of the input file with information about the units. This is the folder where the software looks for the input file with the name *IMO_code*.csv where *IMO_code* is the one in the configuration parameters file and being an existing one in the database.
/misc	utils.py	Miscellaneous functions and global utilities.
/output		Specific folder where output files that are used by the API are written.
/testing	entrypoint.py	Entry point for the software when a service is considered a test.
/testing	spt_score.py	Specific implementation of the automatic validation of the results for the Score service.
/uc	entrypoint.py	Entry point for the software to forward a request to the specific implementation of a service (use case).
/uc	removeservice.py	Specific implementation for *RemoveService*
/uc	resetservice.py	Specific implementation for *ResetService*
/uc	score.py	Specific implementation for *Score*
/uc	distribution.py	Specific implementation for *Distribution*

The next sections include the most relevant tips concerning the development using parts of the code:

6.1 Cleaning of the development environment

A script is used to clean up the development environment by means of deleting cached files generated by the *Python* interpreter as well as compiled bytecode and output files:

```
del *.pyc /s
del .\output\*.txt
del .\output\last.out
rmdir cfg\__pycache__ /S /Q
rmdir db\__pycache__ /S /Q
rmdir error\__pycache__ /S /Q
rmdir input\__pycache__ /S /Q
rmdir misc\__pycache__ /S /Q
rmdir uc\__pycache__ /S /Q
```

6.2 Main entry point of the software

When the software is executed, all required modules are initialized in cascade by means of the corresponding import section:

```
import db.lashfire_spt_db as DB
import db.lashfire_spt_db_ra as DB_RA
import time
from error import ERROR
```

```
from cfg import CONFIG
from input import CARGOUNITS
from uc.entrypoint import selectService
And then, if no errors have been found in the configuration file, input file and required
error messages, then the service is executed, printing the time needed:
Crono = time.time()
if ((ERROR != None) and (CONFIG != None)):
    service = CONFIG["Parameters"]["Service"]
    if service in ServicesNeedingInputFile:
        if len(CARGOUNITS[1]) != 0:
            selectService()
    else:
        selectService()
else:
    print("DO NOT CONTINUE")
# End
DB.closeDB()
DB_RA.closeDB()
print("Execution finished in " + str(time.time() - crono) + " seconds")
```

6.3 Application programming interface

The visual interface communicates with the implementation of the core components using a lightweight RESTful API with *Flask* and the *Python* code. This kind of API allows to attend requests managed through the HTTP protocol being the information represented, in this case, using *JSON* (*JavaScript Object Notation*).

The API is just a *Python* script that imports some libraries and defines all web services available as follows:

```
from flask import Flask, request, jsonify
from json import dump
import subprocess
import os
from flask_cors import CORS

app = Flask(__name__)
CORS(app)

@app.route('/distribution', methods = ['GET'])
def distribution():

@app.route('/score', methods = ['GET'])
def score():
```

This way, the visual interface is a client of the web services published by the core components and interacts via the API using an HTTP request where the parameters are sent using a GET method:

```
http://XXX.YYY.ZZZ.TTT:5000/distribution?Ship=9259496&Layout=1&Route=1&SlotError=0.1&Sep_X=
6&Sep_Y=3&timeout=2000&Improvement=0.15
```

The previous example is calling the *distribution* web service with the required configuration parameters in the URL, which are parsed by the API using the get methods:

```
CONFIG = {}
CONFIG["Parameters"] = {}
CONFIG["Parameters"]["Service"] = "Distribution"
CONFIG["Parameters"]["Ship"] = request.args.get('Ship')
CONFIG["Parameters"]["Layout"] = int(request.args.get('Layout'))
CONFIG["Parameters"]["Route"] = int(request.args.get('Route'))
```

```
CONFIG["Parameters"]["SlotError"] = float(request.args.get('SlotError'))
```

If all parameters are valid, they are written to the *parameters.json* file using *json.dump* imported method, having as a result the expected file with the following contents:


```
{"Parameters": {"Service": "Distribution", "ServiceDescription": "Not provided", "Ship": "9259496", "Layout": 1, "Route": 1, "SlotError": 0.4, "Sep_X": 6.0, "Sep_Y": 3.0, "timeout": 2000, "Improvement": 0.15}}
```


Both client (visual interface) and server (API) have been implemented in a way that the client stores the input file with units in a specific URL which is used by the server to download the file in order to make both files available for the software before launching the implementation of the service:

```
subprocess.run(["curl", BASE_URL + CONFIG["Parameters"]["Ship"] + ".csv", "-o", INPUT_PATH + CONFIG["Parameters"]["Ship"] + ".csv"])
subprocess.run(["python3", LASHFIRE_SPT_SW, ">> " + OUTPUT_PATH + "out.txt"])
```

Once the core component has finished, meaning that the output has been written to a specific file, the API gets the result and formats it using the *Flask.jsonify* method to create the returned result to the request from the client:

```
out = open(OUTPUT_FILE, "r")
for line in out.readlines():
             parts = line.replace("\n", "").split(";")
             result[1][parts[0]]=[parts[1], parts[2], parts[3], parts[4], parts[5], parts[6], parts[7], parts[8], parts[9], parts[10], parts[11]]
out.close()
return jsonify(result)
```

6.4 Database management

Databases are implemented using SQLITE files. SQLITE is a database engine that can be embedded in an application as a library, providing database features using standard SQL interface while avoiding the need for the deployment of an additional database management system.

Connection to a database is made in a simple way, for example:

```
import sqlite3
lashfire_DB_path = "db/"
lashfire_spt_DB = lashfire_DB_path + "lashfire_spt.sqlite"
CONNDB = sqlite3.connect(lashfire_spt_DB)
```

The package *db*, as above-mentioned, implements as many functions needed by the software. The following sample shows how the score (RS0 or RS) values are consolidated in the database:

```
def setScore(units, rs_field, service_id):
    result = False
    CURSOR = CONNDB.cursor()
    if CURSOR != None:
        try:
            CONNDB.isolation_level = None
            CURSOR.execute("BEGIN TRANSACTION;")
            for u in units:
                query = "UPDATE SERVICE_UNITS SET "
                query+= rs_field + "=" + str(float(units[u]))
                query+= " WHERE id_cargo_unit='" + u
                  query+= "' AND id_service=" + str(service_id) + ";"
                CURSOR.execute(query)
            CURSOR.execute("COMMIT;")
            result = True
            #print("setScore::Transaction executed successfully!")
        except CONNDB.Error:
```

```
            print("setScore::Error executing transaction!")
            CURSOR.execute("ROLLBACK;")
    else:
        print("setScore::Error creating cursor!")
    return result
```

6.5 Error management

Messages for errors (and warnings) are classified in groups and defined using a *json* file. A sample part of code is as follows:

```
{
"E" :
{
              "0" :
              {
                            "1" : "Invalid Service value",
                            "2" : "Invalid Ship value",
                            "3" : "Invalid Layout value",
                            "21" : "Invalid value for X separation (meters >=0)",
                            "22" : "Invalid value for Y separation (meters >=0)",
                            "100" : "Parameter Service is mandatory"
              },
              "1" :
              {
                            "0" : "Invalid number of fields",
                            "1" : "List of cargo units is empty",
                            "2" : "Invalid cargo unit type",
                            "3" : "Invalid height",
                            "4" : "Invalid length"
              }
}
```

This package implements all the error checking and secondary verifications. When an error is found, the corresponding message based on the above file and a custom function *msg* is shown. The following example shows the function that checks if the length for a given cargo unit is consistent with the slot where it is placed, which is executed for every single cargo unit of the input file:

```
def isValidSlotVSLength(unit, frame_spacing, fstart, fend, length, err):
    result = False
    dbf = distanceBetweenFrames(frame_spacing, fstart, fend)
    if (dbf == -1):
        msg("E", "1", "102", unit)
    else:
        lengthValue = float(length)
        diff = abs(dbf-lengthValue)
        if (diff <= err): # and (lengthValue <= dbf):
            result = True
        else:
            msg("E", "1", "19", unit, length, dbf)
    return result
```

The below table includes all implemented warning and error messages with the variable arguments that can be added before showing the message:

Table 34.Implemented errors/warnings messages

Type	Group	ID	Description
W	0	1	No electrical connection/s available (%ship, %layout, %deck)
W	1	1	Route of cargo unit does not match selected route (%uid)
W	2	1	Cargo unit is too high (%unit)
W	2	2	Cargo unit type not allowed (%unit)
W	2	3	DG not allowed (%unit)
W	20	1	No available locations for current unit
W	100	1	IdService used is a 'future' ID -> please check coding
E	0	1	Invalid Service value (%[Provided value for the Service parameter])
E	0	2	Invalid Ship value (%[Provided value for the Ship parameter])
E	0	3	Invalid Layout value (%[Provided value for the Layout parameter])
E	0	4	Invalid Route value (%[Provided value for the Route parameter])
E	0	5	No deck/s available (%ship, %layout)
E	0	6	No lane/s available (%ship, %layout, %deck)
E	0	7	No voyage/s available (%ship, %route)
E	0	8	Invalid voyage definition (%ship, %route) → see VOYAGE table definition
E	0	9	Parameter *timeout* is mandatory if *Service == Score*
E	0	10	Invalid *timeout* value (%[Provided value for the *timeout* parameter])
E	0	11	Invalid *Improvement* value (%[Provided value for the *Improvement* parameter])
E	0	12	Invalid SlotError value (%slotValue)
E	0	21	Invalid value for X separation (meters >=0) (%Sep_X value)
E	0	22	Invalid value for Y separation (meters >=0) (%Sep_Y value)
E	0	100	Parameter Service is mandatory
E	0	101	Not empty parameter IdTest is mandatory if IsTest is True or 1
E	1	0	Invalid number of fields (%# of parts, %line)
E	1	1	List of cargo units is empty
E	1	2	Invalid cargo unit type (%uid)
E	1	3	Invalid height (%uid) (i.e. lower than 0)
E	1	4	Invalid length (%uid) (i.e. lower than 0)
E	1	5	Invalid weight (%uid) (i.e. lower than 0)
E	1	6	Invalid DG class (%uid)
E	1	7	Invalid DG state (%uid)
E	1	8	Invalid DG packing (%uid)
E	1	9	Invalid DG package (%uid)
E	1	10	Invalid value for 'flammable' attribute (%uid)
E	1	11	Invalid value for 'requiresConnection' attribute (%uid)
E	1	12	Invalid value for portOrigin or portDestination (%uid, %port | %destination)
E	1	13	Deck does not exist for the selected layout (%uid)
E	1	14	Lane does not exist for the selected layout and deck (%uid)
E	1	15	Electrical connection does not exist for the selected layout and deck (%uid)
E	1	16	Invalid combination of portOrigin and portDestination for selected route(%uid, %port, %destination)
E	1	17	Invalid value for frame_start or frame_end (%uid, %frame_start | %frame_end)

E	1	18	Invalid combination of frame_start and frame_end for selected deck-lane (%unit, %frame_start | %frame_end, %deck_lanes_configuration)
E	1	19	Invalid value for cargo unit length for selected slot (frame_start - frame_end) (%unit, %length, %distance_between_frames)
E	1	20	Invalid cargo type for the specified deck (%unit, %cargo_type, %deck)
E	1	21	Invalid DG cargo class for the selected slot (frame_start - frame_end) (%unit, %class, %deck, %frame_start, %frame_end)
E	1	100	No valid cargo units have been found
E	1	101	Duplicated ID of cargo unit, please verify (%unit)
E	1	102	Distance between frames not calculated, inconsistency between DB and slot (%unit)
E	2	1	Not enough electrical connections ({%unit})
E	2	2	Not enough space for all cargo units (%space summary available, %space summary required)
E	2	3	Overlapping units (%deck, %lane, %unit, %unit)
E	2	100	No valid cargo units have been found (not used)
E	3	1	IdService is mandatory for Service = RemoveService
E	3	2	ServiceDescription does not have a valid integer greater or equal than 1 or ALL
E	10	1	Test does not exist for the service (%id test, %service)
E	20	100	No valid locations have been found (not used)
E	100	1	Fatal error, please check activity log ([%function name])
E	100	2	Inconsistent lastrowid returned by the DB, please check (% function name)
E	100	3	Error retrieving Risk Assessment indexes (% function name)

In the section Score7.1, examples of warning message is shown since there are no electrical connections defined for the ships:

```
WARNING 0.1 : No electrical connection/s available [9417919] [2] [5]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [6]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [9]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [10]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [11]
```

Regarding E1.16 error, the condition to check if values satisfy the rules as specified in the VOYAGE table definition is ((*portOrigin >=0) AND (portDestination==portOrigin+1 or portDestination==-1))*.

This rule allows only two types of port calls for the units along the voyages of a route:

- Cargo units loaded in a port call must be unloaded in the consecutive port.
- Cargo units which must be loaded in the final destination (*portDestination==-1)* can be loaded in any port.

Although other more complex combinations of port calls, even if they need to relocate already loaded cargo units, may exist (at least for PCTC ships), after discussion with operators, a simplification was agreed since mostly of routes are point-to-point or with just one more intermediate port call. This way, the design supports enough representative sample of real routes to validate the usefulness of the algorithm.

It is important to remark that, in order to satisfy DG rules, units belonging to this type are only allowed if their *portOrigin==0*, avoiding other combinations

6.6 Miscellaneous functions

Contains miscellaneous functions and utilities that can be used by others. For example, in the previous sample code, a function *distanceBetweenFrames* is used, which is a function that calculates the length in meters occupied by a slot defined by start and end values of the frames of the ship. Since the frame spacing can change depending on the part of the ship, it is necessary to control the situations where a cargo is placed in areas where the frame spacing change. Information about the frame spacing of a ship is read from the database in a previous step.

```
def distanceBetweenFrames(frame_spacing, fstart, fend):
    result = 0.0
    fstartValue = float(fstart)
    fendValue = float(fend)
    # frame_spacing[0] = frame_start
    # frame_spacing[1] = frame_end
    # frame_spacing[2] = spacing (mm)
    # Search the FIRST section where the slot starts
    for fs in range(len(frame_spacing)):
        if ((fstartValue >= frame_spacing[fs][0]) and (fstartValue < frame_spacing[fs][1])):
            # Direct case if the slot is in a single section
            if fendValue < frame_spacing[fs][1]:
                result = ((fendValue - fstartValue) * frame_spacing[fs][2]) / 1000
            else:
                # Slot includes two sections with different frame_spacing
                if fs == (len(frame_spacing)-1):
                    result = -1
                else:
                    result = (((frame_spacing[fs][1] - fstartValue) * frame_spacing[fs][2])
+ ((fendValue - frame_spacing[fs][1]) * frame_spacing[fs+1][2])) / 1000
    return result
```

6.7 Score

As defined in Section 4, the calculation of the score values includes two steps: first, the calculation of the so-called RS_0, which is the intrinsic value of the cargo unit itself, with no consideration to the slot where it has been placed, that is, with no consideration to the nearby units. So, for each single unit, the initial risk score depends on the frequency and severity coming from the risk assessment. The following code shows the main part of this first step:

```
# Retrieve units for this service with their corresponding cargo types
unitTypes = DB.RS0_getEffectiveType(service_id)
# Dictionary storing RS0 values
print("Setting RS0 values...")
RS0 = {}
for unit in unitTypes.keys():
   strMsg = "unit: " + unit + ", "
   # First, check APVAFV units
   if unitTypes[unit][0] in APVAFV:
      RS0[unit] = 2
      strMsg+= "APVAFV, RS0=2"
   else:
      # Check if type is DG Class or one value from MT_FIREORIGIN2
      if unitTypes[unit][1] != None:
         typeOfUnit = unitTypes[unit][1]
         strMsg+= "DG class "
      else:
         typeOfUnit = unitTypes[unit][0]
      strMsg+= typeOfUnit + ", RS0="
      # use typeOfUnit value to search RS in the database
      try:
         FreqSevIdx[typeOfUnit]
         # If data avail., 1st check for extreme values
         freq = FreqSevIdx[typeOfUnit][0]
```

```
            sev = FreqSevIdx[typeOfUnit][1]
            if (freq == 1 and sev == 4) or (freq == 4 and sev == 1):
                  RS0[unit] = 3
                  strMsg+= str(RS0[unit]) + " (extreme value)"
            else:
                  RS0[unit] = FreqSevIdx[typeOfUnit][2]
                  strMsg+= str(RS0[unit]) + " (as a function of freq. and sever.)"
      except:
                  # RS not found. No historical data for this unit type.
                  # Risk Score assigned is the minimum one.
                  RS0[unit] = 1
                  strMsg+= str(RS0[unit]) + " (no information available)"
# Finally, set RS0 values from dict to DB
result = DB.setScore(RS0, "RS0", service_id)
```

The second step calculates the RS, that is, the risk score considering the units that overlap with the area of influence of the unit for which the RS is being calculated. These areas directly depend on *Sep_X* and *Sep_y* configuration parameters and the layout of the ship. Please refer to the section

Test methodology for more information. There are many functions that support the calculation of RS in order to, for example, get the dependency between decks or the layout of the ship. The main part of the code implementing this calculation is shown below:

```
RS = {}
for unit in service_units.keys():
   # get the list of nearby decks (first decks above and/or below)
   nearbyDecks = concat(deck_dependency[service_units[unit][0]][0],
deck_dependency[service_units[unit][0]][1])
   # then, add the deck of the current unit being processed
   nearbyDecks = concat(nearbyDecks, [service_units[unit][0]])
   # iterate all over nearby decks to get involved lanes based on the surrounding
   # area of the current unit defined by lowerLimit and upperLimit (Y axis)
   # By default, the surrounding area for above and below decks is the same that
   # the one is used to store the unit but, in the same deck will depend on the
   # configuration parameter Sep_Y. These limits are stored in:
   # limits[0] = lowerLimit and limits[1] = upperLimit.
   # Initially, the RS value will be RS0.
   RS[unit] = service_units[unit][4]
   for deck in nearbyDecks:
      sameDeck = (deck == service_units[unit][0])
      # WARNING: lane_info indexed using deck of the unit, not the current deck
      # to avoid indexing invalid combinations [deck][lane]
      cline_start = lane_info[service_units[unit][0]][service_units[unit][1]][2]
      cline_end = lane_info[service_units[unit][0]][service_units[unit][1]][3]
      ship_part = lane_info[service_units[unit][0]][service_units[unit][1]][4]
      limitsY = getLimitsY(sameDeck, cline_start, cline_end, ship_part,
CONFIG["Parameters"]["Sep_Y"])
      # Define what are the lanes that must be considered based on the limits
      lanes = getLanes(deck, lane_info, limitsY)
      frame_start_unit = service_units[unit][2]
      frame_end_unit = service_units[unit][3]
      limitsX = getLimitsX(sameDeck, frame_start_unit, frame_end_unit,
CONFIG["Parameters"]["Sep_X"], frameLimits)
      # Once all information required have been obtained, check for specific units
       nearbyUnits = getUnits(deck, unit, service_units, lanes, limitsX[0], limitsX[1])
       # check for compatibility between current unit and nearby ones and get the
       # new RS values based on compatibility and location of nearby unit.
       for u in nearbyUnits:
         incompatibility =
int(compatibility_info[service_units[unit][4]][service_units[u][4]])
         # get RS values based on the compatibility of each pair of units
         RS[unit] = updateRS(RS[unit], RS_info, service_units, deck_dependency, unit, u,
sameDeck, incompatibility)
# Finally, set RS values from dict to DB
result = DB.setScore(RS, "RS", service_id)
```

6.8 Cargo distribution

This feature has been implemented as an algorithm that searches for combinations of the cargo distribution with lower risk score (RS value) than the suggested stowage plan used as input. There are many constraints on the problem to solve that discourage the approach as a traditional optimization algorithm, among them:

- Although computational time required for the reference test is low enough, a deep search for the optimal distribution of the cargo for a full loaded ship is uncertain and considering that the SPT software has been designed to support the stowage not only in the pre-loading stage but also during the loading stage, it is not feasible that the component takes several seconds every time a request is sent to the software. At this point, it is important to remark that, although not implemented, the software has been designed to easily support use cases like *Confirm Location*, *Discard Unit* or *No Show* which are very common situations in a dynamic operation as the stowage is. All of these use cases require an additional request to the *Distribution* service in order to provide with a new distribution of the units considering the new situation respect to the previous distribution. As a matter of fact, the arrival profile of the units to the terminal is unknown and most likely will not match with the more convenient order to place the units following the distribution with lower risk; then, since the *Distribution* feature will be requested many times, the longer it takes to generate a solution, the higher the delay will be.
- The optimal value for the total RS is unknown and does not necessarily match with the total RS_0, so there is not an initial value to develop a strategy in the search of the convergence to this value.

Given these difficulties and with the objective of getting a better cargo distribution in a reasonable way, some simplifications have been applied to the implementation respect to the ambitious initial scope at the beginning of the LASH FIRE project (again, to highlight that the design of the underlying data model envisages tables, attributes and relationships needed to support them):

- The database is populated with existing electrical connections and infrastructure equipment like life-saving appliances or openings but RS calculation will not consider them and units that require an electrical connection are placed everywhere, assuming that 1) there are enough connections and 2) a connection is available no matter the unit is placed.
- DG goods do not change their slot respect to the one in the suggested stowage plan, which is supposed to be valid in terms of existing regulation. Actually, the software checks that a DG is placed in a suitable area of the ship according to the ALLOWED_DG_CARGO table.
- Units can change their slot but only in the same deck. Allowing changes between decks significantly increases the complexity of the problem.

This way, the main loop for the implementation of the feature looks like:

```
SCORES = USECASE_score.implementation(service_id, 0, RS_supportInfo)[1]
while stop(crono, float(SCORES[1]), float(SCORES[2])) == False:
            iteration += 1
            # LOOP BY DECKS
            for deck in sorted(sortedUnits[0].keys()):
                print("Loop for deck " + str(deck) + " starts")
                for unit in sortedUnits[0][deck]:
                    if unit in swapUnits.keys():
                        swapAndTest(deck, unit, service_id, iteration)
            print("End of iteration " + str(iteration))
SCORES = USECASE_score.implementation(service_id, 1, RS_supportInfo)[1]
```

Summarizing, the feature is implemented by means of a loop that stops when criteria is met and, for each iteration, units are swapped each other based on their areas of influence. The *stop* method has the following implementation:

```
def stop(startTime, initRS, currentRS):
    result = False
    improvementAchieved = False
    # Condition 1: timeout expired
    timeout = int(CONFIG["Parameters"]["timeout"])
    diff = float(float(time.time()) - float(startTime))
    timeoutExpired = diff > (timeout / 1000)
    if timeoutExpired == True:
        print("Cargo distribution STOP: timeout expired")
    # Condition 2: improvement of RS has been achieved [optional condition]
    # only checked if Condition 1 is False
    if timeoutExpired == False:
        try:
            improvement = float(CONFIG["Parameters"]["Improvement"])
            improvementAchieved = currentRS <= (initRS*(1-improvement))
            if improvementAchieved == True:
                print("Cargo distribution STOP: improvement achieved")
        except:
            None
    # Stop if any is True
    result = timeoutExpired or improvementAchieved
    return result
```

When checking if a swap drives to a lower risk, both database and variables in memory are updated accordingly. The latter are used to support a faster execution of the *Score* feature when it is called during the cargo distribution. This avoids to repeatedly query the database since access to disk is slower than access to memory. The following code shows the function that swaps units and verifie if the risk score is lower:

```
def swapAndTest(deck, u, service_id, iteration):
    global SCORES
    global sortedUnits
    global swapUnits
    global RS_supportInfo
    for uComp in swapUnits[u]:
        # Preserve original location of both units
        uLocation = getLocationFromSortedUnits(u)
        uCompLocation = getLocationFromSortedUnits(uComp)
        # Exchange location of u and uComp units in the DB and in RS_supportInfo
        DB.setLocation(u, service_id, None, uCompLocation[0], uCompLocation[1],
uCompLocation[2])
        DB.setLocation(uComp, service_id, None, uLocation[0], uLocation[1], uLocation[2])
        setLocationToMemory("RS_supportInfo", u, uCompLocation)
        setLocationToMemory("RS_supportInfo", uComp, uLocation)
        # calculate new score
        previousSCORES = SCORES
        SCORES = USECASE_score.implementation(service_id, iteration, RS_supportInfo)[1]
        # compare if new RS is better than previous
        if SCORES[2] < previousSCORES[2]:
            # if a lower RS is found, then consolidate swap
            setLocationToMemory("sortedUnits", u, uCompLocation)
            setLocationToMemory("sortedUnits", uComp, uLocation)
        else:
            # no lower RS is found, undo changes in DB and memory
            DB.setLocation(u, service_id, None, uLocation[0], uLocation[1], uLocation[2])
            DB.setLocation(uComp, service_id, None, uCompLocation[0], uCompLocation[1],
uCompLocation[2])
            setLocationToMemory("RS_supportInfo", u, uLocation)
            setLocationToMemory("RS_supportInfo", uComp, uCompLocation)
```

7 Test methodology

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The software has been tested using both de development framework and also a test environment deployed using a VMWare ESXi 12 server on a Dell PowerEdge R630 with two Intel Xeon E5-2609 v3 @ 1.9Ghz processors and 64 Gigabytes of memory (16 of them assigned to the virtual server), running Ubuntu 22.04.1 LTS [GNU/Linux 5.15.0-58-generic x86_64] as operating system. There is no relevant difference between both environments from the computational time perspective except for the distribution feature that takes less than two seconds for the reference test in the virtual server while about 50 times slower in the development environment.

In order to run the software using the generic ships considered in the LASH FIRE project, the first step is to populate the database with custom rows as defined in ANNEX E: Population of the database for generic ships of considered types which also helps to understand the contents of the cargo samples used during the testing.

Scoring (and therefore, distribution) are influenced by three of the configuration parameters that refer to physical calculations, having a direct impact in the considered units for the surrounding area.

First, *SlotError* is used to check whether two units can exchange their slots or not, since units are only exchanged if they are occupying exactly the same cargo meters with an accuracy defined by this parameter.

Then, *Sep_X* and *Sep_Y,* as introduced in 4.2.6, are used to get the list of surrounding units, which are used to calculate how RS_0 can change depending on nearby units (RS calculation). The next diagram shows how these parameters are used by means of two units (red and green) and their corresponding areas of influence.

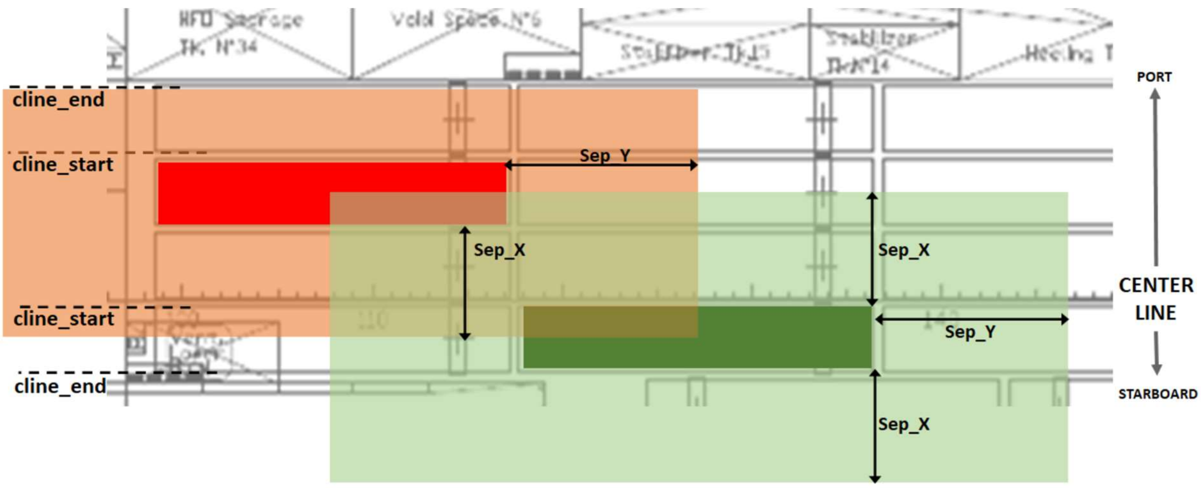


Figure 24 Use of Sep_x and Sep_Y configuration parameters

As described in 4.3.2.3.2.1.1, when calculating the RS value for a given unit, all units in the same deck that overlap with the corresponding areas of influence are considered, even if they just overlap in the border. While the above diagram applies to the same deck, the next one depicts the process for other decks (area of influence for decks other than the same is reduced to the same slot of the unit).

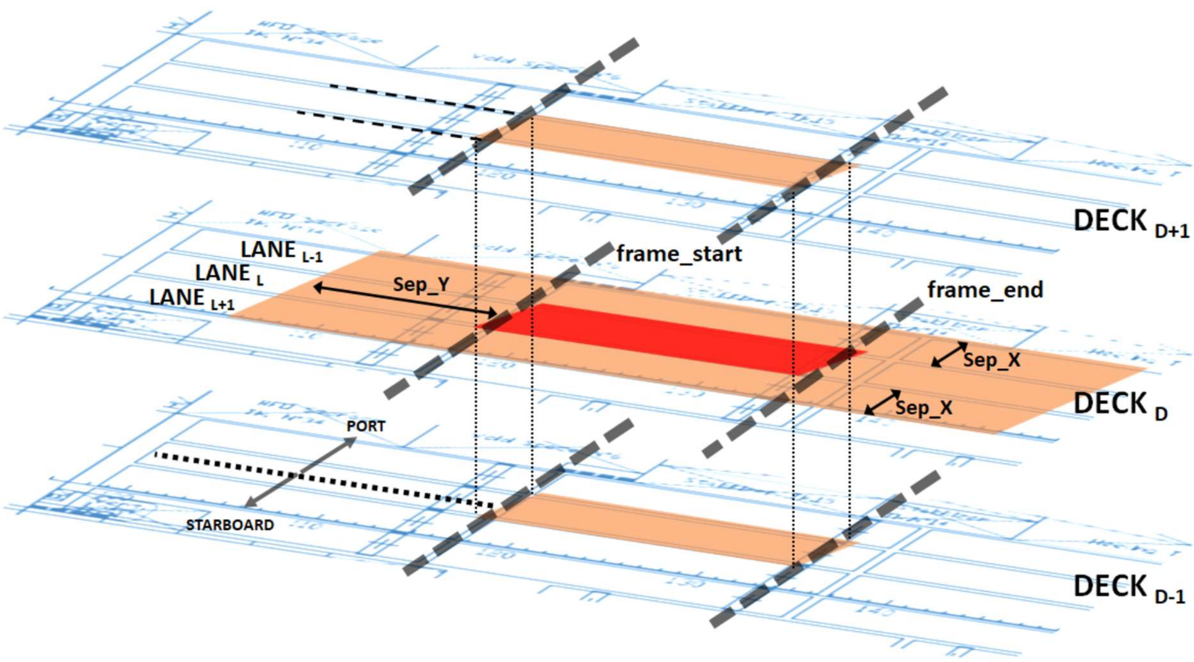


Figure 25 Use of Sep_x and Sep_Y configuration parameters

The number of above and below decks that are considered is taken from the *DECK_DEPENDENCY* table of the data model, which has been configured to check just one level up and one level down.

The values used for these parameters are as follows: *Sep_X* = 6 meters*, Sep_Y* = 3 meters and *SlotError* = 0.4 meters.

7.1 Score

In order to create the set of tests for this feature, the following table compiles the casuistry (or combinations) when the value of RS is not just RS_0 since it changes because of the nearby units considering different locations in terms of decks. This way, the tests are validating that the software is implementing correctly all the cases that the risk assessment methodology envisages.

Table 35. Table of RS_0-RS combinations tested

Test ID	Ship type	RS0	RS
1_1	RO-PAX	1 2 2 3	1 2 3 4
1_2	RO-PAX	3	3
2_1	RO-PAX	1 2 2 3 3	1 2 3 3 4
2_2	RO-PAX	2	2.25
2_3	RO-PAX	3	3.5

2_4	RO-PAX	3	3.25
2_5	RO-PAX	2	2.5
2_6	RO-PAX	Dangerous Goods (Classes 3, 4.3 and 5.1)	
2_7	RO-PAX	Dangerous Goods (Classes 4.1, 4.2 and 4.3)	
3_1	RO-RO	1 2 2 3 3 3 2	1 2 3 4 3.5 3.25 2.25
3_2	RO-RO	2	2.5
3_3	RO-RO	Dangerous Goods (Classes 1.3, 2.2 and 6.1)	
3_4	RO-RO	Dangerous Goods (Classes 1.4, 1.6, 5.1, 8 and 9)	

For each test, in **¡Error! No se encuentra el origen de la referencia.** a layout with the placement of the involved units and the contents of the test files used can be found (the fields of the test files are: *uid;type;height;length;weight;dg_class;dg_state;dg_packing;dg_package;flammable;requiresConnection;id_deck;id_lane;frame_start;frame_end;id_connection;id_route;portOrigin;portDestination*but many of them are not used in this version of the software).

Validation of the results for a given test can be automated since it just consists of a comparison between expected theoretical values (application of the risk assessment) and the outputs of the software. To support this automatic process, the software implements:

- Above-mentioned configuration parameters *IsTest* and *IdTest*
- Table TEST_INDEX in the database including available tests to be validated automatically and for each of the tests in this table:
    - Table TEST_RESULTS_SCORE should be filled accordingly to the corresponding units as per the test file to be executed.

The software already includes information for all the tests in ¡Error! No se encuentra el origen de la referencia. but the code has been implemented in such a way that the scalability is ensured, allowing the possibility of adding rows of new tests in order to be validated in an automatic way without changing the code (only the database and creating the corresponding test file).

Randomly using T2_6 as an example, the next steps show how it works. Assuming that the corresponding test file has been already created, first it is necessary to check that the database includes required information to validate the results automatically:

Table: TEST_INDEX

	uid	id_service_type
1	T1_1	Score
2	T1_2	Score
3	T2_1	Score
4	T2_2	Score
5	T2_3	Score
6	T2_4	Score
7	T3_1	Score
8	T3_2	Score
9	T2_5	Score
10	T2_6	Score
11	T2_7	Score
12	T3_3	Score
13	T3_4	Score
14	T3_5	Score

Table: TEST_RESULTS_SCORE

	id_test	id_cargo_unit	RS0	RS
	T2_6	Filter	Filter	Filter
1	T2_6	7001	2	2.0
2	T2_6	7002	1	1.0
3	T2_6	7003	2	2.25
4	T2_6	7004	1	1.0
5	T2_6	7005	1	1.0
6	T2_6	7006	2	3.0
7	T2_6	7007	1	1.0
8	T2_6	7008	3	4.0
9	T2_6	8001	1	1.0
10	T2_6	8002	1	1.0
11	T2_6	8003	2	3.0
12	T2_6	8004	3	4.0
13	T2_6	8005	1	1.0
14	T2_6	8006	2	3.0
15	T2_6	8007	2	3.0
16	T2_6	8008	3	4.0

Figure 26 TEST_INDEX contents and TEST_RESULTS_SCORE contents (filtering by id_test = T2_6)

This way, the database contains information about expected value for both RS_0 and RS for units 7001 to 7008 and 8001 to 8008.

Before launching the test, the corresponding *parameters.json* file and the test file, renamed to *IMO.csv* (where IMO is the IMO code of the ship), must be created in the *cfg* and *input* folders, respectively; the next figure shows the status of the environment with these files in the valid folders:

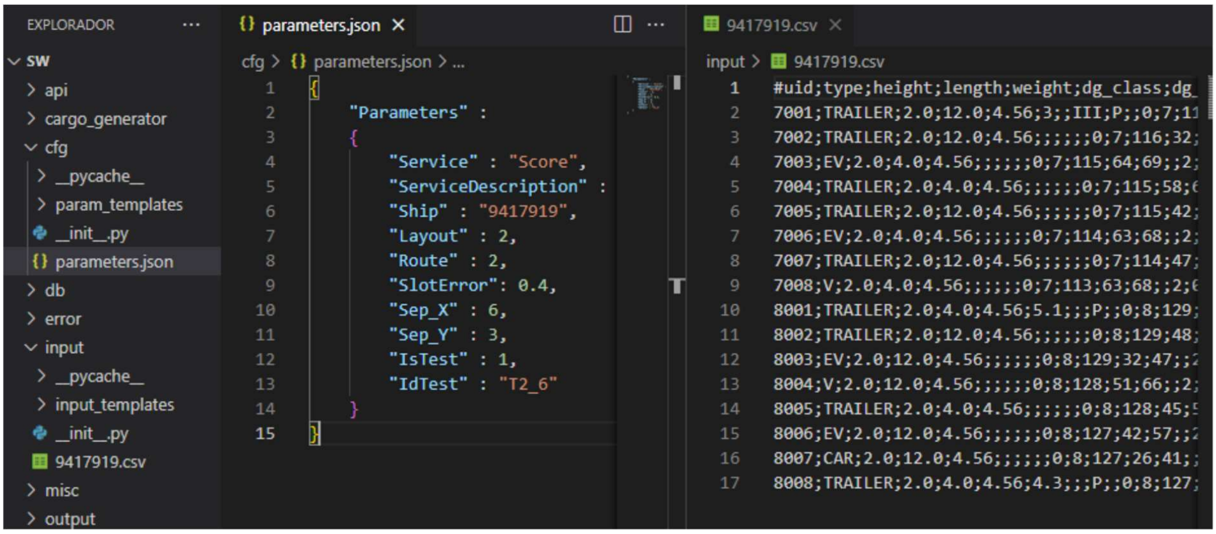


Figure 27 Required files before launching the sample test

After launching the test, if no errors are found, the software (if executed from the development environment or the console/terminal) shows the following, which includes the label PASS for all the units:

```
PS G:\TEMP\LASHFIRE\SW> & "C:/Program Files/Python311/python.exe" g:/TEMP/LASHFIRE/SW/lashfire
_spt.py
initialization of module: db
Connection successfully
end initialization of module: db
initialization of module: error
end initialization of module: error
initialization of module: cfg
WARNING 0.1 : No electrical connection/s available [9417919] [2] [5]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [6]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [9]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [10]
WARNING 0.1 : No electrical connection/s available [9417919] [2] [11]
{'Parameters': {'Service': 'Score', 'ServiceDescription': 'Distribution', 'Ship': '9417919', '
Layout': 2, 'Route': 2, 'SlotError': 0.4, 'Sep_X': 6, 'Sep_Y': 3, 'IsTest': True, 'IdTest': 'T
2_6'}}
end initialization of module: cfg
initialization of module: input
Read 16 units...
Found 0 invalid units. Units being removed:
Found 16 valid units: 7001 7002 7003 7004 7005 7006 7007 7008 8001 8002 8003 8004 8005 8006 80
07 8008
setCargoUnits::Transaction executed successfully!
end initialization of module: input
Now accessing entrypoint for use cases...
Implementation of SCORE use case...
insertService::Transaction executed successfully!
Service: Score created with id: 2
Starting RS0 calculation stage...
units read from CARGO_UNIT: 16
units written to SERVICE_UNITS: 16
moveUnitsToServiceUnits::Transaction executed successfully!
Setting RS0 values...
Starting RS calculation stage...
Generating output files...
setINIT_RS::Transaction executed successfully!
updateService::Transaction executed successfully!
Total RS0: 28.0 - Total RS: 35.25
Now accessing entrypoint for use case test checking...
Implementation of SCORE use case test: T2_6 for IdService: 2
**************************** TEST RESULTS ****************************
Unit: 7001, PASS
Unit: 7002, PASS
Unit: 7003, PASS
Unit: 7004, PASS
Unit: 7005, PASS
Unit: 7006, PASS
Unit: 7007, PASS
Unit: 7008, PASS
Unit: 8001, PASS
Unit: 8002, PASS
Unit: 8003, PASS
Unit: 8004, PASS
Unit: 8005, PASS
Unit: 8006, PASS
Unit: 8007, PASS
Unit: 8008, PASS
************************ END OF TEST RESULTS *************************
Execution finished in 1.1549932956695557 seconds
PS G:\TEMP\LASHFIRE\SW>
```

Figure 28 Example of test with no errors found

If errors are found, that is, discrepancies between expected results from the database and calculated results from the execution, then the corresponding errors are found. The following screenshot shows the output if the test is run again but removing unit 7008 from the test file (not from the database). For the specifc case of unit 7008, the output shows that is missing and, since there is a modification of the distribution, calculation of RS for unit 7006 differs from expected results because of their areas of influence.

```
Implementation of SCORE use case test: T2_6 for IdService: 3
****************************** TEST RESULTS ******************************
Unit: 7001, PASS
Unit: 7002, PASS
Unit: 7003, PASS
Unit: 7004, PASS
Unit: 7005, PASS
Unit: 7006, FAIL: expected RS0: 2 calculated RS0: 2 expected RS: 3.0 calculated RS: 2.0
Unit: 7007, PASS
Unit: 7008, MISS (*)
Unit: 8001, PASS
Unit: 8002, PASS
Unit: 8003, PASS
Unit: 8004, PASS
Unit: 8005, PASS
Unit: 8006, PASS
Unit: 8007, PASS
Unit: 8008, PASS
************************* END OF TEST RESULTS *************************
```

Figure 29 Example of test with errors found (test file does not include an expected unit)

On the other hand, units of the test file and the ones of the database could also differ because the information in the database is not consistent. The below image depicts what is the output of the software in case there is a typo for unit 8002 in the database, creating its row with an invalid identifier (18002). Unit 18002 appears as missing and 8002 has -1 as expected values, which means that there is no information in the database.

```
Implementation of SCORE use case test: T2_6 for IdService: 4
****************************** TEST RESULTS ******************************
Unit: 18002, MISS (*)
Unit: 7001, PASS
Unit: 7002, PASS
Unit: 7003, PASS
Unit: 7004, PASS
Unit: 7005, PASS
Unit: 7006, PASS
Unit: 7007, PASS
Unit: 7008, PASS
Unit: 8001, PASS
Unit: 8002, FAIL: expected RS0: -1 calculated RS0: 1 expected RS: -1 calculated RS: 1.0
Unit: 8003, PASS
Unit: 8004, PASS
Unit: 8005, PASS
Unit: 8006, PASS
Unit: 8007, PASS
Unit: 8008, PASS
************************* END OF TEST RESULTS *************************
Execution finished in 1.2579460144042969 seconds
```

Figure 30 Example of test with errors found (test file and database do not match)

Finally, using the methodology described, all the tests have been successfully passed.

7.2 Cargo distribution

In addition to the multiple tests performed during the development of the feature, a test reference (Test with id T3_5) has been used to validate the performance of the implementation. Some of the main characteristics of the test are:

- 27 units using 3 consecutive decks (9 units per deck) in slots that overlap each other from the vertical perspective.
- Units are a mix of cars (CAR), reefer units (V) and trailers (TRAILER), one of them transporting Class 2.2 dangerous goods.
- Total RS_0 of the suggested stowage plan is 38 while total RS is 46. In terms of decks:
    - Deck #2. Total RS0: 12, Total RS: 14.
    - Decks #3 and #3. Total RS0: 13, Total RS: 16.
- Total RS of the calculated stowage plan is 38.75. In terms of decks:
    - Deck #2. Total RS0: 12, Total RS: 12.25.
    - Decks #3. Total RS0: 13, Total RS: 13.5.
    - Decks #4. Total RS0: 13, Total RS: 13.

The following image depicts the output generated by the SPT after executing the test:

1. No errors have been found when initializing.
2. Dump of configuration parameters is valid.
3. No invalid units have been found in the input file.
4. Execution is labelled as service number 7.
5. Loop stops because timeout expires after one iteration processing the three decks.
6. Message showing initial and final RS values is shown.

```
Execution finished in 0.0018203258514404297 seconds
PS G:\TEMP\LASHFIRE\SW> & "C:/Program Files/Python311/python.exe" g:/TEMP/LASHFIRE/SW/la
initialization of module: db
Connection successfully
end initialization of module: db
initialization of module: error
end initialization of module: error
initialization of module: cfg
{'Parameters': {'Service': 'Distribution', 'ServiceDescription': 'Distribution', 'Ship':
ror': 0.4, 'Sep_X': 6, 'Sep_Y': 3, 'IsTest': True, 'timeout': 2000, 'IdTest': 'T3_5'}}
end initialization of module: cfg
initialization of module: input
Read 27 units...
Found 0 invalid units. Units being removed:
Found 27 valid units: 4001 4002 4003 4004 4005 4006 4007 4008 4009 3001 3002 3003 3004 3
2005 2006 2007 2008 2009
setCargoUnits::Transaction executed successfully!
end initialization of module: input
Now accessing entrypoint for use cases...
Implementation of CARGO DISTRIBUTION use case...
insertService::Transaction executed successfully!
Service: Distribution created with id: 7
Starting RS0 calculation stage...
units read from CARGO_UNIT: 27
units written to SERVICE_UNITS: 27
moveUnitsToServiceUnits::Transaction executed successfully!
Setting RS0 values...
Starting RS calculation stage...
setINIT_RS::Transaction executed successfully!
Loop for deck 2 starts
Loop for deck 3 starts
Loop for deck 4 starts
End of iteration 1
Cargo distribution STOP: timeout expired
INIT_RS: 46.0 --> After cargo distribution: 38.75
updateService::Transaction executed successfully!
Generating output files...
Execution finished in 38.61000466346741 seconds
```

Figure 31 Terminal output of the SPT for the Distribution feature using test T3_5

If table SERVICE_UNITS for service id = 7 is checked, then we can see the following (partial):

Table: SERVICE_UNITS

	id_service	id_cargo_unit	id_deck	INIT_id_lane	id_lane	INIT_frame_start	frame_start	INIT_frame_end	frame_end	onnec	RS0	INIT_RS	RS
	7	Filter	F...	Filter	Fil...	Filter	Filter	Filter	Filter			Fil...	...
7	7	4003	4	78	79	116.0	106.0	125.0	115.0	NULL	1	1.0	1.0
8	7	4002	4	78	80	106.0	116.0	115.0	125.0	NULL	2	3.0	2.0
9	7	4001	4	74	74	90.0	90.0	99.0	99.0	NULL	1	1.0	1.0
10	7	3009	3	45	44	115.0	105.0	124.0	114.0	NULL	1	1.0	1.0
11	7	3008	3	45	45	105.0	105.0	114.0	114.0	NULL	1	1.0	1.0
12	7	3007	3	44	45	115.0	115.0	124.0	124.0	NULL	2	3.0	2.5
13	7	3006	3	44	39	105.0	86.0	114.0	95.0	NULL	3	4.0	3.0
14	7	3005	3	43	43	115.0	115.0	124.0	124.0	NULL	2	3.0	2.0
15	7	3004	3	43	43	105.0	105.0	114.0	114.0	NULL	1	1.0	1.0
16	7	3003	3	41	41	86.0	86.0	95.0	95.0	NULL	1	1.0	1.0
17	7	3002	3	40	40	86.0	86.0	95.0	95.0	NULL	1	1.0	1.0
18	7	3001	3	39	44	86.0	115.0	95.0	124.0	NULL	1	1.0	1.0
19	7	2009	2	18	18	111.0	111.0	120.0	120.0	NULL	3	4.0	3.25

Figure 32 Screenshot of the results of the test in the database

The next table graphically shows the units and their RS_0 (green color) and RS (red color) values before the cargo distribution and after the execution. It is just a diagram that does not represent exactly the physical placement. For a more accurate reference please go to **¡Error! No se encuentra el origen de la referencia.**. The table shows how units have been moved respect to the suggested plan; as an example, unit 3007 decreases from 3 to 2.5, as previously shown in the database screenshot.

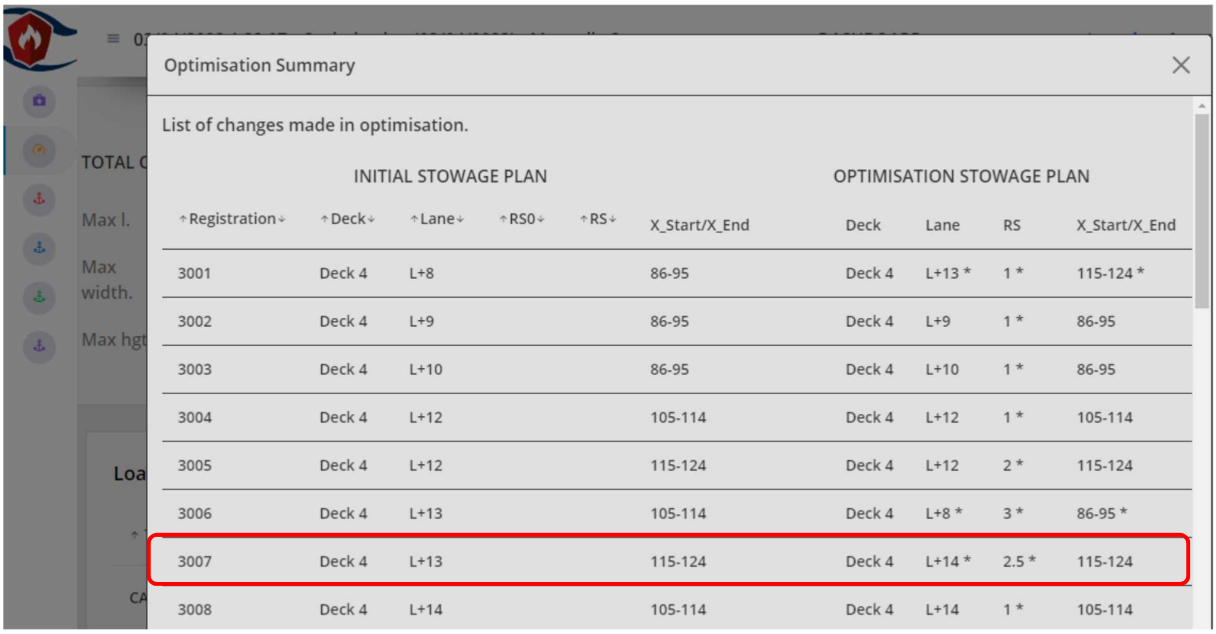
Table 36. Suggested stowage plan for test T3_5 (left) vs generated stowage plan by the SPT (right)

Deck	Id Unit RS0 RS		
4 **13 16**	4001 1 1	4002 2 3	4003 1 1
	4004 2 3	4005 3 4	4006 1 1
	4007 1 1	4008 1 1	4009 1 1
3 **13 16**	3001 1 1	3004 1 1	3005 2 3
	3002 1 1	3006 3 4	3007 2 3
	3003 1 1	3008 1 1	3009 1 1
2 **12 14**	2001 1 1	2002 1 1	2003 1 1
	2004 1 1	2005 1 1	2006 1 1
	2007 1 1	2008 2 3	2009 3 4

→

Deck	Id Unit RS0 RS		
4 **13 13**	4001 1 1	4007 1 1	4009 1 1
	4006 1 1	4003 1 1	4004 2 2
	4005 3 3	4008 1 1	4002 2 2
3 **13 13.5**	3006 3 3	3004 1 1	3005 2 2
	3002 1 1	3009 1 1	3001 1 1
	3003 1 1	3008 1 1	3007 2 2.5
2 **12 12.25**	2004 1 1	2002 1 1	2003 1 1
	2007 1 1	2005 1 1	2006 1 1
	2008 2 2	2001 1 1	2009 3 3.25

Finally, the rows of the database as shown in Figure 32 Screenshot of the results of the test in the databaseFigure 32, are sent to the visual interface, as depicted in the next screenshot:



INITIAL STOWAGE PLAN						OPTIMISATION STOWAGE PLAN			
Registration	Deck	Lane	RS0	RS	X_Start/X_End	Deck	Lane	RS	X_Start/X_End
3001	Deck 4	L+8			86-95	Deck 4	L+13 *	1 *	115-124 *
3002	Deck 4	L+9			86-95	Deck 4	L+9	1 *	86-95
3003	Deck 4	L+10			86-95	Deck 4	L+10	1 *	86-95
3004	Deck 4	L+12			105-114	Deck 4	L+12	1 *	105-114
3005	Deck 4	L+12			115-124	Deck 4	L+12	2 *	115-124
3006	Deck 4	L+13			105-114	Deck 4	L+8 *	3 *	86-95 *
3007	Deck 4	L+13			115-124	Deck 4	L+14 *	2.5 *	115-124
3008	Deck 4	L+14			105-114	Deck 4	L+14	1 *	105-114

Figure 33 Screenshot of the results of the test in the database

8 Conclusions

Main author of the chapter: Francisco Rodero, CIM

8.1 General

The Stowage Planning Tool is a software component entirely developed during the LASH FIRE project that supports load planning while including fire hazard management by means of a risk assessment of the units based on historical data. The software has been successfully tested when it comes to the implementation of the scoring feature and the subsequent cargo distribution in order to reduce the overall risk in terms of that score value. This way, this solution helps to increase the fire protection of ro-ro ships at the ignition prevention stage, which represents a contribution to the global objective #1 of the project.

Although the objective has been achieved, the development of the software suffered a slight delay because of the need to ensure accurate calculations of the physical influence between the cargo units, key element of a valid application of the risk assessment. However, the extra effort resulted on successful identification of these influence areas based on configuration parameters and the physical layout stored in the database. This provides with enough flexibility to support scalability to ships other than the generic ones used in the project.

8.2 Software design

The works described in this document have been addressed to achieve the main objective of the software: supporting load planning with fire hazard management of the units. In that sense, three main tasks have been carried out to create the SPT:

- An analysis has been performed over the data gathered from incident reports in order to get valuable information that can be used during the execution of the algorithm in terms of a risk assessment of the units. That is, how frequency and severity indexes are calculated, how a risk index is generated from the previous two and, finally, how a risk score is defined for a cargo unit and what is based on. All of these being the main criteria during the selection of the best placement of units during the distribution algorithm.
- Step-by-step workflow diagrams have been created to define what are the specific actions that have been implemented to satisfy the two main requisites of the algorithm: being able to score a suggested stowage plan provided by external software from operators and, optionally, propose an alternative distribution of the cargo aiming at reducing the risk overall.
- Requirements that satisfy operator's needs for such a software have been considered during the design stage by means of compiling all agreements during meetings. Although only the top-level features (scoring and cargo distribution) have been implemented, the design of the underlying database envisages features beyond this; in other words, the data model already includes definitions supporting the rest of the use-cases. In the same way, the HMI supports the scalability of the software as shown in D8.7 "Description of stowage plan visualization aid demonstration".

This way, the SPT together with the corresponding visual interface represent a tool capable of providing a digital support from the ignition prevention perspective in ro-ro spaces. Moreover, this support encompass not only the load planning stage but also the stowage process itself thanks to the interface with the VHD

8.3 Up-to-date historical information

One of the main pillars of the algorithm is the risk assessment which is based on the format and availability of fire-related data from incident reports in the maritime sector. Nowadays, this information requires some manual tasks (mainly because the existing taxonomies are heterogeneous) before being ready to be automatically processed and, besides that, it is prone to change along the years. Thus, there is the need for a standardized way of reporting, together with improvements on the availability by means of open-data and/or public-access repositories. This way, the software could take advantage of an automatic updating of the risk assessment if data on new incidents becomes available and cargo types increase or decrease its associated risk (as it could happen with electrical vehicles in a short term) without manual pre-processing. Standardization and comprehensive information could also drive to other further developments like the application of AI algorithms to automatically find out which other parameters must be considered when evaluating the risk.

8.4 Improvements of the risk assessment

When it comes to the information of a given unit, the data model includes its weight but most of times (except for DG), accurate information for this attribute is not available since the operators book lane meters or customers are unwilling to provide this information. The same goes for the contents, where units other than DG usually just provide high-level generic descriptions, if any. This lack on detailed information prevents the development of more sophisticated tools where, for example, the results of a fire propagation simulation (where detailed information about materials and weights is essential) can be used as an additional criterion during the risk assessment in order to suggest the best cargo distribution not only from the ignition prevention perspective but also from the fire propagation, if it happens.

Also, another interesting feature the SPT can be enhanced with is the possibility of distributing the cargo not only based on the risk score but also depending on the actual contents of the units aiming at creating kind of barriers that surround higher risk units in case of an eventual ignition. This, of course, requires an accurate knowledge of the materials and quantity of the units.

8.5 Management of the Terminal

An additional benefit of careful stowage planning is that in case of a fire, the crew will have up-to-date, accurate information about what is burning, and what could be the next cargo type to catch fire, in case the fire is spreading. However, this risk reduction comes with a price tag – in the present case, some cost is driven by CAPEX (Stowage Planning System cost, procurement, installation), but the most serious price component is OPEX, especially brought about an anticipated additional management overhead at terminals, as compared with today's practice. In other words, the cargo distribution suggested by the algorithm is supposed to have a lower overall risk (compared to a current stowage plan where risks of cargo other than DG is not considered) by managing the cargo in a per-unit basis. That is, units are uniquely identified when they are stowed instead of grouping them by cargo type without single identification. So, in order to get the maximum benefit, cargo units should be loaded to the ship as recommended by the algorithm. However, the arrival profile of the units to the terminal is unknown and, even if it was known, capacity of the parking area in the land-side is not infinite (many small terminals do not even have pre-loading area and trucks go from the gates to the ship, often creating queues in road network that accesses the terminal). The approach to deal with this operating mode of the terminals is through the use cases #3, #10 and #14, which set the loading status as initial (non-movable) load of the ship and executes the algorithm to distribute the remaining units; the more different is the arrival profile compared to the ideal profile (units arrive in such an order that they can directly enter the ship and match the suggested distribution by the algorithm) the more different will be the final cargo distribution and therefore, the risk will not be reduced as much as it could.

8.6 Integration as a *plug-in*

The software can be executed as a desktop application but an additional benefit of implementing the software also as a *plug-in* through the REST API described earlier in this document is that operators can easily integrate these features in their current systems just using the defined interface and translating the information of their booking systems to the format required by the SPT, which drives to a potential short-term impact.

8.7 Adaptation to other ships

Ship types considered in the project are ro-ro cargo, ro-pax and vehicle carrier. However, with minor modifications of the database design and adaptation of the algorithm to include specific rules, stowage of container ships could also be covered in a mid-term (scalability of the software). Anyway, even if technically possible, conceptual consistency of the methodology behind the risk assessment should be checked as a compulsory initial step before further developments.

8.8 Actions when distributing the cargo

Besides the above-mentioned improvements in case of having more accurate information about the units, there is still the possibility to change the behaviour of the current algorithm aiming at getting results with a potential lower risk.

One of these changes is that the algorithm in charge of distributing units has been implemented in a way that while swapping units, the final combination that is consolidated for the final solution is selected randomly. One improvement for this selection is to consider the distance between the units, so that separation between two incompatible units is maximized. This way, there is an undoubtable benefit related to risk reduction from the propagation perspective; however, the impact of this feature actually depends on the cargo since the more units with high risk the less available remaining space to use.

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10 Indexes

10.1 Index of tables

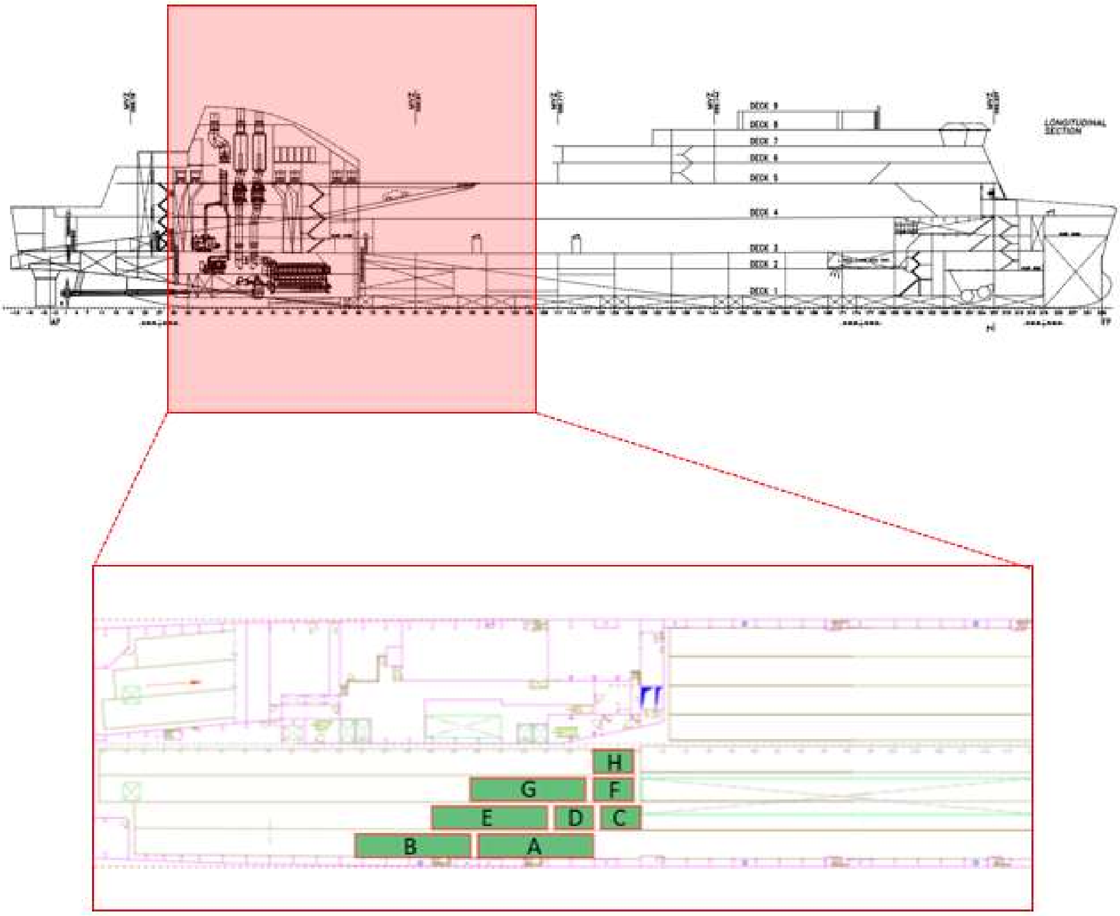
10.2 Index of figures

11 ANNEXES

11.1 ANNEX A Test reference files

Main author of the chapter: África Marrero, CIM

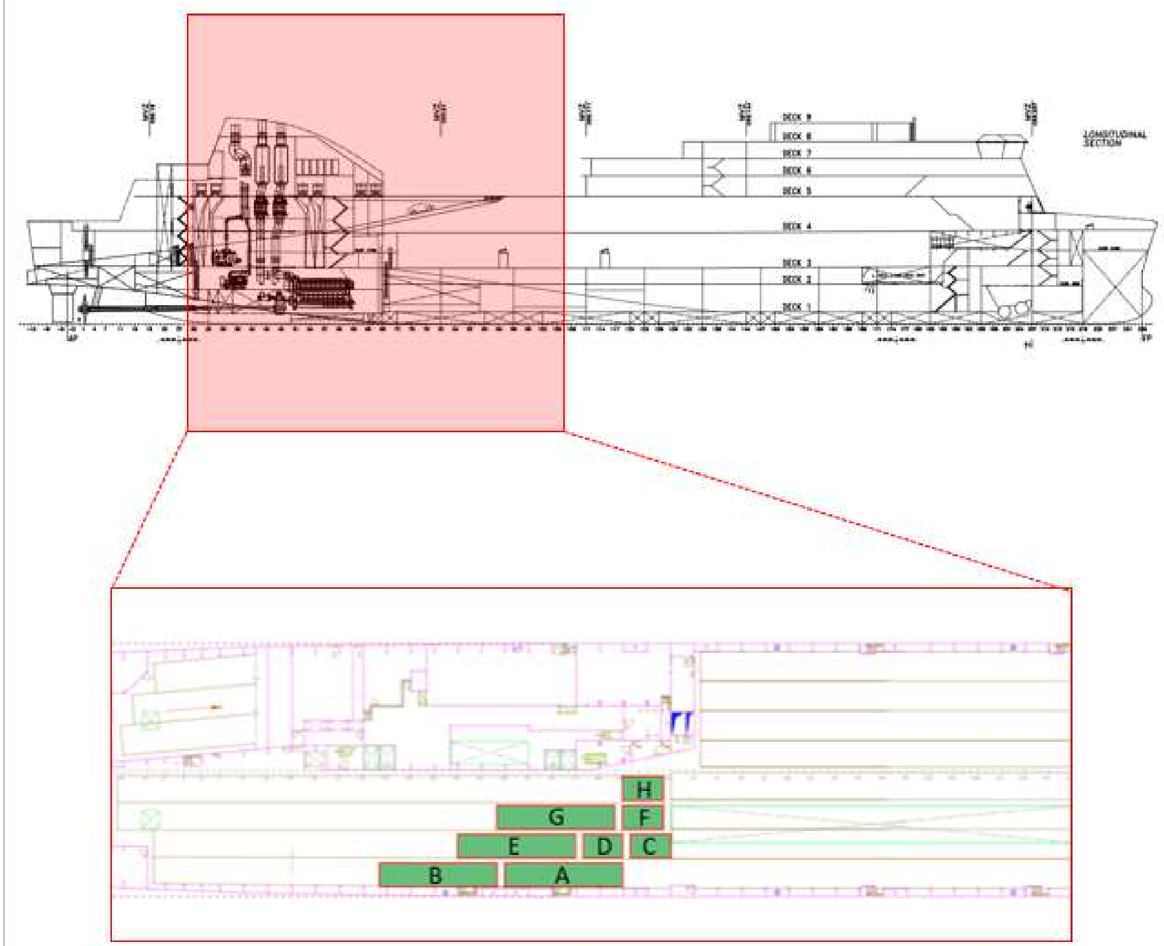
Test ID	1_1



	#uid	Type	Deck	RS0	RS
A	7001	V	3	3	4
B	7002	V	3	3	4
C	7003	CAR	3	2	3
D	7004	EV	3	2	3
E	7005	BUS	3	2	3
F	7006	EV	3	2	2
G	7007	TRAC	3	1	1
H	7008	EV	3	2	2

```
7001;V;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;V;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;CAR;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;EV;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;BUS;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;EV;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAC;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;EV;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
```

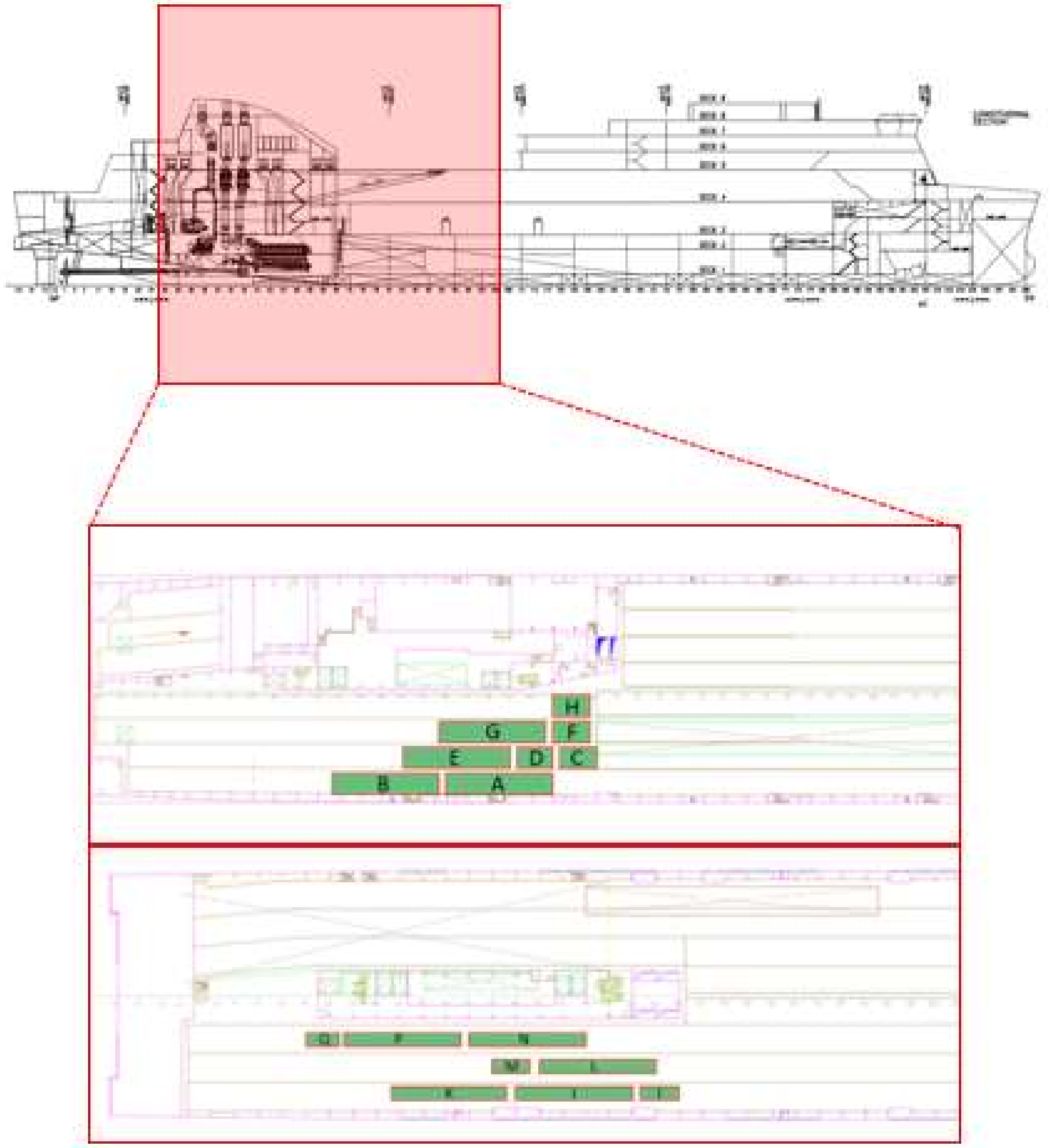
Test ID	1_2



	#uid	Type	Deck	RS0	RS
A	7001	TRAC	3	1	1
B	7002	V	3	3	3
C	7003	CAR	3	2	2
D	7004	CAR	3	2	2
E	7005	TRAC	3	1	1
F	7006	CAR	3	2	2
G	7007	TRAC	3	1	1
H	7008	EV	3	2	2

```
7001;TRAC;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;V;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;CAR;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;CAR;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;TRAC;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;CAR;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAC;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;EV;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
```

Test ID	2_1



	#uid	Type	Deck	RS0	RS
A	7001	V	3	3	4
B	7002	V	3	3	4
C	7003	CAR	3	2	3
D	7004	EV	3	2	3
E	7005	BUS	3	2	3
F	7006	EV	3	2	2
G	7007	TRAC	3	1	1
H	7008	EV	3	2	2
I	8001	CAR	4	2	3
J	8002	TRAC	4	1	1
K	8003	BUS	4	2	3
L	8004	V	4	3	4
M	8005	CAR	4	2	3
N	8006	BUS	4	2	3
P	8007	TRAC	4	1	1
Q	8008	CAR	4	2	2

```
7001;V;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;V;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;CAR;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;EV;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;BUS;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;EV;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAC;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;EV;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
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8002;TRAC;2.0;12.0;4.56;;;;;;0;8;129;48;63;;2;0;-1
8003;BUS;2.0;12.0;4.56;;;;;;0;8;129;32;47;;2;0;-1
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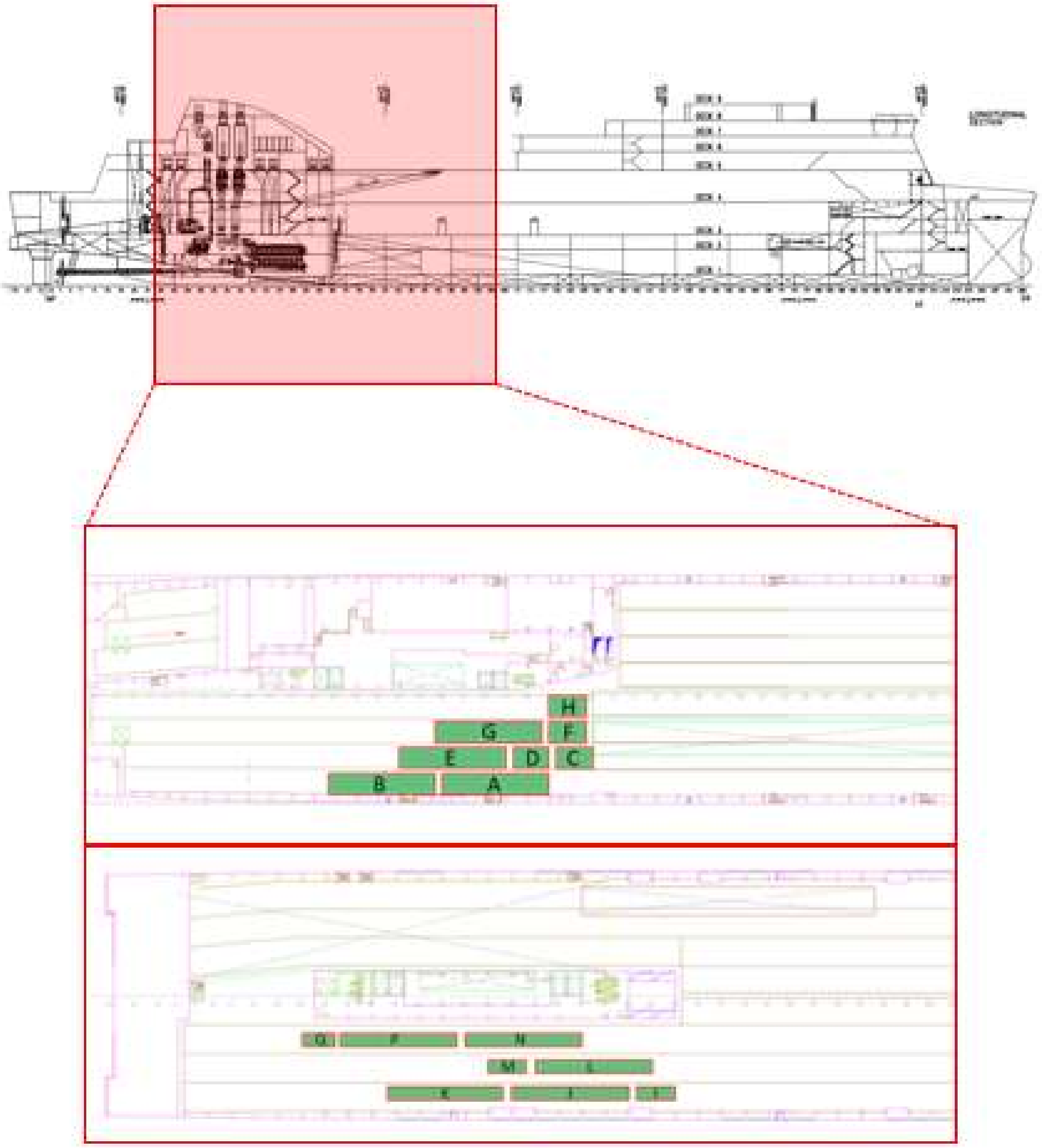
8006;BUS;2.0;12.0;4.56;;;;;;0;8;127;42;57;;2;0;-1
8007;TRAC;2.0;12.0;4.56;;;;;;0;8;127;26;41;;2;0;-1
8008;CAR;2.0;4.0;4.56;;;;;;0;8;127;19;25;;2;0;-1
```

Test ID	2_2



	#uid	Type	Deck	RS0	RS
A	7001	V	3	3	4
B	7002	V	3	3	4
C	7003	CAR	3	2	3
D	7004	EV	3	2	3
E	7005	V	3	3	4
F	7006	EV	3	2	3
G	7007	TRAC	3	1	1
H	7008	EV	3	2	2
I	8001	CAR	4	2	2
J	8002	TRUCK	4	2	2,5
K	8003	TRAC	4	1	1
L	8004	TRAC	4	1	1
M	8005	CAR	4	2	2
N	8006	TRAC	4	1	1
P	8007	TRAC	4	1	1
Q	8008	CAR	4	2	2

```
7001;V;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;V;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;CAR;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;EV;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;V;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;EV;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAC;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;EV;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
8001;CAR;2.0;4.0;4.56;;;;;;0;8;129;64;69;;2;0;-1
8002;TRUCK;2.0;12.0;4.56;;;;;;0;8;129;48;63;;2;0;-1
8003;TRAC;2.0;12.0;4.56;;;;;;0;8;129;32;47;;2;0;-1
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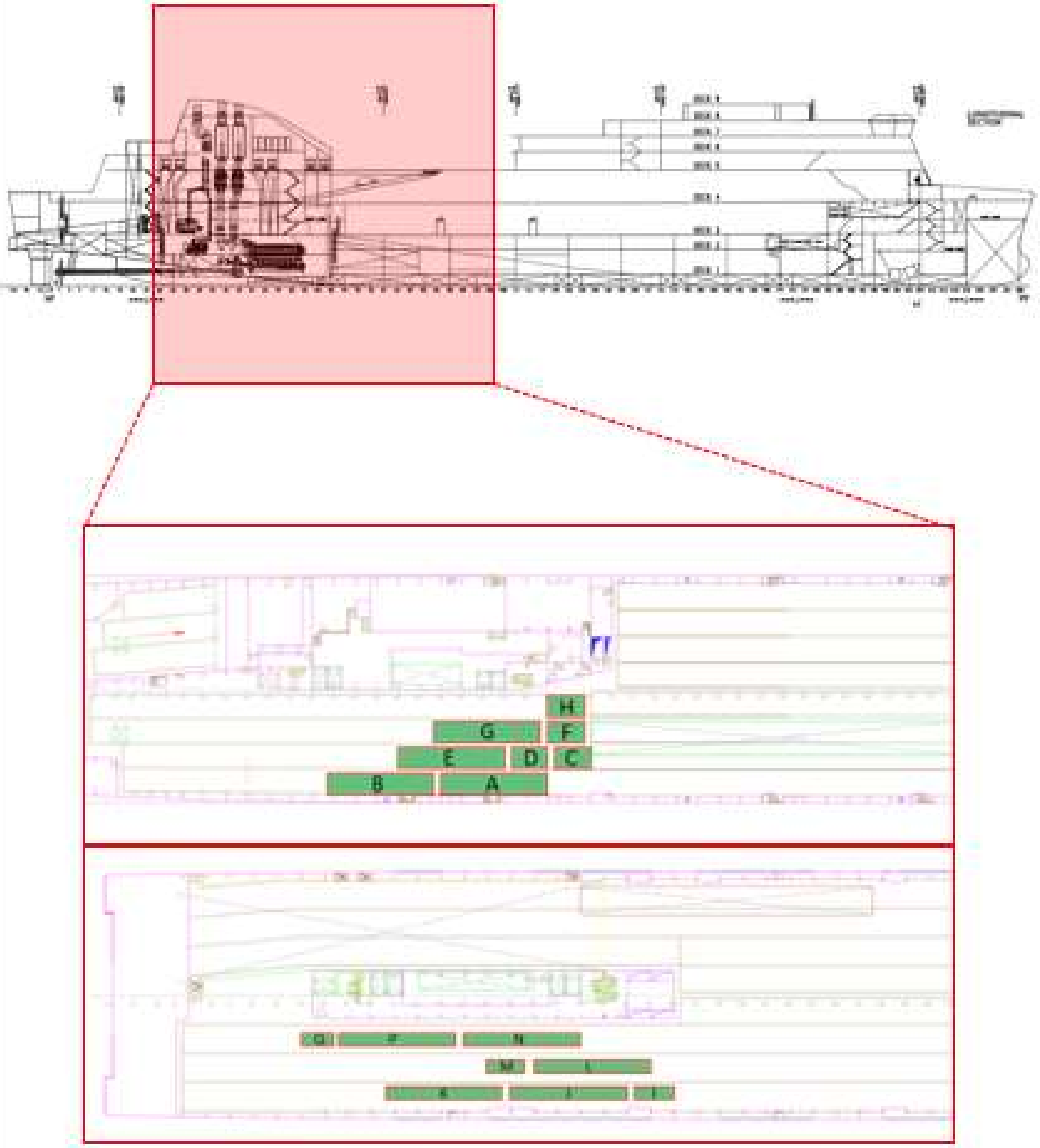
8006;TRAC;2.0;12.0;4.56;;;;;;0;8;127;42;57;;2;0;-1
8007;TRAC;2.0;12.0;4.56;;;;;;0;8;127;26;41;;2;0;-1
8008;CAR;2.0;4.0;4.56;;;;;;0;8;127;19;25;;2;0;-1
```

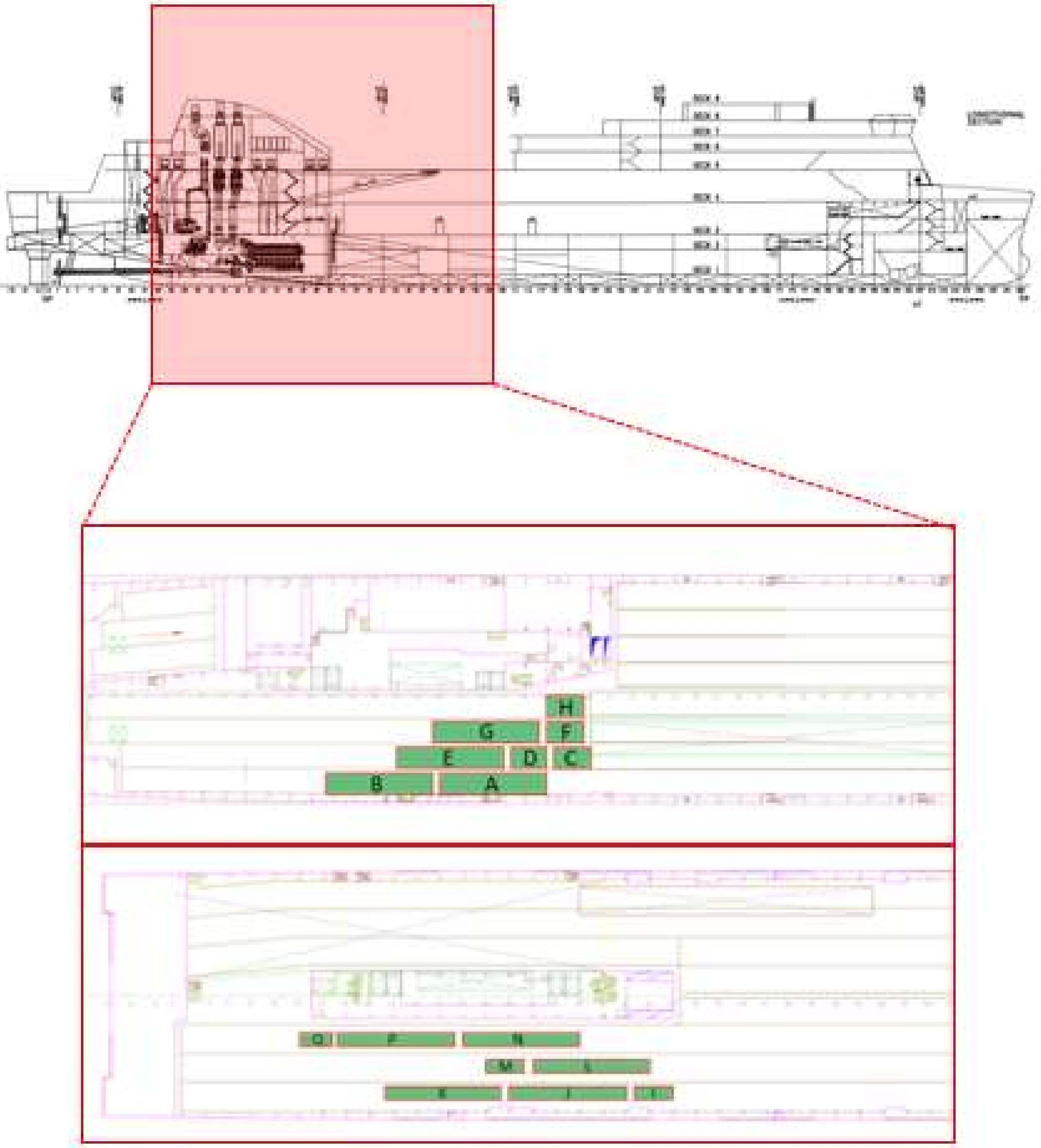
Test ID	2_3



	#uid	Type	Deck	RSo	RS
A	7001	V	3	3	4
B	7002	V	3	3	4
C	7003	CAR	3	2	3
D	7004	V	3	3	4
E	7005	V	3	3	4
F	7006	EV	3	2	3
G	7007	TRAC	3	1	1
H	7008	EV	3	2	2
I	8001	TRAC	4	1	1
J	8002	TRAC	4	1	1
K	8003	V	4	3	3,5
L	8004	TRAC	4	1	1
M	8005	TRAC	4	1	1
N	8006	TRAC	4	1	1
P	8007	TRAC	4	1	1
Q	8008	CAR	4	2	2

```
7001;V;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;V;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;CAR;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;V;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;V;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;EV;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAC;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;EV;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
8001;TRAC;2.0;4.0;4.56;;;;;;0;8;129;64;69;;2;0;-1
8002;TRAC;2.0;12.0;4.56;;;;;;0;8;129;48;63;;2;0;-1
8003;V;2.0;12.0;4.56;;;;;;0;8;129;32;47;;2;0;-1
8004;TRAC;2.0;12.0;4.56;;;;;;0;8;128;51;66;;2;0;-1
8005;TRAC;2.0;4.0;4.56;;;;;;0;8;128;45;50;;2;0;-1
8006;TRAC;2.0;12.0;4.56;;;;;;0;8;127;42;57;;2;0;-1
8007;TRAC;2.0;12.0;4.56;;;;;;0;8;127;26;41;;2;0;-1
8008;CAR;2.0;4.0;4.56;;;;;;0;8;127;19;25;;2;0;-1
```

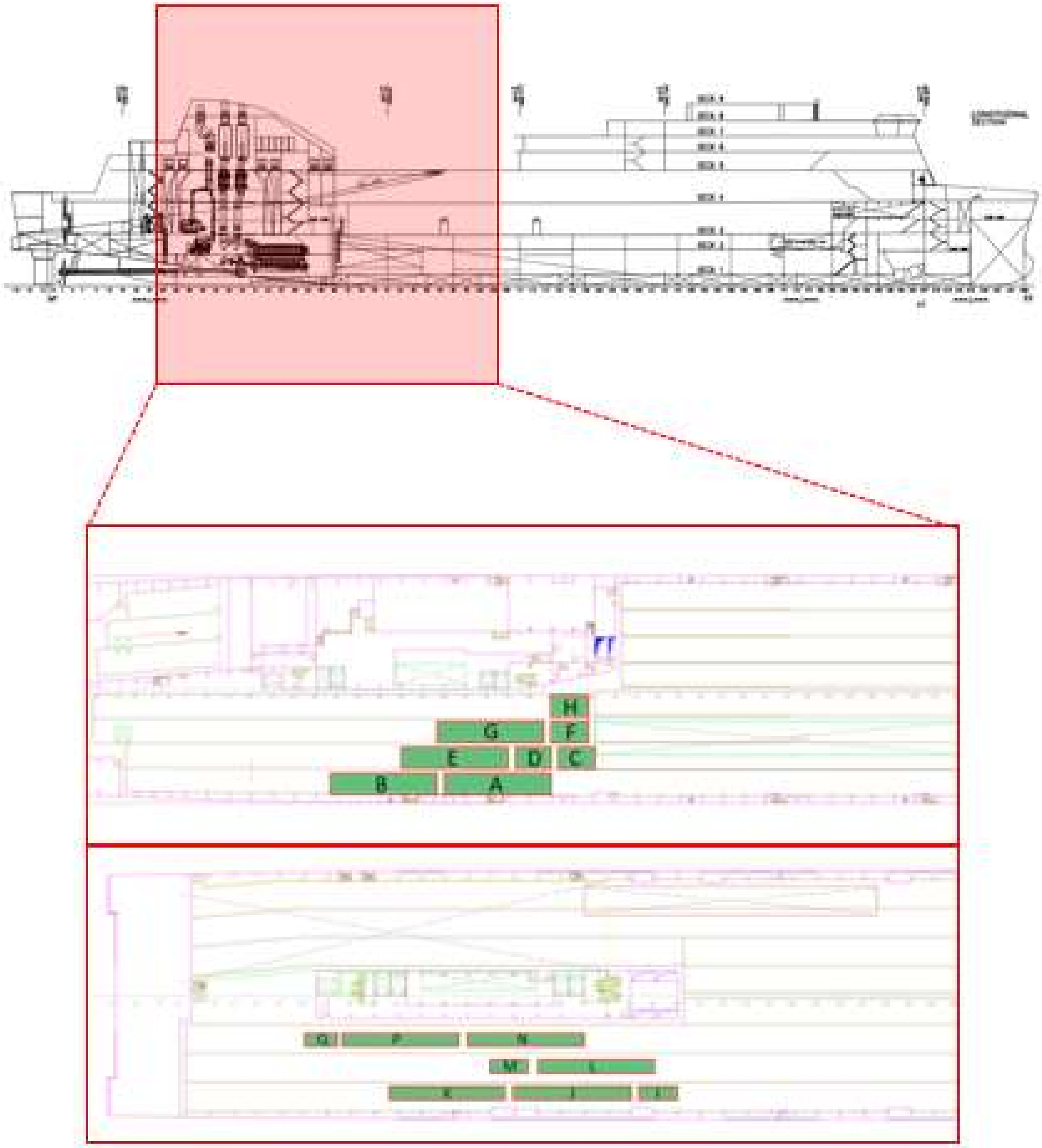
Test ID	2_4



	#uid	Type	Deck	RSo	RS
A	7001	V	3	3	3,25
B	7002	TRAC	3	1	1
C	7003	TRAC	3	1	1
D	7004	TRAC	3	1	1
E	7005	TRAC	3	1	1
F	7006	CAR	3	2	2
G	7007	TRAC	3	1	1
H	7008	CAR	3	2	2
I	8001	V	4	3	4
J	8002	V	4	3	4
K	8003	EV	4	2	3
L	8004	V	4	3	4
M	8005	V	4	3	4
N	8006	EV	4	2	3
P	8007	TRAC	4	1	1
Q	8008	CAR	4	2	2

```
7001;V;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;TRAC;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;TRAC;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;TRAC;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;TRAC;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;CAR;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAC;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;CAR;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
8001;V;2.0;4.0;4.56;;;;;;0;8;129;64;69;;2;0;-1
8002;V;2.0;12.0;4.56;;;;;;0;8;129;48;63;;2;0;-1
8003;EV;2.0;12.0;4.56;;;;;;0;8;129;32;47;;2;0;-1
8004;V;2.0;12.0;4.56;;;;;;0;8;128;51;66;;2;0;-1
8005;V;2.0;4.0;4.56;;;;;;0;8;128;45;50;;2;0;-1
8006;EV;2.0;12.0;4.56;;;;;;0;8;127;42;57;;2;0;-1
8007;TRAC;2.0;12.0;4.56;;;;;;0;8;127;26;41;;2;0;-1
8008;CAR;2.0;4.0;4.56;;;;;;0;8;127;19;25;;2;0;-1
```

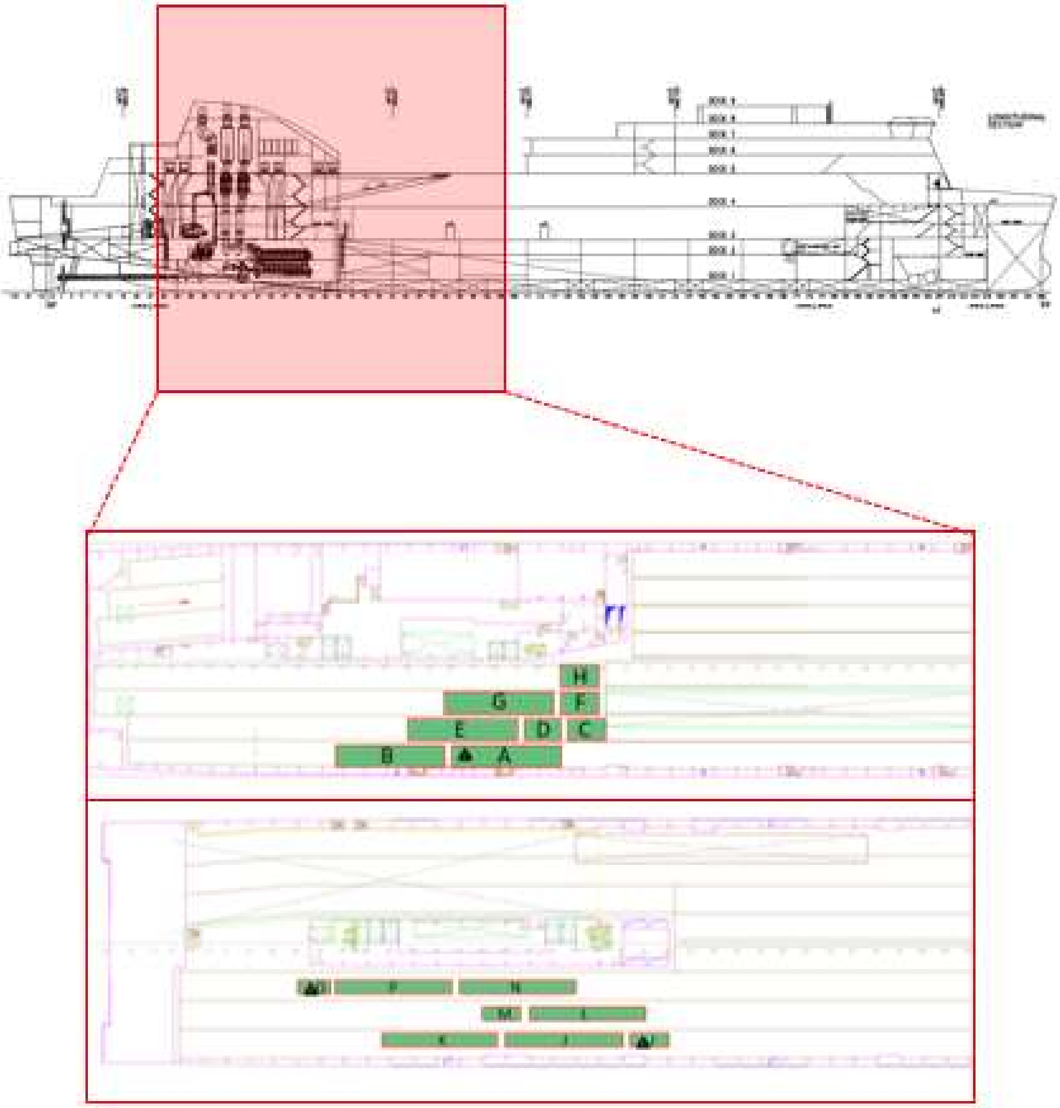
Test ID	2_5



	#uid	Type	Deck	RS0	RS
A	7001	EV	3	2	2,25
B	7002	TRAC	3	1	1
C	7003	TRAC	3	1	1
D	7004	TRAC	3	1	1
E	7005	TRAC	3	1	1
F	7006	CAR	3	2	2
G	7007	TRAC	3	1	1
H	7008	CAR	3	2	2
I	8001	V	4	3	4
J	8002	V	4	3	4
K	8003	EV	4	2	3
L	8004	V	4	3	4
M	8005	V	4	3	4
N	8006	V	4	3	4
P	8007	TRAC	4	1	1
Q	8008	CAR	4	2	2

```
7001;EV;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;TRAC;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;TRAC;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;TRAC;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;TRAC;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;CAR;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAC;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;CAR;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
8001;V;2.0;4.0;4.56;;;;;;0;8;129;64;69;;2;0;-1
8002;V;2.0;12.0;4.56;;;;;;0;8;129;48;63;;2;0;-1
8003;EV;2.0;12.0;4.56;;;;;;0;8;129;32;47;;2;0;-1
8004;V;2.0;12.0;4.56;;;;;;0;8;128;51;66;;2;0;-1
8005;V;2.0;4.0;4.56;;;;;;0;8;128;45;50;;2;0;-1
8006;V;2.0;12.0;4.56;;;;;;0;8;127;42;57;;2;0;-1
8007;TRAC;2.0;12.0;4.56;;;;;;0;8;127;26;41;;2;0;-1
8008;CAR;2.0;4.0;4.56;;;;;;0;8;127;19;25;;2;0;-1
```

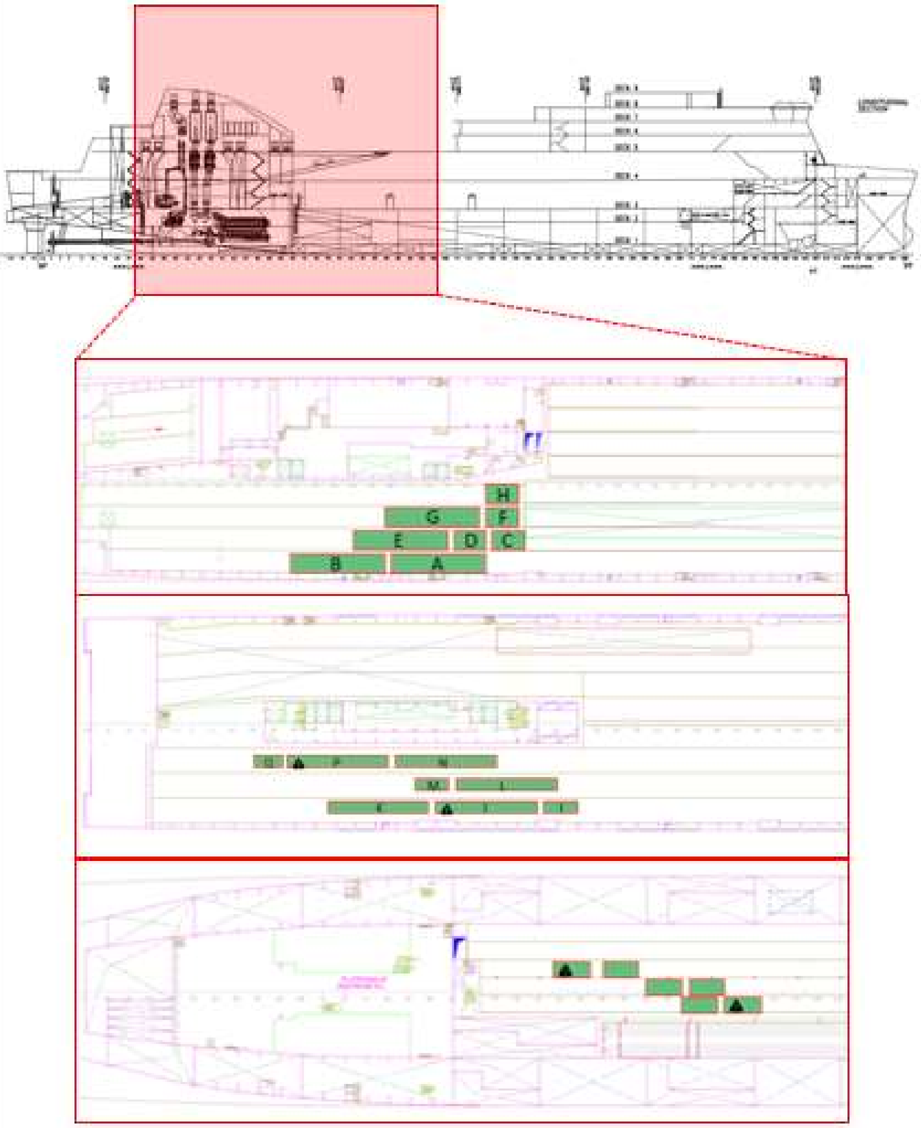
Test ID	2_6



	#uid	Type	Deck	RS0	RS
A	7001	TRAILER (3)	3	2	2
B	7002	TRAILER	3	1	1
C	7003	EV	3	2	2,25
D	7004	TRAILER	3	1	1
E	7005	TRAILER	3	1	1
F	7006	EV	3	2	3
G	7007	TRAILER	3	1	1
H	7008	V	3	3	4
I	8001	TRAILER(5.1)	4	1	1
J	8002	TRAILER	4	1	1
K	8003	EV	4	2	3
L	8004	V	4	3	4
M	8005	TRAILER	4	1	1
N	8006	EV	4	2	3
P	8007	CAR	4	2	3
Q	8008	TRAILER(4.3)	4	3	4

```
7001;TRAILER;2.0;12.0;4.56;3;;III;P;;0;7;116;48;63;;2;0;-1
7002;TRAILER;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;EV;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;TRAILER;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;TRAILER;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;EV;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;TRAILER;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;V;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
8001;TRAILER;2.0;4.0;4.56;5.1;;;P;;0;8;129;64;69;;2;0;-1
8002;TRAILER;2.0;12.0;4.56;;;;;;0;8;129;48;63;;2;0;-1
8003;EV;2.0;12.0;4.56;;;;;;0;8;129;32;47;;2;0;-1
8004;V;2.0;12.0;4.56;;;;;;0;8;128;51;66;;2;0;-1
8005;TRAILER;2.0;4.0;4.56;;;;;;0;8;128;45;50;;2;0;-1
8006;EV;2.0;12.0;4.56;;;;;;0;8;127;42;57;;2;0;-1
8007;CAR;2.0;12.0;4.56;;;;;;0;8;127;26;41;;2;0;-1
8008;TRAILER;2.0;4.0;4.56;4.3;;;P;;0;8;127;19;25;;2;0;-1
```

Test ID	2_7



	#uid	Type	Deck	RSo	RS
A	7001	V	3	3	4
B	7002	V	3	3	4
C	7003	EV	3	2	3
D	7004	CAR	3	2	3
E	7005	CAR	3	2	3
F	7006	EV	3	2	2
G	7007	CAR	3	2	2
H	7008	CAR	3	2	2
I	8001	TRAILER	4	1	1
J	8002	TRAILER(4.1)	4	3	3,5
K	8003	TRAILER	4	1	1
L	8004	TRAILER	4	1	1
M	8005	TRAILER	4	1	1
N	8006	TRAILER	4	1	1
P	8007	TRAILER(4.1)	4	3	3
Q	8008	TRAILER	4	1	1
R	6001	TRAILER(4.3)	2	3	3
S	6002	TRAILER	2	1	1
T	6003	TRAILER	2	1	1
U	6004	TRAILER	2	1	1
V	6005	TRAILER	2	1	1
W	6006	TRAILER(4.3)	2	3	3

```
7001;V;2.0;12.0;4.56;;;;;;0;7;116;48;63;;2;0;-1
7002;V;2.0;12.0;4.56;;;;;;0;7;116;32;47;;2;0;-1
7003;EV;2.0;4.0;4.56;;;;;;0;7;115;64;69;;2;0;-1
7004;CAR;2.0;4.0;4.56;;;;;;0;7;115;58;63;;2;0;-1
7005;CAR;2.0;12.0;4.56;;;;;;0;7;115;42;57;;2;0;-1
7006;EV;2.0;4.0;4.56;;;;;;0;7;114;63;68;;2;0;-1
7007;CAR;2.0;12.0;4.56;;;;;;0;7;114;47;62;;2;0;-1
7008;CAR;2.0;4.0;4.56;;;;;;0;7;113;63;68;;2;0;-1
8001;TRAILER;2.0;4.0;4.56;;;;;;0;8;129;64;69;;2;0;-1
8002;TRAILER;2.0;12.0;4.56;4.2;;;P;;0;8;129;48;63;;2;0;-1
8003;TRAILER;2.0;12.0;4.56;;;;;;0;8;129;32;47;;2;0;-1
8004;TRAILER;2.0;12.0;4.56;;;;;;0;8;128;51;66;;2;0;-1
8005;TRAILER;2.0;4.0;4.56;;;;;;0;8;128;45;50;;2;0;-1
8006;TRAILER;2.0;12.0;4.56;;;;;;0;8;127;42;57;;2;0;-1
8007;TRAILER;2.0;12.0;4.56;4.1;;;P;;0;8;127;26;41;;2;0;-1
8008;TRAILER;2.0;4.0;4.56;;;;;;0;8;127;19;25;;2;0;-1
6001;TRAILER;2.0;4.0;4.56;4.3;S;I;P;0;0;6;98;83;88;;2;0;-1
6002;TRAILER;2.0;4.0;4.56;;;;;;0;6;98;90;95;;2;0;-1
6003;TRAILER;2.0;4.0;4.56;;;;;;0;6;97;96;101;;2;0;-1
6004;TRAILER;2.0;4.0;4.56;;;;;;0;6;97;102;107;;2;0;-1
6005;TRAILER;2.0;4.0;4.56;;;;;;0;6;104;101;106;;2;0;-1
6006;TRAILER;2.0;4.0;4.56;4.3;S;I;P;0;0;6;104;107;112;;2;0;-1
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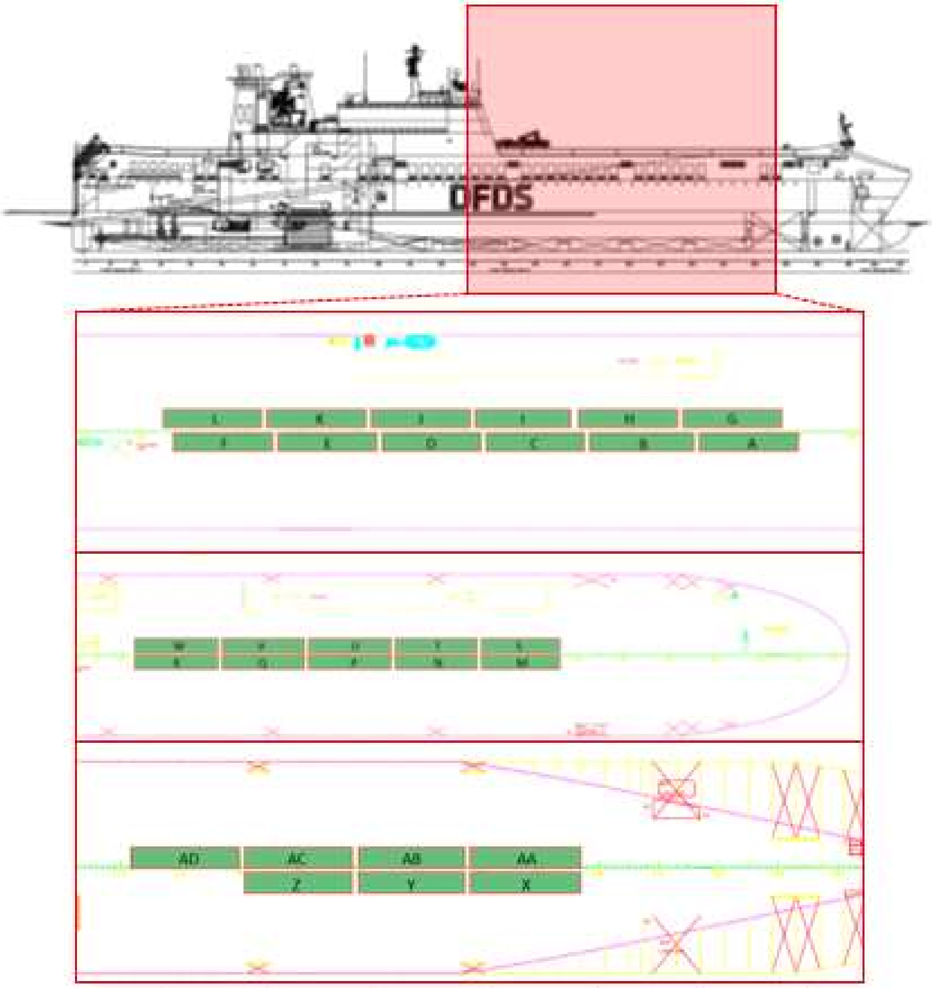
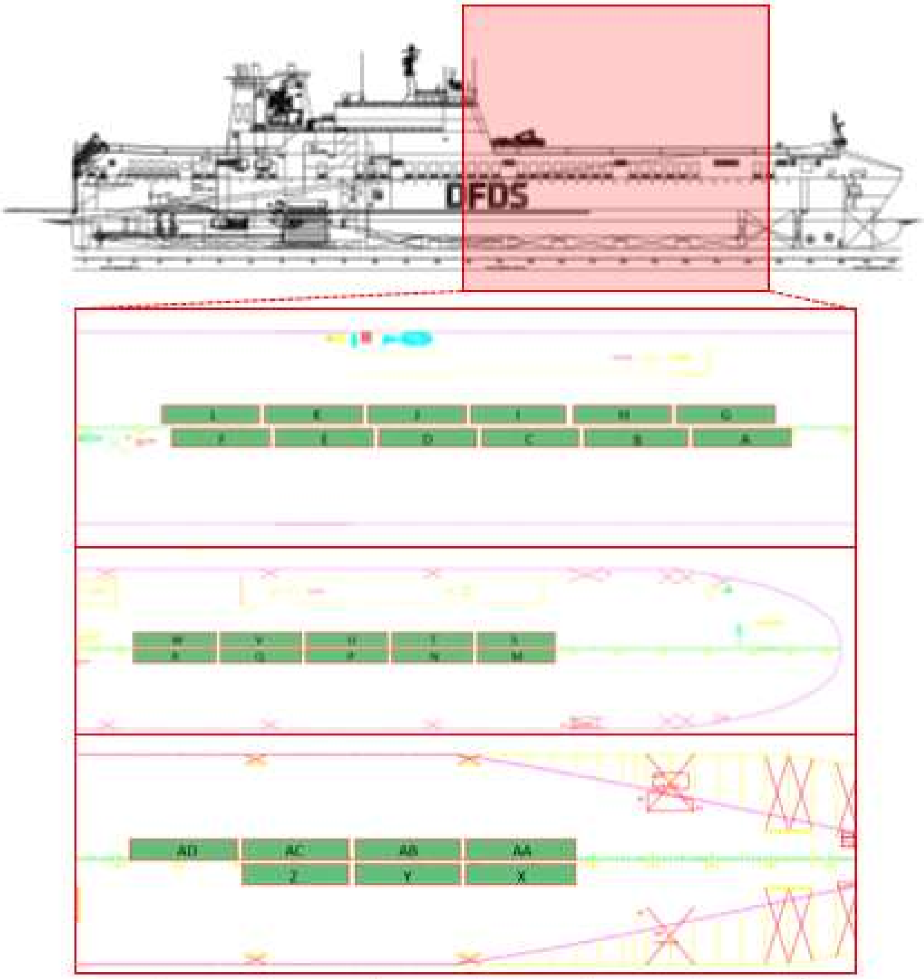
Test ID	3_1



	#uid	Type	Deck	RSo	RS
A	4001	V	4	3	3,5
B	4002	TRAILER	4	1	1
C	4003	BUS	4	2	2
D	4004	TRAILER	4	1	1
E	4005	TRAILER	4	1	1
F	4006	BUS	4	2	3
G	4007	TRAILER	4	1	1
H	4008	TRAILER	4	1	1
I	4009	BUS	4	2	2
J	4010	TRAILER	4	1	1
K	4011	V	4	3	4
L	4012	V	4	3	4
M	3001	EV	3	2	2,5
N	3002	EV	3	2	2,5
P	3003	EV	3	2	2
Q	3004	EV	3	2	2
R	3005	EV	3	2	2
S	3006	EV	3	2	2
T	3007	EV	3	2	2
U	3008	EV	3	2	2
V	3009	EV	3	2	2,5
W	3010	EV	3	2	2,5
X	2001	V	2	3	4
Y	2002	TRAILER	2	1	1
Z	2003	TRAILER	2	1	1
AA	2004	EV	2	2	3
AB	2005	TRAILER	2	1	1
AC	2006	TRAILER	2	1	1
AD	2007	V	2	3	3,25

```
4001;V;2.0;13.3;4.56;;;;;;0;4;77;202;220;;1;0;-1
4002;TRAILER;2.0;14.0;4.56;;;;;;0;4;77;182;201;;1;0;-1
4003;BUS;2.0;13.3;4.56;;;;;;0;4;77;163;181;;1;0;-1
4004;TRAILER;2.0;13.3;4.56;;;;;;0;4;77;144;162;;1;0;-1
4005;TRAILER;2.0;13.3;4.56;;;;;;0;4;77;125;143;;1;0;-1
4006;BUS;2.0;13.3;4.56;;;;;;0;4;77;106;124;;1;0;-1
4007;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;199;217;;1;0;-1
4008;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;180;198;;1;0;-1
4009;BUS;2.0;13.3;4.56;;;;;;0;4;85;161;179;;1;0;-1
4010;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;142;160;;1;0;-1
4011;V;2.0;13.3;4.56;;;;;;0;4;85;123;141;;1;0;-1
4012;V;2.0;13.3;4.56;;;;;;0;4;85;104;122;;1;0;-1
3001;EV;2.0;13.0;4.56;;;;;;0;3;42;189;206;;1;0;-1
3002;EV;2.0;13.3;4.56;;;;;;0;3;42;170;188;;1;0;-1
3003;EV;2.0;13.3;4.56;;;;;;0;3;42;151;169;;1;0;-1
3004;EV;2.0;13.3;4.56;;;;;;0;3;42;132;150;;1;0;-1
3005;EV;2.0;13.3;4.56;;;;;;0;3;42;113;131;;1;0;-1
3006;EV;2.0;13.0;4.56;;;;;;0;3;57;189;206;;1;0;-1
3007;EV;2.0;13.3;4.56;;;;;;0;3;57;170;188;;1;0;-1
3008;EV;2.0;13.3;4.56;;;;;;0;3;57;151;169;;1;0;-1
3009;EV;2.0;13.3;4.56;;;;;;0;3;57;132;150;;1;0;-1
3010;EV;2.0;13.3;4.56;;;;;;0;3;57;113;131;;1;0;-1
2001;V;2.0;13.3;4.56;;;;;;0;2;19;179;197;;1;0;-1
2002;TRAILER;2.0;13.3;4.56;;;;;;0;2;19;160;178;;1;0;-1
2003;TRAILER;2.0;13.3;4.56;;;;;;0;2;19;141;159;;1;0;-1
2004;EV;2.0;13.3;4.56;;;;;;0;2;27;179;197;;1;0;-1
2005;TRAILER;2.0;13.3;4.56;;;;;;0;2;27;160;178;;1;0;-1
2006;TRAILER;2.0;13.3;4.56;;;;;;0;2;27;141;159;;1;0;-1
2007;V;2.0;13.3;4.56;;;;;;0;2;27;122;140;;1;0;-1
```

Test ID	3_2



	#uid	Type	Deck	RS_0	RS
A	4001	TRAILER	4	1	1
B	4002	V	4	3	3,5
C	4003	TRAILER	4	1	1
D	4004	TRAILER	4	1	1
E	4005	TRAILER	4	1	1
F	4006	EV	4	2	2
G	4007	TRAILER	4	1	1
H	4008	TRAILER	4	1	1
I	4009	TRAILER	4	1	1
J	4010	TRAILER	4	1	1
K	4011	TRAILER	4	1	1
L	4012	EV	4	2	2
M	3001	V	3	3	4
N	3002	V	3	3	4
P	3003	V	3	3	4
Q	3004	EV	3	2	3
R	3005	EV	3	2	2
S	3006	V	3	3	4
T	3007	V	3	3	4
U	3008	V	3	3	4
V	3009	EV	3	2	3
W	3010	EV	3	2	2
X	2001	TRAILER	2	1	1
Y	2002	EV	2	2	2,25
Z	2003	TRAILER	2	1	1
AA	2004	TRAILER	2	1	1
AB	2005	EV	2	2	2,25
AC	2006	TRAILER	2	1	1
AD	2007	EV	2	2	2

```
4001;TRAILER;2.0;13.3;4.56;;;;;;0;4;77;202;220;;1;0;-1
4002;V;2.0;14.0;4.56;;;;;;0;4;77;182;201;;1;0;-1
4003;TRAILER;2.0;13.3;4.56;;;;;;0;4;77;163;181;;1;0;-1
4004;TRAILER;2.0;13.3;4.56;;;;;;0;4;77;144;162;;1;0;-1
4005;TRAILER;2.0;13.3;4.56;;;;;;0;4;77;125;143;;1;0;-1
4006;EV;2.0;13.3;4.56;;;;;;0;4;77;106;124;;1;0;-1
4007;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;199;217;;1;0;-1
4008;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;180;198;;1;0;-1
4009;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;161;179;;1;0;-1
4010;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;142;160;;1;0;-1
4011;TRAILER;2.0;13.3;4.56;;;;;;0;4;85;123;141;;1;0;-1
4012;EV;2.0;13.3;4.56;;;;;;0;4;85;104;122;;1;0;-1
3001;V;2.0;12.4;4.56;;;;;;0;3;42;189;206;;1;0;-1
3002;V;2.0;13.3;4.56;;;;;;0;3;42;170;188;;1;0;-1
3003;V;2.0;13.3;4.56;;;;;;0;3;42;151;169;;1;0;-1
3004;EV;2.0;13.3;4.56;;;;;;0;3;42;132;150;;1;0;-1
3005;EV;2.0;13.3;4.56;;;;;;0;3;42;113;131;;1;0;-1
3006;V;2.0;12.4;4.56;;;;;;0;3;57;189;206;;1;0;-1
3007;V;2.0;13.3;4.56;;;;;;0;3;57;170;188;;1;0;-1
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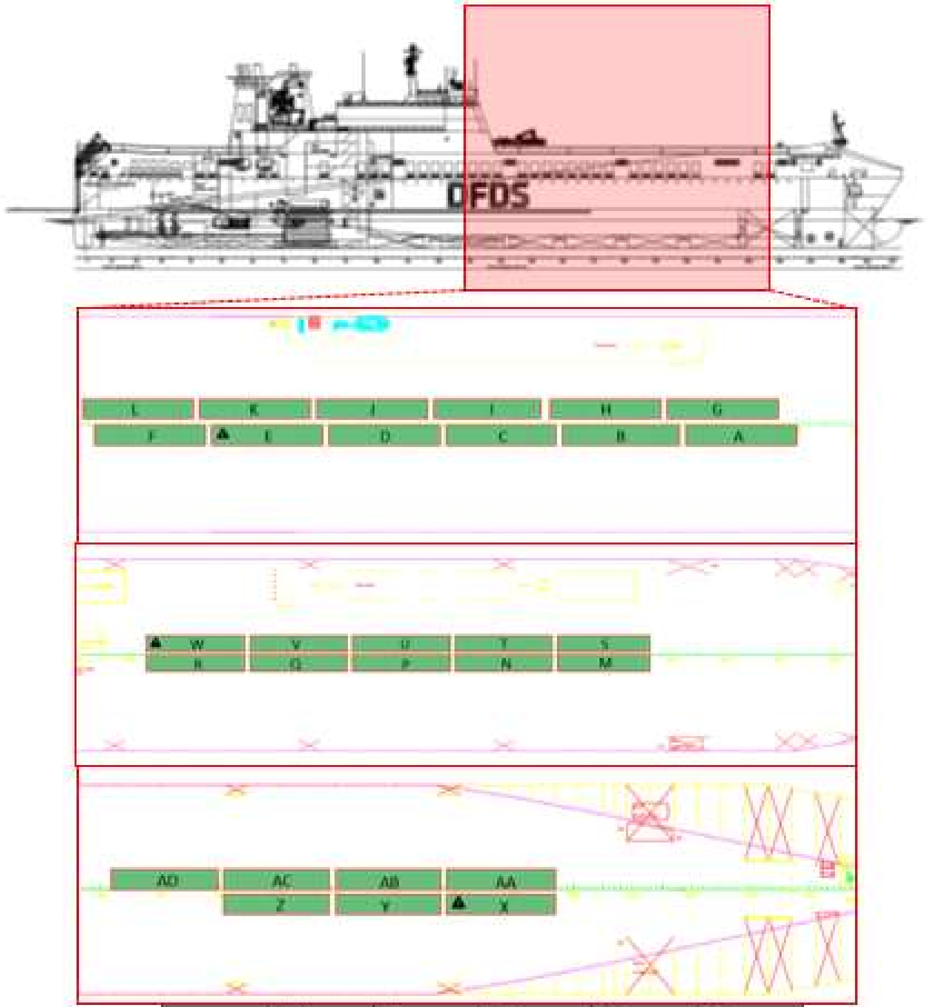

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C	4003	TRAILER	4	1	1
D	4004	TRAILER	4	1	1
E	4005	TRUCK(1.3)	4	2	2
F	4006	EV	4	2	2
G	4007	TRAILER	4	1	1
H	4008	TRAILER	4	1	1
I	4009	TRAILER	4	1	1
J	4010	TRAILER	4	1	1
K	4011	EV	4	2	2,5
L	4012	CAR	4	2	2
M	3001	TRAILER	3	1	1
N	3002	EV	3	2	2
P	3003	TRAILER	3	1	1
Q	3004	TRAILER	3	1	1
R	3005	CAR	3	2	3
S	3006	CAR	3	2	2
T	3007	TRAILER	3	1	1
U	3008	TRAILER	3	1	1
V	3009	V	3	3	4
W	3010	TRUCK(2.2)	3	2	3
X	2001	TRUCK(6.1)	2	1	1
Y	2002	EV	2	2	2
Z	2003	TRAILER	2	1	1
AA	2004	TRAILER	2	1	1
AB	2005	TRAILER	2	1	1
AC	2006	TRAILER	2	1	1
AD	2007	EV	2	2	2,25

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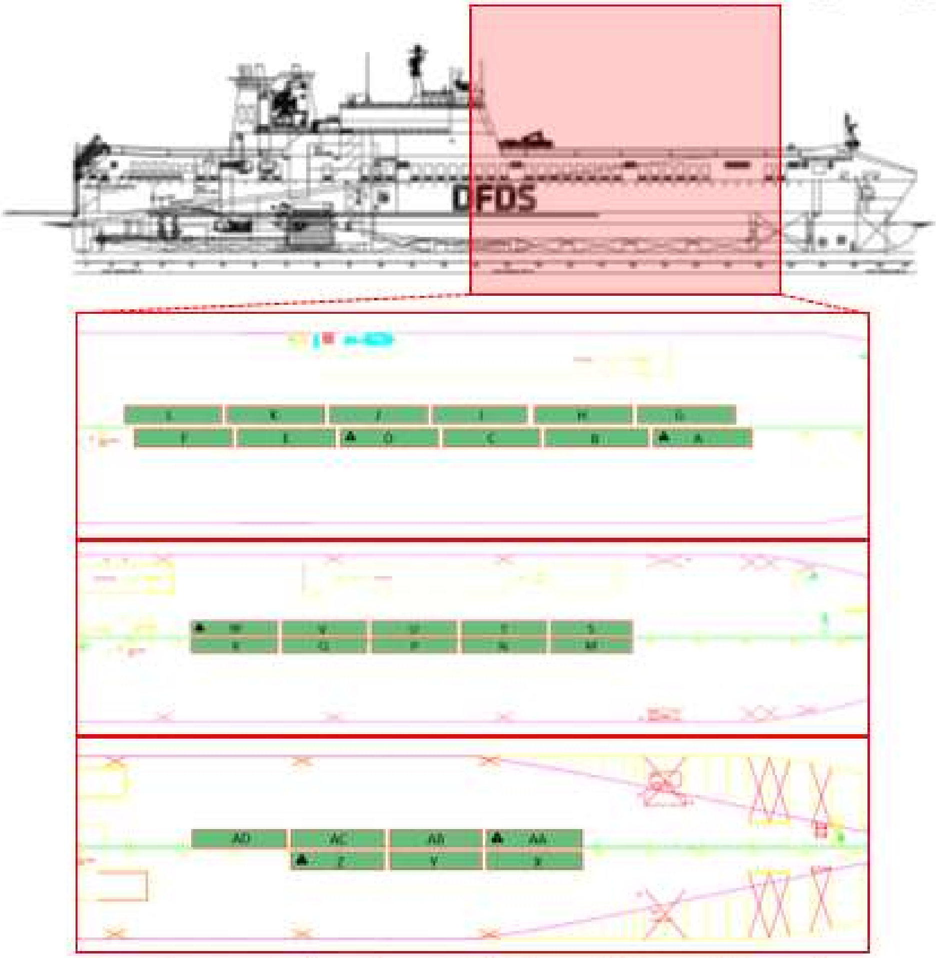

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C	4003	TRAILER	4	1	1
D	4004	TRAILER(8)	4	2	2
E	4005	TRAILER	4	1	1
F	4006	TRAILER	4	1	1
G	4007	EV	4	2	2,5
H	4008	TRAILER	4	1	1
I	4009	TRAILER	4	1	1
J	4010	TRAILER	4	1	1
K	4011	TRAILER	4	1	1
L	4012	CAR	4	2	2
M	3001	CAR	3	2	3
N	3002	CAR	3	2	3
P	3003	CAR	3	2	3
Q	3004	CAR	3	2	3
R	3005	CAR	3	2	3
S	3006	V	3	3	4
T	3007	CAR	3	2	3
U	3008	V	3	3	4
V	3009	V	3	3	4
W	3010	TRUCK(5.1)	3	1	1
X	2001	TRAILER	2	1	1
Y	2002	TRAILER	2	1	1
Z	2003	TRAILER(9)	2	2	2
AA	2004	TRAILER(1.4)	2	2	2,25
AB	2005	TRAILER	2	1	1
AC	2006	TRAILER	2	1	1
AD	2007	TRAILER	2	1	1

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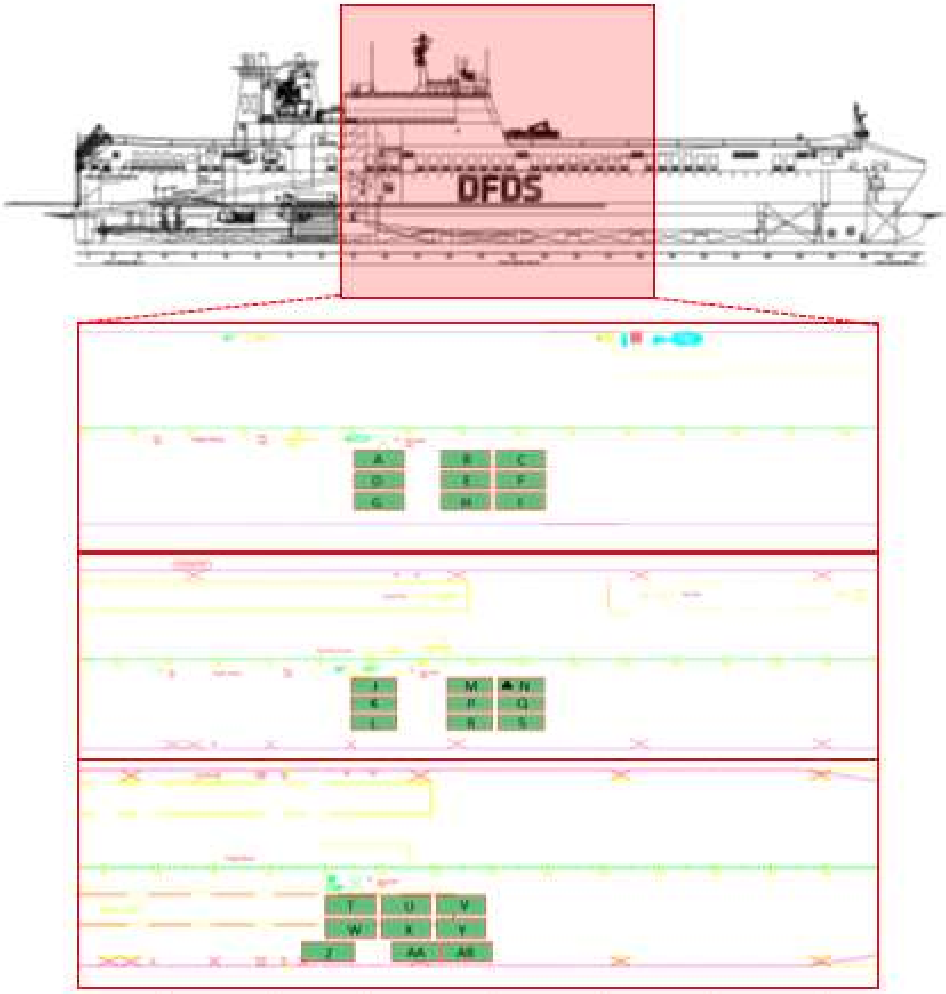

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C	4003	TRAILER	4	1	1
D	4004	CAR	4	2	3
E	4005	V	4	3	4
F	4006	TRAILER	4	1	1
G	4007	TRAILER	4	1	1
H	4008	TRAILER	4	1	1
I	4009	TRAILER	4	1	1
J	3001	TRAILER	3	1	1
K	3002	TRAILER	3	1	1
L	3003	TRAILER	3	1	1
M	3004	TRAILER	3	1	1
N	3005	TRAILER(2.2)	3	2	3
P	3006	V	3	3	4
Q	3007	CAR	3	2	3
R	3008	TRAILER	3	1	1
S	3009	TRAILER	3	1	1
T	2001	TRAILER	2	1	1
U	2002	TRAILER	2	1	1
V	2003	TRAILER	2	1	1
W	2004	TRAILER	2	1	1
X	2005	TRAILER	2	1	1
Y	2006	TRAILER	2	1	1
Z	2007	TRAILER	2	1	1
AA	2008	CAR	2	2	3
AB	2009	V	2	3	4

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2009;V;2.0;6.5;4.56;;;;;;0;2;18;111;120;;1;0;-1
```

11.2 ANNEX B Context-of-use

Main author of the chapter: África Marrero, CIM

11.2.1 High-level description of users

11.2.1.1 Shore-based stowage planner

Responsibilities and Activities: The shore-based stowage planner is responsible for the safe stowage of assigned ships while optimising the utilisation and efficiency of the operation. The main functions include efficient stowage planning which takes account of the safe operation of the ships, without compromising the safety of the crew and/or shore-based staff. The general activities of the position include:

- Alerting the Operations team of any stevedoring issues that may affect the delivery time of the ship.
- Sending stevedoring instructions and liaising with terminal and agents to ensure smooth operations at the terminal
- Contingency (breakdown) re-planning

Training & Education: The shore-based stowage planner should have marine/logistics related qualifications (i.e. ex-seafarer with experience from the ro-ro/ro-pax segment, or equivalent) with a high level of English.

Work Location: Office-like environment ashore.

11.2.1.2 Deck crew

Responsibilities and Activities: Under the direction of the ship's master/chief officer, the deck crew is responsible for the safe and effective operation of the ship, both at sea and in port. All deck operations and maintenance actions are also carried out by the deck crew. Working under the supervision of the Cargo Officer/Chief Mate, the deck crew is also responsible for safe loading and unloading of the ship, as well as lashing of cargo. Underway, it is the deck crew which undertakes the fire patrols in the ro-ro spaces.

Training & Education: In order to carry out any professional maritime activity, it is essential to obtain the Basic Maritime Safety Training certificate, a complete training that is based on the following four basic pillars: survival at sea, firefighting, safety at work and first aid. In the case of this type of ship, the deck crew must also have the following certificates: STCW Basic Safety Training, Basic Maritime Security Training, Passenger Ship Certificate and Initial Specific Health and Safety Training. It is moreover recommended that deck crew is instructed in the safe handling of dangerous goods according to the IMDG code.

Work Location: Work assignments relevant to the LASH FIRE use-cases are performed on the open and enclosed ro-ro decks, subject to weather variations as well as variations in natural and electrical light.

11.2.1.3 Cargo/Loading officer

Responsibilities and Activities: The Cargo/Loading Officer, a role often fulfilled by the ship’s Chief Mate, or by a representative of the port (Port Captain or Cargo Superintendent) is the responsible person for safe and efficient handling and stowage of cargo on board. With the aim of a good distribution of cargo at ports of loading and unloading, in order to obtain the quickest possible turnaround of the ship and minimise dwell time in port, the functions of this crew member include adequate preparation of the deck prior to loading, proper supervision during cargo work (including supervision of deck crew), preservation of the cargo while in transit (lashing, fire patrols) and cooperation/coordination with the relevant port authorities while in port. With respect to the SPT, the main functions of Cargo/Loading officer include:

- Plan and supervise the proper stowage of cargo on board, ensuring safety of life and property, and avoiding excessive stresses[3] on the ship, while achieving minimum immersion at the bow as well as adequate trim and stability[4] during loading and unloading operations and at all stages of the voyage.
- Achieving adequate stowage of cargo that does not obstruct proper and expeditious discharge, considering proper port rotation and also ensuring that the cargo is not over-stowed.
- Preparation of cargo plans, stowage lists, cargo summaries, dangerous cargo lists, etc. Establishing and maintaining a dangerous cargo register.

Training & Education: Merchant marine university studies must be completed which a complement of four-year period as a cadet in a shipping company that includes training at sea and studies in a Registered Training Organization.

Work Location: Deck office/Cargo office, ro-ro decks and weather deck.

11.2.1.4 Tug/tractor driver

Responsibilities and Activities: The tug/tractor driver(s) handle cargo trailers and units that are not self-propelled. Within the context of the LASH FIRE project, the tug/tractor(s) pick up designated cargo units at designated spots in the terminal during loading sequences, and drive/haul them onboard the ship, to be placed at designated stowage positions[5]. During unloading the loading process is repeated in reverse, i.e. the tugs/tractors pick up designated cargo units on the deck of the ship, and drive them to designated parking spots where they will be picked up for hinterland operations.

Training & Education: The driver of the tug/tractor must have a class 1 heavy vehicle licence.

Work Location: The usual working location is in the truck cabin, carrying out the different interactions with the rest of the personnel involved in the loading and unloading processes of the ship.

11.2.1.5 Terminal worker/gate keeper

Responsibilities and Activities: The check-in/terminal worker controls all ship activities, such as loading and unloading of ship cargoes, including gate and quay operations at the terminal. He/she must also supervise, monitor and work closely with the stevedore manager in the unloading and loading of ships and in terminal operations.

Training & Education: Basic education (high school) and previous experience in cargo management.

Work Location: Port terminal pre-loading area.

11.2.1.6 Bridge officer

Responsibilities and Activities: The bridge deck officer is responsible for the organisation of work on board, the preparation of deck department working schedules, calculation of trim, stability and hull girder strength, the corresponding planning and supervision of stowage and/or cargo calculations and operations, the planning and supervision of deck maintenance work, the supervision of safety and fire-fighting equipment (which may, or usually is, assigned to another officer to assist him in this matter),

[3] Calculation and monitoring of hull girder longitudinal stress is beyond the functionality of the SPT
[4] Calculation of ship stability is beyond the functionality of the SPT
[5] This description deviates from the present norm when it comes to non-IMDG cargo units, where the process is less managed.

the preparation of orders necessary for the maintenance and proper operation of the ship, as well as the navigational watch to which he is assigned. The SPT will, as a final step, have the verification and acceptance of the stowage plan, which will be carried out by the Bridge Officer, in addition to the functions related to the interactions of the SPT and FRCM.

Training & Education: The position requires a university education, periods of training as nautical trainees on board ships and, in many cases, passing a professional aptitude test.

Work Location: Ship's bridge, which means that the design of relevant parts of the SPT should take account of nautical practice for light condition variations, platform movement and the impact of other ambient/environmental conditions.

11.2.2 Use cases

11.2.2.1 UC1: Evaluate stowage plan fire safety

Given a suggested stowage plan composed of a list of cargo units and their corresponding location (deck, lane and slot), a value scoring fire safety is returned. Final score also takes into consideration the environment, that is, what are the adjacent cargo units and ship equipment nearby such as LSA (Life Safe Appliances), openings and so on.

D08.3 #7: The system shall provide the user with the visualization of the risk level of cargo located on each deck

D08.3 #8: The system shall provide the user with the visualization of the overall risk level of the ship's cargo

D08.3 #12: The system shall offer the user the possibility to display deck plans of all the predefined ships.

D08.3 #13: The system shall offer the user the possibility to visualize the voyage history of a given ship.

D08.3 #18: The system shall visually identify dangerous goods from other non-dangerous goods by colour coding.

11.2.2.2 UC2: Optimize stowage plan

One of the components of the Stowage Planning Tool is an optimization algorithm that distributes cargo units along available space aiming at reducing overall risk. This function takes a list of cargo units with their associated characteristics: physical attributes such as height, length or weight, DG information if it is the case, electrical connection requirements and other information about the voyage as input. It returns a cargo distribution considering physical layout and location constraints which gives the minimum value for the fire safety score.

11.2.2.3 UC3: Confirmation of cargo unit location

Once a cargo unit is loaded, its location may or may not match the stowage position used by the stowage planning tool. The objective being to have an updated loading status, this use case confirms the location of a cargo unit (deck, lane and slot) and if it is hooked up to an electrical connection, it also records the appropriate identifier. Two different solutions are expected to be needed for this use-case, depending on whether the cargo unit is self-propelled or not.

D08.3 #3: The system shall offer the user the possibility to confirm the location of a loading unit on a parking slot of a deck.

D08.3 #11: The system shall provide the user with an incident table if the load cannot be located where expected.

11.2.2.4 UC4: Disable area for loading

If, for any reason before or during the loading process, the use of specific areas of the ship must be blocked for operational purposes, and are thus not available as cargo space, such information must be entered into to the Stowage Planning Tool. Information needed includes the deck, the lane and the range by means of frame start and frame end.

11.2.2.5 UC5: Monitoring of loading process

Returns the current loading status of the ship, that is, the list of already loaded units with their corresponding placement, raised alarm for each unit (if any) and additional extra information.

D08.3 #4: The system shall always offer the visualization of the current status of the cargo unit.

D08.3 #5: The system shall offer the user the possibility to extract the current cargo manifest.

D08.3 #6: The system shall offer the user the visualization of a unit load and its individual risk level.

D08.3 #14: The system shall offer in real status the % of the loading process (Cargo currently confirmed and loaded on ship/total cargo to be loaded on ship), at deck and ship level.

D08.3 #20: The system shall allow marking of the unit load being loaded and unloaded.

D08.3 #22: The system must be able to display information of a cargo unit in such a way that all users can identify the cargo.

11.2.2.6 UC6: Stowage information supporting fire management

This use case pertains to retrieve, for a given unit, information which can be useful to support fire management. It includes recommendations and constrain locations based on the cargo type (for example: Fore and Aft - Separated from LSA at least 3 metres or place on weather deck).

D08.3 #2: The system will provide the user with information on the selected load unit.

D08.3 #10: The system shall provide cargo location safety recommendations for each cargo unit.

D08.3 #24: The system shall allow searches within the loads

11.2.2.7 UC7: Validate distribution

This use case serves to provide input to/update the cargo distribution used in the Stowage Planning Tool in the cases where an external function/system is used for non-fire related stowage planning. Since the algorithm supporting fire hazard management in such cases operates as a plug-in, that is, that the external software system calls this LASH FIRE component in order to score or modify a given cargo distribution, a mismatch can result in cases where the LASH FIRE component performs optimization. By invoking UC7, a user can ensure a match between the systems.

11.2.2.8 UC8: Get location for unit

For each cargo unit that is going to be loaded, this use case gets the suggested location based on the validated stowage plan.

D08.3 #1: The system will provide the user with information on the selected load unit.

11.2.2.9 UC9: Reserved for internal purposes

N/A

11.2.2.10 UC10: Reject unit for loading

During the loading process and before a cargo unit is entering the ship, a LASH FIRE feature is that every single unit is scanned through the tunnel of sensors (so-called VHD). Depending on the alarm raised, the unit may be discarded which means that it will not be finally loaded to the ship. The identifier of the unit must be notified to the Stowage Planning Tool to manage the availability of the slot previously assigned to the unit and re-run the cargo distribution algorithm considering already loaded units and remaining ones.

D08.3 #9: The system shall offer the user the possibility to visualize the information provided by external systems such as sensors and drones, for a cargo unit.

11.2.2.11 UC11: End of loading/discharging

Notifies the end of the stowage process. Full information for each cargo unit is generated, merging the last loading status and additional data from risk assessment and VHD. This information can be broadcasted/transferred to other data consumers, such as FRMC.

11.2.2.12 UC12: Cargo unit feedback

Use case that allows to add free text to a specific unit including any kind of information.

D08.3 #15: The system shall offer users the possibility to do manual annotations on each loading unit.

D08.3 #16: The system shall provide users with the possibility to do manual annotations on each deck.

D08.3 #17: The system shall provide users with the ability to do manual annotations on the overall ship's view.

11.2.2.13 UC13: Fire Patrol Report

This use case will generate the data needed by an external system to prepare a specific report for fire patrol purposes, containing recommendations based on the final cargo distribution at/after departure.

11.2.2.14 UC14: No-show/rearrange cargo

Confirmation of a no-show for a given unit. Similar to UC10, but the unit is tagged in a different way to preserve loading status consistency. Considerations about available space management above-mentioned are also valid.

11.3 ANNEX C: Table definition

This section contains in alphabetical order, for each table from the data model, its definition, which includes the name of the attributes, their basic data type and a brief description of the meaning. In case of references to other tables (foreign keys), the referenced attribute is also mentioned. Attribute used as primary key, if any, is highlighted in grey colour.

Basic data types just include INT (INTEGER, which may also be used for binary/Boolean values), REAL (REAL) and TXT (TEXT, which may include specific formats for defining dates, for example). Specific data types will be selected during the implementation phase depending on the technology used.

All tables with the prefix “MT_” are master tables. Master tables are tables which contents are static (or expected to have no changes for a long time) and are used to store pre-fixed values.

11.3.1 Cargo Distribution Database

11.3.1.1 ALLOWED_CARGO_TYPE

Filters high level type of cargo that can be stowed in a given deck based on the categories from the cargo fire hazard database (table MT_FIREORIGIN2) used for risk assessment. For more information about fire hazard database and risk assessment, see IR08.3 and IR08.15 respectively.

Table ALLOWED_DG_CARGO will always override these settings if inconsistencies are found.

Table 37. ALLOWED_CARGO_TYPE table definition

Attribute	Type	References	Description
id_deck	INT	DECK.uid	Deck
cargo_type	TXT	MT_FIREORIGIN2.uid	Cargo type allowed in the deck

The images below show an example based on a real drawing of a ship where weather deck is identified as 4 and where only trailers (mapped to TRUCK type as basic record from MT_FIREORIGIN2) are allowed.

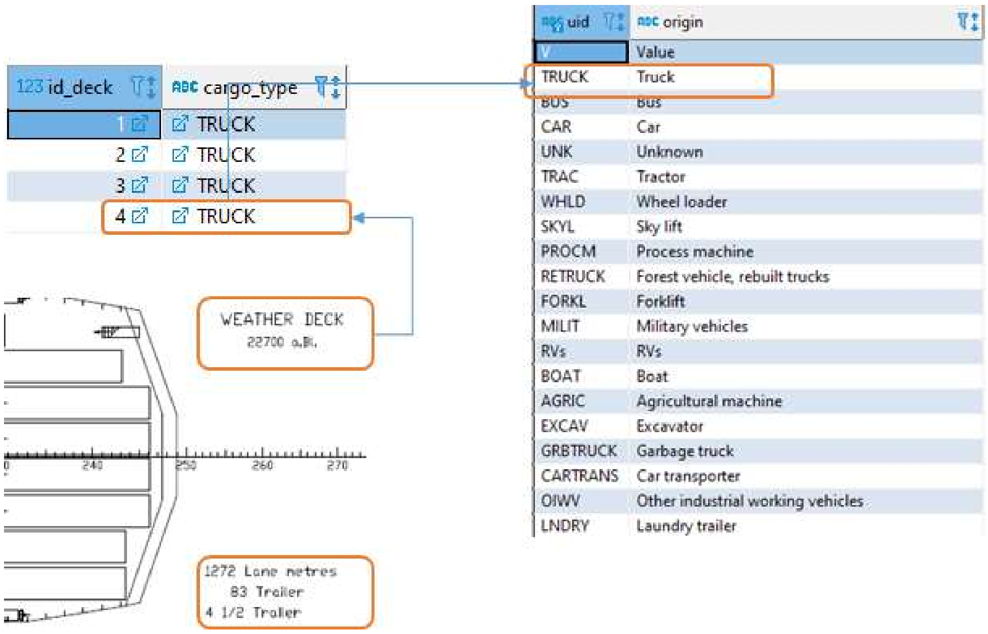


Figure 34. Example of the use of ALLOWED_CARGO_TYPE

11.3.1.2 ALLOWED_DG_CARGO

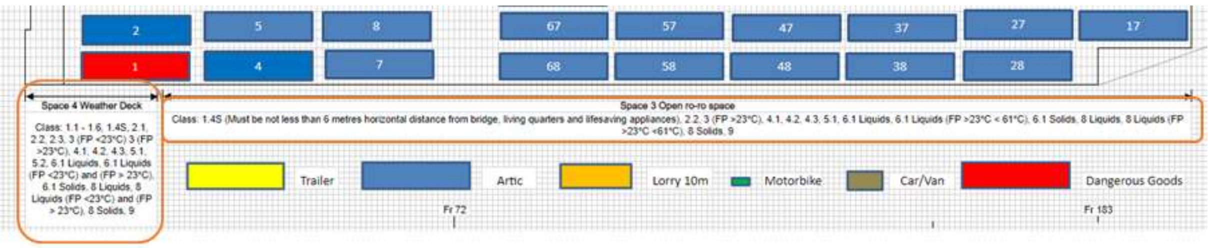
This table is used to define how suitable is a given ship for the carriage of dangerous goods together with the support of secondary master tables to manage what (class), where exactly (deck and frames) and how (packed/bulk, solid/liquid, flashpoint, flammable or not…).

There is a check constraint for attributes *frame_start* and *frame_end* that is defined as *frame_end* > *frame_start*.

Table 38. ALLOWED_DG_CARGO table definition

Attribute	Type	References	Description
id_deck	INT	DECK.uid	Deck
id_dg_class	TXT	MT_DG_CLASS.uid	DG class involved
package_type	TXT	MT_DG_PACKAGE.uid	Package type used
frame_start	INT		Start frame of the deck where restriction applies
frame_end	INT		End frame of the deck where restriction applies
dg_flashpoint	TXT	MT_DG_PACKING.uid	Flashpoint level
dg_state	TXT	MT_DG_STATE.uid	State of the DG
flammable	INT		Indicates if the cargo is flammable or not

The images below show examples of definition for allowed DG cargo taken from materials provided by operators.



Appendix

	Cargo Space	1	2	3	4	5
	Cargo Space Name	**Deck 1 Tanktop Cargo Space I Frame 97 to 217**	**Deck 2 main Deck Car go Space II Fr -3 to 237**	**Deck 3 Upper Deck Car go Space III Fr. -3 - 246**	**Deck 4 weather Cargo Space IV Fr 75 to 136**	**Deck 4 Weather Weather Deck Fr 0 to 75 & 136 to 246**
Class	Type *	**3A**	**3A**	**3C**	**3C**	**6**
1.1-1.6	Explosives	---	---	---	---	**P**
1.4(S)	Explosives, Division 1.4 Compatibility group 'S'	**P**	**P**	**P**	**P**	**P**
2.1	Flammable Gases	---	---	---	---	**P**
2.2	Non-flammable, Non-toxic Gases	**P**	**P**	**P**	**P**	**P**
2.3	Toxic Gases (flammabie)	---	---	---	---	---

Figure 35. Example of definitions for allowed DG cargo

The following image partially shows how information detailed in the second of the previous samples could be stored to be correctly considered by software components.

39	1	4.3	P	97	217	[NULL]	L	[NULL]
40	2	4.3	P	3	237	[NULL]	L	[NULL]
41	3	4.3	P	3	246	[NULL]	L	[NULL]
42	4	4.3	P	0	246	[NULL]	L	[NULL]
43	1	4.3	P	97	217	[NULL]	S	[NULL]
44	2	4.3	P	3	237	[NULL]	S	[NULL]
45	3	4.3	P	3	246	[NULL]	S	[NULL]
46	4	4.3	P	0	246	[NULL]	S	[NULL]
47	1	5.1	P	97	217	[NULL]	[NULL]	[NULL]
48	2	5.1	P	3	237	[NULL]	[NULL]	[NULL]
49	3	5.1	P	3	246	[NULL]	[NULL]	[NULL]
50	4	5.1	P	0	246	[NULL]	[NULL]	[NULL]
51	4	5.2	P	0	75	[NULL]	L	[NULL]
52	4	5.2	P	136	246	[NULL]	L	[NULL]
53	4	6.1	P	0	75	II	L	[NULL]
54	4	6.1	P	136	246	II	L	[NULL]
55	3	6.1	P	3	246	III	L	[NULL]
56	4	6.1	P	0	246	III	L	[NULL]
57	3	6.1	P	3	246	[NULL]	L	0
58	4	6.1	P	0	246	[NULL]	L	0
59	1	6.1	P	97	217	[NULL]	S	[NULL]
60	2	6.1	P	3	237	[NULL]	S	[NULL]
61	3	6.1	P	3	246	[NULL]	S	[NULL]
62	4	6.1	P	0	246	[NULL]	S	[NULL]
63	4	8	P	0	75	II	L	[NULL]
64	4	8	P	136	246	II	L	[NULL]
65	1	8	P	97	217	III	L	[NULL]
66	2	8	P	3	237	III	L	[NULL]
67	3	8	P	3	246	III	L	[NULL]
68	4	8	P	0	246	III	L	[NULL]

Figure 36. Example of the use of ALLOWED_DG_CARGO

11.3.1.3 CARGO_UNIT

Includes all information about a cargo unit which is expected to be loaded in a ship.

Table 39. CARGO_UNIT table definition

Attribute	Type	References	Description
Uid	TXT		Unique identifier of the unit
type	TXT	MT_FIREORIGIN2.uid	Based on FIRE_ORIGIN2 from cargo fire hazard database. Used to support risk assessment.
height	REAL		Used to check if it fits in a deck (meters)
length	REAL		To manage space allocation (meters)
weight	REAL		To support future embedded stability calculation (kg)
dg_class	TXT	MT_DG_CLASS.uid	Used to support location constraints for DG cargo
dg_state	TXT	MT_DG_STATE.uid	
dg_packing	TXT	MT_DG_PACKING.uid	
dg_package	TXT	MT_DG_PACKAGE.uid	
flammable	INT		
requiresConnection	INT		Binary value. Valid for EV or reefer units
id_deck	INT	DECK.uid	Supports *plugin* mode since it needs suggested location provided by SW from operators to calculate the *score*.
id_lane	INT	LANE.uid	
frame_start	REAL		
frame_end	REAL		
id_connection	INT	ELECTRICAL_CONNECTIONS.uid	
id_route	INT	ROUTE.uid	Route where the voyage defined by *portOrigin* and *portDestination* is located
portOrigin	INT		Identifier of the port where the cargo unit is loaded
portDestination	INT		Identifier of the port where the cargo unit is unloaded

Attributes *portOrigin* and *portDestination*, together with *id_route*, are used to support routes where several port calls exist between the initial port and the final destination as described in the VOYAGE table.

11.3.1.4 DECK

Defines available decks for cargo in a given ship.

Table 40.DECK table definition

Attribute	Type	References	Description
uid	INT		Internal identifier
id_layout	INT	LAYOUT.uid	Reference to the layout
number	INT		Number assigned to the deck (bottom-up)
name	TXT		Name assigned to the deck
id_type	TXT	MT_DECK_TYPE.uid	Reference to the type of deck

The figure below shows an example which could be valid for the generic ship *Magnolia Seaways* (DFDS).

uid	id_layout	number	name	id_type
1	1	1	Tank Top	C
2	1	2	Main Deck	C
3	1	3	Upper Deck	O
4	1	4	Weather Deck	W

Figure 37. Example of the use of DECK table for Magnolia Seaways (DFDS).

11.3.1.5 DECK_DEPENDENCY

Defines what is the dependency between decks in terms of risk assessment. That is, given a deck, in what other (besides the same) decks above and below other units must be selected when considering surrounding units.

Table 41.DECK table definition

Attribute	Type	References	Description
id_deck	INT	DECK.uid	Deck identifier
id_deckLocation	TXT	MT_DECKLOCATION.uid	Reference to the location of the dependent deck
Id_dependentDeck	INT	DECK.uid	Dependent Deck identifier

11.3.1.6 FRAME_SPACING

Includes information about physical characteristics of a given ship to give support to the cargo distribution (accuracy for final placements) from the available space management point of view.

Table 42.FRAME_SPACING table definition

Attribute	Type	References	Description
id_ship	TXT	SHIP.imo	Reference to the ship
frame_start	INT		Initial frame of the ship
frame_end	INT		End frame of the ship
spacing	INT		Length between two consecutive frames that are located in-between frame_start and frame_end (in milimeters).

There is a check constraint for attributes *frame_start* and *frame_end* that is defined as *frame_end* > *frame_start*.

The above image shows an example of use for this table:

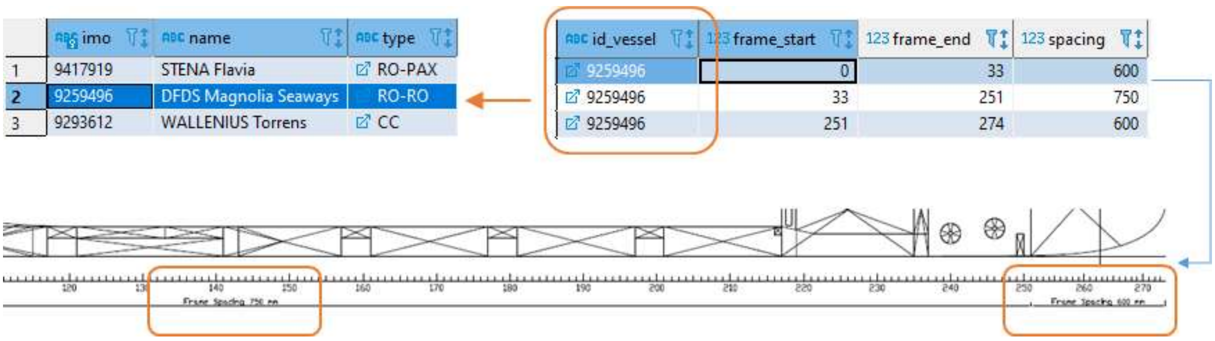


Figure 38. Example of use of FRAME_SPACING table

11.3.1.7 LANE

Contains information about existing lanes for a given deck.

There is a check constraint for attributes *frame_start* and *frame_end* that is defined as *frame_end* > *frame_start*. Values for both *cline_start* and *cline_end* can be negative (PORT) or positive (STARBOARD).

Table 43.LANE table definition

Attribute	Type	References	Description
uid	INT		Internal identifier
id	TXT		Human-friendly name for the deck
id_deck	INT	DECK.uid	Reference to the deck where the lane is located
frame_start	REAL		Starting frame from which cargo can be stowed
frame_end	REAL		End frame where cargo can be stowed
cline_start	REAL		Distance between the center line and the start of the lane
cline_end	REAL		Distance between the center line and the end of the lane
max_height	INT		Maximum height allowed for cargo (meters)
id_ship_part	TXT	MT_SHIP_PARTS.uid	Identifier to the specific area of the ship

The attribute *id* is set using the following guidelines:

- Lanes are numbered from 1 to N, where 1 is the closest one to the middle/center line of the ship (which may contain a lane zero); +N is the closest one to the starboard side and –N the closest one to the port side.
- If different sets of lanes exist, then numbering is assigned from aft to forward as shown in the picture below.
- Lanes can be irregular even defined for just one single spot as L+2

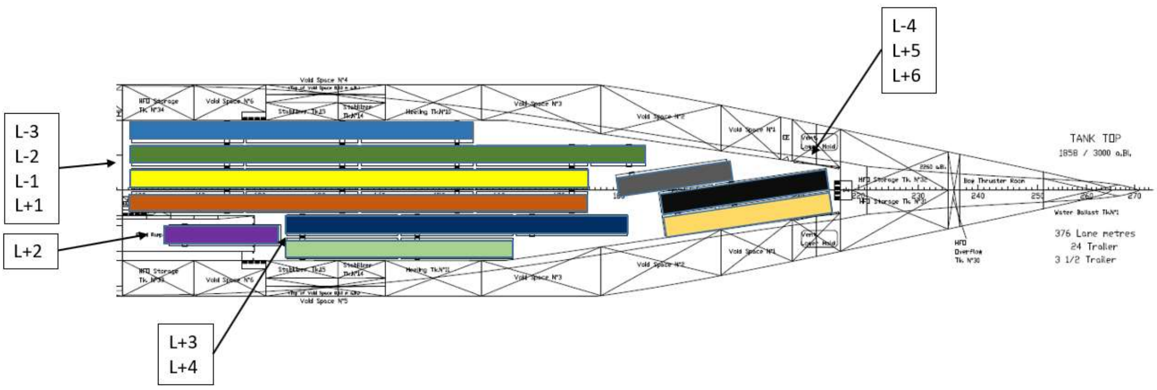


Figure 39. Example of use of LANE table

11.3.1.8 LAYOUT

Allows potential different configurations for a given ship (for example: upper deck disabled). By default, will be used to store information about the usual/normal configuration.

Table 44.LAYOUT table definition

Attribute	Type	References	Description
uid	INT		Internal identifier
id_ship	TXT		Reference to the ship
description	TXT		

11.3.1.9 LOCATION_CONSTRAINTS

The main objective of this table is to support the algorithm when the software is running as a plugin. When the software operates in this mode, it just scores a given cargo distribution but, optionally, it can suggest certain modifications in order to reduce the risk.

These modifications can be limited using this table, where constraints in a per-unit-basis are defined by means of the areas where the units cannot be placed (please note that multiple records can be found for a given unit).

Table ALLOWED_DG_CARGO will always override these settings if inconsistencies are found.

There is a check constraint for attributes *frame_start* and *frame_end* that is defined as *frame_end* > *frame_start*.

Table 45. CARGO_UNIT_CONSTRAINTS table definition

Attribute	Type	References	Description
id_cargo_unit (*)	TXT	CARGO_UNIT.uid	Cargo unit involved
id_deck	INT	DECK.uid	Specific areas where a given cargo unit is not allowed to be placed.
id_lane	INT	LANE.uid	
frame_start	INT		
frame_end	INT		

(*) Aiming at adding value to this table, attribute *id_cargo_unit* can also be null, which supports the feature of disabling areas in order to make them unavailable during the distribution. Summarising, if the identifier of the cargo unit is provided, then the constraints only apply to these units; if no identifier is provided then the constraints apply to every cargo.

11.3.1.10 MT_DECKLOCATION

Includes possible values for considered types of deck.

Table 46.MT_DECK_TYPE table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description of the location for a deck

As master table it contains static values which are shown in the next table:

Table 47.MT_DECKLOCATION contents

uid	name
S	Same deck
U	Up (above deck)
D	Down (below deck)

11.3.1.11 MT_DECK_TYPE

Includes possible values for considered types of deck.

Table 48.MT_DECK_TYPE table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
name	TXT		Descriptive name of the type

As master table it contains static values which are shown in the next table:

Table 49.MT_DECK_TYPE contents

uid	name
O	Open
C	Closed
W	Weather

11.3.1.12 MT_DG_CLASS

Includes possible values for considered dangerous goods class.

Table 50.MT_DG_CLASS table definition

Attribute	Type	References	Description
uid	TXT		Identifier which corresponds to the class
description_class	TXT		Description of the class
description_subclass	TXT		Description of the subclass

As master table it contains static values which are shown in the next table:

Table 51.MT_DG_CLASS contents

uid	description_class	Description_subclass
1.1	Explosive substances and articles	Substances and objects that present a risk of explosion of the entire mass
1.2	Explosive substances and articles	Substances and objects that present a projection risk, but not an explosion risk of the whole mass
1.3	Explosive substances and articles	Substances and objects that present a fire risk and a risk of occurrence small shock wave or projection effects, or both, but not a risk explosion of the entire mass
1.4	Explosive substances and articles	Substances and objects that do not present any considerable risk
1.5	Explosive substances and articles	Very insensitive substances that present a risk of explosion of the entire mass
1.6	Explosive substances and articles	Extremely insensitive objects that do not present a risk of explosion of the entire mass
2.1	Gases	Flammable gases
2.2	Gases	Non-flammable, non-toxic gases
2.3	Gases	Toxic gases
3	Flammable liquids	-
4.1	Flammable solids	Flammable solids, self-reactive substances, polymerizing substances and solid desensitized explosives
4.2	Flammable solids	Substances liable to spontaneous combustion
4.3	Flammable solids	Substances which, in contact with water, emit flammable gases
5.1	Oxidizing substances and organic peroxides	Oxidizing substances
5.2	Oxidizing substances and organic peroxides	Organic peroxides
6.1	Toxic substances and infectious substances	Toxic substances
6.2	Toxic substances and infectious substances	Infectious substances
7	Radioactive goods	-
8	Corrosive substances	-
9	Miscellaneous dangerous substances and articles	-

11.3.1.13 MT_DG_PACKAGE

Includes possible values for considered types of package.

Table 52.MT_DG_PACKAGE table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 53.MT_DG_PACKAGE contents

uid	name
B	Bulk goods
P	Packaged goods

11.3.1.14 MT_DG_PACKING

Includes possible values for considered types of packing.

Table 54.MT_DG_PACKING table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
flashpoint_desc	TXT		Description

As master table it contains static values which are shown in the next table:

Table 55.MT_DG_PACKING contents

uid	name
I	-
II	less than 23 degrees Celsius
III	greater or equal than 23 and lower or equal than 60 degrees Celsius

11.3.1.15 MT_DG_STATE

Includes possible values for considered types of state.

Table 56.MT_DG_STATE table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 57.MT_DG_STATE contents

uid	name
S	Solid
L	Liquid

11.3.1.16 MT_FIREORIGIN2

Includes possible values for considered fire origins as defined in the cargo fire hazard database.

Table 58.MT_FIREORIGIN2 table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
origin	TXT		Description

As master table it contains static values which are shown in the next table:

Table 59.MT_FIREORIGIN2 contents

uid	name
V	For internal use
TRUCK	Truck
BUS	Bus
CAR	Car
UNK	Unknown
TRAC	Tractor
WHLD	Wheel loader
SKYL	Sky lift
PROCM	Process machine
RETRUCK	Forest vehicle, rebuilt trucks
FORKL	Forklift
MILIT	Military vehicles
RVs	RVs
BOAT	Boat
AGRIC	Agricultural machine
EXCAV	Excavator
GRBTRUCK	Garbage truck
CARTRANS	Car transporter
OIWV	Other industrial working vehicles
LNDRY	Laundry trailer

LPG	LPG
MTH	Methanol
HYD	Hydrogen fuel-cell
EV	Electrical vehicle
LNGCNG	LNG/CNG
EXPL	Explosive
GAS	Gas
FLML	Flammable liquid
FLMS	Flammable solid
PEROX	Oxidizing substances and organic peroxides
TOXIC	Toxic substances and infectious substances
RADIO	Radioactive goods
CORROS	Corrosive substances
MISCDG	Miscellaneous dangerous substances and articles
UNDECDG	Undeclared DG
PROLLS	Paper rolls
PPUPL	Paper rolls
FIBRE	Fibre boards
CARDBOX	Cardboard boxes

11.3.1.17 MT_LOADING_STATUS

Includes possible values for considered states of a cargo unit supporting the stowage process and the distribution algorithm. For example, the first distribution for a given ship (pre-loading stage), voyage and list of cargo units will set to NOT_LOADED. During the loading stage, units are updated according the stowage progress and if, for some reason, cargo distribution must be executed again, the algorithm will consider current loading status (all units with LOADED) and will distribute pending cargo (all units with NOT_LOADED).

Table 60.MT_LOADING_STATUS table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 61.MT_LOADING_STATUS contents

uid	name
NO_SHOW	Cargo unit not arrived to terminal
NOT_LOADED	Cargo unit in terminal but not loaded
LOADED	Cargo unit loaded
DISCARDED	Cargo unit discarded during loaded

11.3.1.18 MT_SERVICE_TYPE

Includes possible values for services that are tracked in the database (so far, all except *ResetService*).

Table 62.MT_SERVICE_TYPE table definition

Attribute	Type	References	Description

uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 63.MT_SERVICE_TYPE contents

uid	name
Distribution	Runs the cargo distribution algorithm
Score	Runs the scoring service for a given cargo distribution
RemoveService	Deletes results of a certain (or all) service

11.3.1.19 MT_SHIPELEMENT_TYPE

Includes possible values for considered types of ship elements and other infrastructure.

Table 64.MT_SHIPELEMENT_TYPE table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 65.MT_SHIPELEMENT_TYPE contents

uid	name
EC	Electrical Connection
LBY	Life buoys
LJK	Life jacket
LRT	Life raft
RB	Rescue boat
RPF	Rocket parachute flares
LEA	Launching and embarkation appliances
RMP	Ramp
EMEX	Emergency exit
MV	Mechanical ventilation
NV	Natural ventilation
CCR	Control centre or control room

11.3.1.20 MT_SHIP_PARTS

Includes possible values for considered parts of the ship.

Table 66.MT_SHIP_PARTS table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 67.MT_SHIP_PARTS contents

uid	name
PORT	PORT SIDE (left side of the ship)
STARBOARD	STARBOARD SIDE (right part of the ship)
FWD	Front side
AFT	Rear side
CLINE	Centre line

11.3.1.21 MT_SHIP_TYPE

Includes possible values for considered types of ship.

Table 68.MT_SHIP_TABLE table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 69.MT_SHIP_TABLE contents

uid	name
RO-RO	Cargo ship
RO-PAX	Passenger ship
CC	Vehicle carrier

11.3.1.22 MT_VHD_ALARM

Includes possible values for considered alarms raised during the scanning of the unit in the VHD System.

Table 70.MT_VHD_ALARM table definition

Attribute	Type	References	Description
uid	TXT		Internal identifier
description	TXT		Description

As master table it contains static values which are shown in the next table:

Table 71.MT_VHD_ALARM contents

uid	name
NO_ALARM	No alarm generated
WARNING	Warning
ALARM	Alarm

11.3.1.23 ROUTE

Contains potential routes for a given ship. Information here is used together with table VOYAGE in order to calculate distance between ports. Field *departure* is used to distinguish different itineraries for routes that share the same name (description). For example, route name ”R” departing at 8am could go from port P1 to P5 and the same route ”R” departing at 4pm could go from port P1 to P5 with an intermediate call P3.

An alternative to manage these situations could be using different names (for example, ”Route R (Direct)” and ”Route R (Non Direct)”) but sometimes the commercial reference uses the same name and the difference between them is known because of the departure time.

In addition, as a future extension, departure time adds information that could be used to assess the risk in case of time of departure has a relevant impact.

Table 72.ROUTE table definition

Attribute	Type	References	Description
Uid	INT		Internal identifier
description	TXT		Description
departure	TXT		Time of departure
id_ship	TXT	SHIP.imo	Ship associated to the route

11.3.1.24 SERVICE

This table is just used to manage services executed by the algorithm. In other words, it supports the possibility of running multiple times the algorithm without the need of removing outputs from previous executions.

Table 73. SERVICE table definition

Attribute	Type	References	Description
uid	INT		Internal identifier using *autoincrement* SQL feature for an automatic management of the identifier. This feature creates a *sqlite_sequence* table in the database.
id_service_type	TXT	MT_SERVICE_TYPE.uid	Type of service executed
id_layout	INT	LAYOUT.uid	Layout used to run the algorithm
timestamp	TXT		Date and time when the outputs have been generated
id_route	INT	ROUTE.uid	Route used to run the algorithm
description	TXT		Free text field that can be used to create a description or even to automatically fulfil with constraints and parameters used.
completed	INT		Indicates weather the services has been completed or not

Please note that *id_layout* allows to know what is the ship used.

11.3.1.25 SERVICE_UNITS

Provides persistence for the cargo distribution generated by the algorithm. It stores, for each cargo unit involved in the execution, its suggested location in the ship by means of {deck + lane + frame_start + frame_end} together with their initial location as well as score values.

Table 74. SERVICE_UNITS table definition

Attribute	Type	References	Description
id_service	INT	CARGO_DISTRIBUTION.uid	References the execution of the algorithm
id_cargo_unit	TXT	CARGO_UNIT.uid	Cargo unit involved
id_deck	INT	DECK.uid	Suggested deck
INIT_id_lane	INT	LANE.uid	Initial lane
id_lane	INT	LANE.uid	Suggested lane
INIT_frame_start	REAL		Start of initial slot
frame_start	REAL		Start of suggested slot
INIT_frame_end	REAL		End of initial slot
frame_end	REAL		End of suggested slot
id_connection	INT	ELECTRICAL_CONNECTIONS.uid	If needed, identifier of the suggested electrical connection
RS0	INT		Initial value for RS_0
INIT_RS	REAL		Initial value for RS
RS	REAL		Value for RS after distribution
loading_status	TEXT	MT_LOADING_STATUS.uid	Status of the cargo unit
alarm	TEXT	MT_VHD_ALARM	Alarm type generated in VHD
feedback	TEXT		Free text for any purpose
timestamp	TEXT		Date and time of the last change of the loading _status

11.3.1.26 SHIP

Contains the ships that are being used. It could be a master table since in the project three generic ships are being used but design tries to be scalable and, therefore, new ships could be added in the future without a relevant impact in the development.

This table uses attribute *imo* instead of *uid* as it is a term well known by the users.

Table 75.SHIP table definition

Attribute	Type	References	Description
imo	TXT		Internal identifier corresponding to the IMO number
Name	TXT		Name of the ship
type	TXT	MT_SHIP_TYPE.uid	Type of ship

Although it is not a master table, the next table shows the information concerning the three generic ships considered in the project.

Table 76.SHIP contents

imo	Name	Type
9417919	STENA Flavia	RO-PAX
9259496	DFDS Magnolia Seaways	RO-RO
9293612	WALLENIUS Torrens	CC

11.3.1.27 SHIP_ELEMENTS

This table is designed to support the management of infrastructure and elements of the ship that may influence the placement of a cargo unit.

Table 77.SHIP_ELEMENTS table definition

Attribute	Type	References	Description
uid	INT		Internal identifier
id_deck	INT	DECK.uid	Deck where the connection is located
id_lane	INT	LANE.uid	Attributes that define the area covered by the connection for a given lane.
frame_start	INT		
frame_end	INT		
id_type	TXT	MT_SHIPELEMENT_TYPE	Reference to the type of element

For each element, its scope is *approximately* defined by means of the area in-between *frame_start* and *frame_end* of a lane (allowing more than one lane with different *frame_start* and *frame_end* values).

There is a check constraint for attributes *frame_start* and *frame_end* that is defined as *frame_end* > *frame_start*.

The image below represents a simplification on how can be used this table to define available electrical connections. For the connection shown, units can be reached if they are placed between frame 117 and 130 of lanes L-1, L-2 and L-3. Of course, since information can be adjusted in a per-lane basis, start and end frames for L-1, L-2 and L-3 could be different.

For the specific case of electrical connections, there are the following assumptions:

1. there are not enough electrical connections for all cargo units that can be loaded in a deck.
2. for those units that need to be connected, they must be placed in specific spots to ensure the cable reaches the unit.

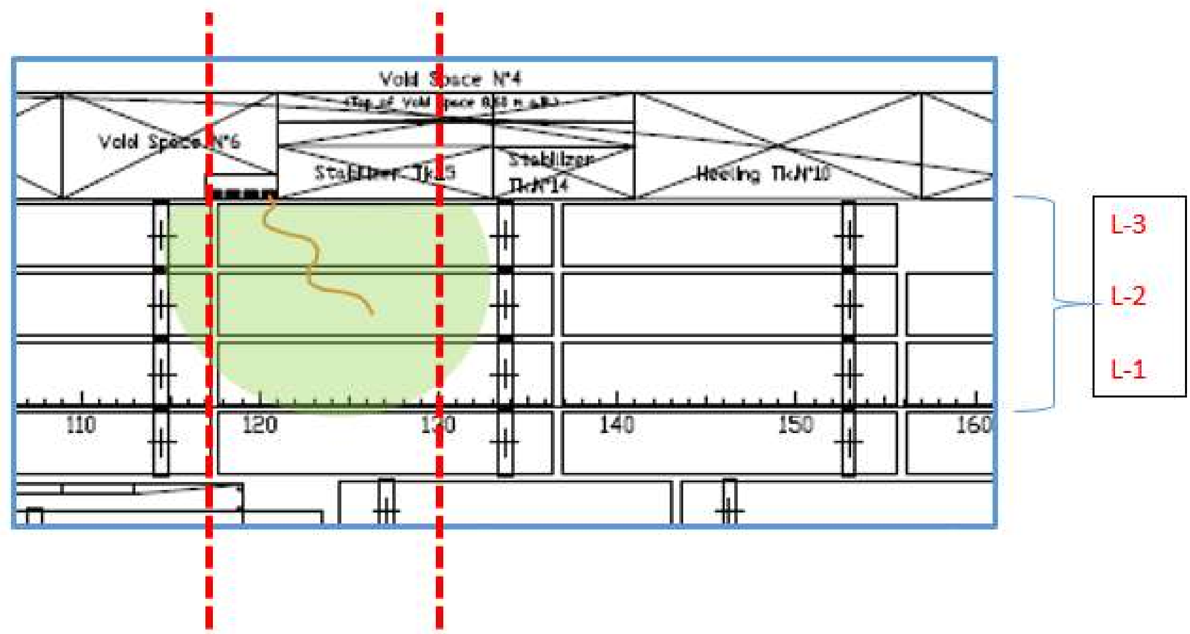


Figure 40. Example of use of electrical connections

The idea behind electrical connections is also applied to the rest of elements. This table allows the definition of an influence area which is considered when distributing the cargo.

11.3.1.28 TEST_INDEX

Contains an enumeration of available tests with results to be compared with the outputs of an execution depending on the use of the related configuration parameters.

Table 78.TEST_INDEX table definition

Attribute	Type	References	Description
uid	TXT		Identifier
id_service_type	TXT		Service associated to the test
description	TXT		Optional description

This table has been populated according to values as per **¡Error! No se encuentra el origen de la referencia.**.

11.3.1.29 TEST_RESULTS_SCORE

Stores the expected values for both RS_0 and RS for a given test.

Table 79.TEST_INDEX table definition

Attribute	Type	References	Description
id_test	TXT	TEST_INDEX.uid	Identifier
id_cargo_unit	TXT		Identifier of the unit
RS0	INT		Expected value for RS_0

RS	REAL		Expected value for RS

This table has been populated according to values as per **¡Error! No se encuentra el origen de la referencia.**.

11.3.1.30 VOYAGE

Table mainly used to define origin and destination, including potential intermediate calls, for a given route. The attributes *pax* and *distance* are used during the risk assessment and values for *portOrigin* and portDestination contain specific values as follows:

- 0 for the initial port
- -1 for the final destination
- Values from 1 to N for intermediate calls, if any.

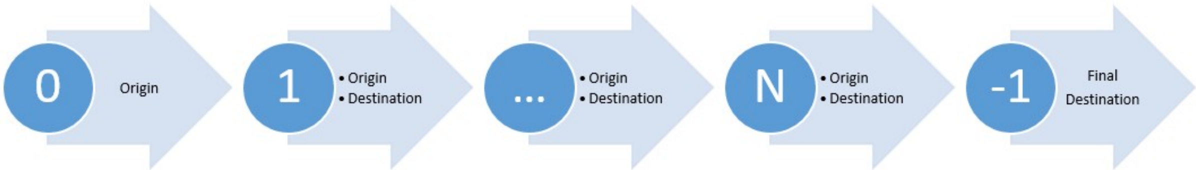


Figure 41. Use of portOrigin and portDestination attributes

There is no unique identifier for the records of this table since they can be uniquely identified by the pair (portOrigin, portDestination). In that sense, a check constraint is defined for them following the next rules:

1. When the route is composed of just one single voyage then the voyage will be defined with *portOrigin == 0* and *portDestination == -1*
2. In the case of routes with two voyages, there will be two records:
   a. One record with *portOrigin == 0* and *portDestination == 1*
   b. One record with *portOrigin == 1* and *portDestination == -1*
3. In the case of routes with N voyages where N>2:
   a. One record with *portOrigin == 0* and *portDestination == 1*
   b. A set of records with *portOrigin == p* and *portDestination == portOrigin+1* (***for all p values in the range [1, N-2], both included***)
   c. One record with *portOrigin == N-1* and *portDestination == -1*

In other words, the first valid value for *portOrigin* is always 0, which represents the starting port of a given route (also matches with the value for *portOrigin* of the first voyage in case of routes with multiple voyages). The value for the last *portDestination* is always -1, which represents the final port of a given route (also matches with the value for *portDestination* of the last voyage in case of routes with multiple voyages). If the route is single voyage, then *portOrigin* is 0 and *portDestination* is -1. If there are more than one voyages, the intermediate port calls are numbered from 1 to N as follows: {0, [1, 2,...N], -1}, so the pairs for [*portOrigin, portDestination*] should be: {[0,1], [1,2],...,[N-1, N], [N,-1]}.

Then, for a given route with intermediate calls, there will be more than one record with the same value for *id_route* and the corresponding *portOrigin* and *portDestination* values.

Table 80.VOYAGE table definition

Attribute	Type	References	Description
uid	INT		Unique identifier
id_route	INT	ROUTE.uid	References the route
portOrigin	INT		Defines a port of origin

portDestination	INT	MT_SHIP_TYPE.uid	Defines a port of destination
pax	INT		Number of passengers during the path portOrigin-portDestination
distance	REAL		Distance between portOrigin and porDestination (nautical miles)

11.3.2 Risk Assessment Database

All the information needed to perform the risk assessment could be used by the software by means of, for example, external files. However, since this is an evolution of the FCHD, although values are not changed during the execution, the final implementation has been developed using the following table definition and contents.

11.3.2.1 CargoIndexes

Stores the different indexes for cargo used during risk assessment based on the cargo type/fire origin as per the results of the FCHD.

Table 81. CargoIndexes table definition

Attribute	Type	References	Description
id_fireOrigin1	TXT	MT_FIREORIGIN1.id	First level of fire origin
id_fireOrigin2	TXT	MT_FIREORIGIN2.uid	Second level of fire origin
FreqOccur	REAL		Frequency of occurrence
FreqOccurNM	REAL		Frequency of occurrence per nautical mile
FrequencyIndex	INT	FrequencyIndex.idx	Frequency Index
SeverityIndex	INT	SeverityIndex.idx	Severity Index
RiskCargoIndex	INT		Risk Cargo Index
RiskScore0	INT		Initial risk score

Table 82. CargoIndexes contents

id_fireOrigin1	id_fireOrigin2	FreqOccur	FreqOccurNM	FrequencyIndex	SeverityIndex	RiskCargoIndex	RiskScore0
RU	V	8,1577E-07	2,2129E-16	4	2	8	3
CV	BUS	4,7586E-07	1,2909E-16	3	1	3	2
CV	TRUCK	1,5168E-07	4,1146E-17	3	2	6	2
SV	RVs	7,9311E-08	2,1514E-17	2	2	4	2
CV	CAR	6,9077E-08	1,8738E-17	2	2	4	2
SV	TRAC	3,9655E-08	1,0757E-17	1	1	1	1
NEC	EV	2,9741E-08	8,0679E-18	1	1	1	1
SV	TRAILER	3,8376E-09	1,041E-18	1	1	1	1
DG	1,1	1,1897E-07	-1	3	1	3	2
DG	1,2	1,1897E-07	-1	3	1	3	2
DG	1,3	1,1897E-07	-1	3	1	3	2
DG	2,1	1,1897E-07	-1	3	1	3	2
DG	2,2	1,1897E-07	-1	3	1	3	2
DG	2,3	1,1897E-07	-1	3	1	3	2
DG	3	3,569E-07	-1	3	2	6	2
DG	4,1	5,9483E-07	-1	4	2	8	3

DG	4,2	5,9483E-07	-1	4	2	8	3
DG	4,3	5,9483E-07	-1	4	2	8	3
DG	8	1,1897E-07	-1	3	1	3	2
DG	9	2,3793E-07	-1	3	1	3	2
DG	1,4	1,1897E-07	-1	3	1	3	2
DG	1,5	1,1897E-07	-1	3	1	3	2
DG	1,6	1,1897E-07	-1	3	1	3	2

11.3.2.2 Compatibilities

Stores type of compatibility between cargo units depending on their risk score.

Table 83. Compatibilities table definition

Attribute	Type	References	Description
riskScore0_A	INT		Risk score for the first cargo unit
riskScore0_B	INT		Risk score for the second cargo unit
id_compatibility	INT	MT_COMPATIBILITY.uid	Type of compatibility between two cargo units

Table 84. Compatibilities contents

riskScore0_A	riskScore_B	id_compatibility
1	1	C
1	2	C
1	3	C
2	1	C
2	2	CAP
2	3	I
3	1	CRS
3	2	I
3	3	I

11.3.2.3 FrequencyIndex

Stores the indexes for the frequency based on the occurrence.

Table 85. FrequencyIndex table definition

Attribute	Type	References	Description
idx	INT		Frequency index
description	TXT		Brief description of the meaning
greaterEqualThan	REAL		Minimum value of the occurrence interval
lowerThan	REAL		Maximum value of the occurrence interval

Table 86. FrequencyIndex contents

Idx	Description	greaterEqualThan	lowerThan
1	Extremely remote	0	5.0e-08

2	Remote	0,0000005	1.0e-07
3	Reasonably probable	0,000001	5.0e-07
4	Frequent	0,000005	Inf

11.3.2.4 MT_COMPATIBILITY

Stores possible values for the compatibility between cargo units.

Table 87. MT_COMPATIBILITY table definition

Attribute	Type	References	Description
uid	TXT		Unique identifier
compatible	INT		1 for compatible, 0 otherwise
description	TXT		Brief description of the meaning

As master table it contains static values which are shown in the next table:

Table 88. COMPATIBILITY contents

uid	compatible	description
C	1	Compatible
CAP	1	Compatible but it should be avoided if possible
I	0	Incompatible
CRS	1	Compatible if recommendations are satisfied

11.3.2.5 MT_FIREORIGIN1

Stores possible values for the fire origin (first level).

Table 89. MT_FIREORIGIN1 table definition

Attribute	Type	References	Description
id	TXT		Unique identifier
origin	TXT		Brief description of the meaning

As master table it contains static values which are shown in the next table:

Table 90. MT_FIREORIGIN1 contents

id	origin
RU	Reefer unit
CV	Conventional vehicle
SV	Special vehicle
NEC	New energy carrier
DG	Dangerous goods
PLT	Palletized

11.3.2.6 MT_FIREORIGIN2

Stores possible values for the fire origin (second level) as defined in D08.1

In addition to the records used in the previous definition and in order to simplify the implementation, this table also includes a total of 20 additional records concerning all the classes for dangerous goods, which are detailed below.

Table 91. MT_FIREORIGIN2 additional contents (sample)

id	origin
1.1	DG Class 1.1
1.2	DG Class 1.2
…	…
7	DG Class 7
8	DG Class 8
9	DG Class 9

11.3.2.7 MT_FROM

Stores possible values for reference object in order to support recommendations.

Table 92. MT_FROM table definition

Attribute	Type	References	Description
uid	TXT		Unique identifier
description	TXT		Brief description of the meaning

As master table it contains static values which are shown in the next table:

Table 93. MT_FROM contents

uid	description
A	Access
ARE	Access ramp exits
DG	Dangerous goods
EE	Emergency exits
LSA	Life-saving appliances
MV	Mechanical Ventilation
NVO	Natural Ventilation opening
R	Ramp
AL	Adjacent Load

11.3.2.8 MT_LOCATION

Stores possible values for reference location in order to support recommendations.

Table 94. MT_LOCATION table definition

Attribute	Type	References	Description
uid	TXT		Unique identifier
description	TXT		Brief description of the meaning

As master table it contains static values which are shown in the next table:

Table 95. MT_LOCATION contents

uid	description
ATH	Athwartships
FA	Fore and Aft

11.3.2.9 MT_VHD_ALARM

Stores possible values for alarms received from VHD, if any.

Table 96. MT_VHD_ALARM table definition

Attribute	Type	References	Description
uid	TXT		Unique identifier
description	TXT		Brief description of the meaning

As master table it contains static values which are shown in the next table:

Table 97. MT_VHD_ALARM contents

uid	description
NO_ALARM	No alarm generated
WARNING	Warning
ALARM	Alarm

11.3.2.10 RS_BasedOnDeckAndCompatibility

Stores values for risk score depending on the compatibility of two given units (A and B) and the location of the unit B respect the unit A.

Table 98. RS_BasedOnDeckAndCompatibility table definition

Attribute	Type	References	Description
RS0	INT		RS_0 value for unit A
OtherDeck	TXT	MT_DECKLOCATION.uid	Location of unit B respect to unit A
compatible	INT		1 for compatible, 0 otherwise
RS	REAL		RS value for unit A

Table 99. RS_BasedOnDeckAndCompatibility contents

RS0	OtherDeck	compatible	RS
1	S	1	10
2	S	1	20
3	S	1	30
1	S	0	20
2	S	0	30
3	S	0	40
1	U	1	10
2	U	1	20
3	U	1	30
1	U	0	125
2	U	0	225

3	U	0	325
1	D	1	10
2	D	1	20
3	D	1	30
1	D	0	15
2	D	0	25
3	D	0	35

11.3.2.11 SeverityIndex

Stores the indexes for the severity.

Table 100. SeverityyIndex table definition

Attribute	Type	References	Description
idx	INT		Severity index
description	TXT		Qualitative meaning
human	TXT		Quantitative definition from human perspective
ship	TXT		Quantitative definition from ship perspective

Table 101. SeverityIndex contents

Idx	Description	Human	ship
1	Minor	Single or minor injures	Local equipment and structural damages (10.000-50000â,¬)
2	Significant	1-5 severe or 10-50 minor injures	Non severe ship damage (100000-500000â,¬)
3	Severe	1-5 fatality or 10-50 severe injures	Severe damages (yard repair required, downtime 1 week) (1-5 Mâ,¬)
4	Catastrophic	Multiple fatalities	Very severe damage or total los (10-100Mâ,¬)

11.4 ANNEX D: Risk Assessment considerations and background

11.4.1 Alternative powered vehicles / Alternative fuel vehicles

One of the main aspects to consider with conventional cars is that when they catch fire they do so slowly and their fuel tanks rarely explode, and the spread of fire to adjacent vehicles occurs only slowly, if at all. However, fire tests on cars using alternative fuels have shown that the assumptions so far considered for conventional vehicles are not valid, and therefore these new vehicles must be analysed both for their stowage and in the event of a fire in a different way than conventional vehicles.

The use of alternative fuel vehicles has now occurred in almost all types of transport, such as cars, buses, heavy goods vehicles, train locomotives and aircraft. It can be foreseen that more and more such vehicles will be on the roads, therefore, the number of such vehicles on roll-on/roll-off cargo ships will grow, not only private vehicles, but a mass transport of these newly built vehicles.

Increasing emissions and sensitivity of consumers to environmental protection force automotive industry to research possibilities of alternative technologies. Herewith, application of alternative powered vehicles can not only make significant contribution to environmental protection, but also provide cardinal improvements of vehicle quality in general. (Tuan et al. 2018)

After a decade of rapid growth, in 2020 the global alternative fuels car stock hit the 10 million mark, a 43% increase over 2019, and representing a 1% stock share. Overall the global market for all types of cars was significantly affected by the economic repercussions of the Covid-19 pandemic. The first part of 2020 saw new car registrations drop about one-third from the preceding year. About 3 million new electric cars were registered in 2020. For the first time, Europe led with 1.4 million new registrations. (IEA,2021)

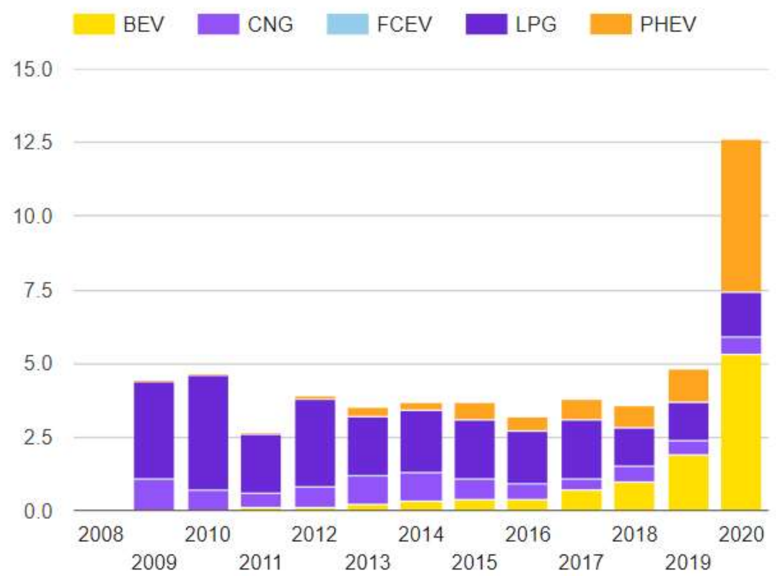


Figure 42 AF Market share new registration M1 (2020) Source: EAFO,EU

The figure above does not require extensive interpretation. After a decade of rapid growth, in 2020 the global alternative fuels car stock hit the 10 million mark, a 43% increase over 2019, and representing a 1% stock share. The production of alternative vehicles is clearly a key strategy for traditional industries, which are increasing year after year, making the purchase of these cars a great opportunity for customers. Actually, plug-in hybrid electric vehicles are currently soaring in Europe, as well as other types of alternative fuels powered vehicles, at a time when authorities are trying to combat global warming.

In more detail, vehicles that support their technology on natural gas are in a clear minority (CNG and LPG, in purple), while fuel cells (FCEV) do not even appear in the figure. Some believe that this situation will be quickly reversed, and that it will be the fuel cell vehicles that will gain ground and will contribute to designate a real transition of the transport sector towards a new energy paradigm. Yet, the technologies represented in purple have declined in recent years in favour of PHEVs, which is also remarkable.

This account of the accelerating popularity of new technologies brings us to the central theme of this section. The storage methods presented in the figure, recently known by their valued performance and transport advantages, despite its high efficiency can though pose a considerable risk if potential failures are not prevented and addressed by appropriate security strategies.

11.4.1.1 Types of alternative power vehicles

The transport sector consumes approximately 30 percent of energy in the European Union - of which cars, trucks and light vehicles are responsible for 80 percent. Electric vehicles (EVs) will play an important role in increasing energy-efficiency and reducing emissions. The goals in the EU's Transport White Paper include having CO2-neutral logistics in cities by 2030 and phasing out conventionally fueled vehicles in cities by 2050. The EU's directive on introducing alternative fuels infrastructure supports these targets.

- Electric vehicles (EVs): these vehicles run solely on battery power, dispensing with the gas engine altogether. In a sense, the electric vehicle is the ultimate green vehicle. The electricity that powers it can come from renewable sources like wind and solar power. This means that a car that runs on electricity can produce no emissions at all, as long as its power source is clean.

- Hybrid electric vehicles (HEVs): these vehicles combine a gas and electric propulsion system. The battery in gas-electric hybrids is charged from the engine and through braking, so charging the battery via the mains supply is not intended. This allows the battery to power the car at low speeds and during stops and starts. Hence, only very short distances can be travelled purely on electricity.

- Plug-in hybrid electric vehicles (PHEVs): these vehicles, similar to the gas-electric hybrid, have larger batteries that can run the car on electricity alone for limited distances with zero emissions. But they are also equipped with an internal combustion engine that powers the vehicle when the battery is depleted.

- Natural gas vehicles (NGVs): these vehicles are similar to gas-powered cars but use compressed or liquefied natural gas. They produce fewer greenhouse gas emissions and have fewer pollutants than conventional vehicles. But they still have a smaller range than electric vehicles.

- Fuel cell electric vehicles (FCEVs): the fuel cells installed in these vehicles convert hydrogen and oxygen into electricity and in turn power an electric motor. The hydrogen is stored in a compressed tank within the vehicle and when the vehicle is in operation, the fuel cell and electric motor convert the stored hydrogen into electricity to power it.

- Flexible fuel vehicles (FFVs): the fuel cells present in this type of electric vehicle work with a mix of gas and ethanol. This chemical combination is called syngas. In this case, fuel cells lose part of their efficiency to gain flexibility, which still makes this alternative a step towards a greener environment and a better future.

11.4.1.2 IMO Rules relate to APV/AFV

According to IMO rules[6], the carriage of AFVs can be permitted on regular vehicle decks provided that:

- The vehicle fuel system is checked for leak-tightness and is in proper condition for carriage.
- Suitable fire protection system is provided in the vehicle space.
- Ignition sources are separated from vehicles.
- Adequate ventilation (6 or 10 air changes per hour).
- Vehicles and engines fuelled by flammable gas have their shut off valves closed.
- Lithium batteries meet UN38.3 testing criteria.

11.4.2 Dangerous Goods

11.4.2.1 Classification

- Class 1- Explosive substances and articles

Explosives are materials or items which could rapidly conflagrate or detonate as a consequence of chemical reaction.

Subdivisions

- Division 1.1: Substances and objects that present a risk of explosion of the entire mass
- Division 1.2: Substances and objects that present a projection risk, but not an explosion risk of the whole mass
- Division 1.3: Substances and objects that present a fire risk and a risk of occurrence small shock wave or projection effects, or both, but not a risk explosion of the entire mass
- Division 1.4: Substances and objects that do not present any considerable risk
- Division 1.5: Very insensitive substances that present a risk of explosion of the entire mass
- Division 1.6: Extremely insensitive objects that do not present a risk of explosion of the entire mass

- Class 2- Gases

Gases are defined by dangerous goods regulations as substances which have a vapour pressure of 300 kPa or greater at 50°c or which are completely gaseous at 20°c at standard atmospheric pressure, and items containing these substances. The class encompasses compressed gases, liquefied gases, dissolved gases, refrigerated liquefied gases, mixtures of one or more gases with one or more vapours of substances of other classes, articles charged with a gas and aerosols.

Subdivisions

- Division 2.1: Flammable gases
- Division 2.2: Non-flammable, non-toxic gases
- Division 2.3: Toxic gases

- Class 3- Flammable liquids

[6] *IMO MSC.1/Circ.1471, SOLAS Ch. II-2 Reg.20-1, SP 961 and SP 962 of the IMDG code*

Flammable liquids are defined by dangerous goods regulations as liquids, mixtures of liquids or liquids containing solids in solution or suspension which give off a flammable vapour (have a flash point) at temperatures of not more than 60-65°C, liquids offered for transport at temperatures at or above their flash point or substances transported at elevated temperatures in a liquid state and which give off a flammable vapour at a temperature at or below the maximum transport temperature.

- Class 4- Flammable solids

Flammable solids are materials which, under conditions encountered in transport, are readily combustible or may cause or contribute to fire through friction, self-reactive substances which are liable to undergo a strongly exothermic reaction or solid desensitized explosives. Also included are substances which are liable to spontaneous heating under normal transport conditions, or to heating up in contact with air, and are consequently liable to catch fire and substances which emit flammable gases or become spontaneously flammable when in contact with water.

Subdivisions

- Division 4.1: Flammable solids
- Division 4.2: Substances liable to spontaneous combustion
- Division 4.3: Substances which, in contact with water, emit flammable gases

- Class 5-Oxidizing substances and organic peroxides

Oxidizers are defined by dangerous goods regulations as substances which may cause or contribute to combustion, generally by yielding oxygen because of a redox chemical reaction. Organic peroxides are substances which may be considered derivatives of hydrogen peroxide where one or both hydrogen atoms of the chemical structure have been replaced by organic radicals.

Subdivisions

- Division 5.1: Oxidizing substances
- Division 5.1: Organic peroxides

- Class 6- Toxic substances and infectious substances

Toxic substances are those which are liable either to cause death or serious injury or to harm human health if swallowed, inhaled or by skin contact. Infectious substances are those which are known or can be reasonably expected to contain pathogens. Dangerous goods regulations define pathogens as microorganisms, such as bacteria, viruses, rickettsia, parasites and fungi, or other agents which can cause disease in humans or animals.

Subdivisions

- Division 6.1: Toxic substances
- Division 6.2: Infectious substances

- Class 7- Radioactive goods

Dangerous goods regulations define radioactive material as any material containing radionuclides where both the activity concentration and the total activity exceeds certain pre-defined values. A radionuclide is an atom with an unstable nucleus, and which consequently is subject to radioactive decay.

- Class 8- Corrosive substances

Corrosives are substances which by chemical action degrade or disintegrate other materials upon contact.

- Class 9- Miscellaneous dangerous substances and articles

Miscellaneous dangerous goods are substances and articles which during transport present a danger or hazard not covered by other classes. This class encompasses, but is not limited to, environmentally hazardous substances, substances that are transported at elevated temperatures, miscellaneous articles and substances, genetically modified organisms and micro-organisms and (depending on the method of transport) magnetized materials and aviation regulated substances.

11.4.2.2 Stowage of dangerous cargo

When dangerous goods are carried in ro-ro spaces, the IMDG Code applies and details, for each product or class of dangerous goods:

- Stowage and packaging rules (inside the container or tank);
- On-board stowage and segregation rules;
- Provisions in case of an incident and fire precautions.

The above is complemented by “The EmS Guide: Emergency Response Procedures for Ships Carrying Dangerous Goods” which includes detailed recommendations and schedules for each class of dangerous goods in case of fire or spillage.

SOLAS includes general requirements for proper handling and management of cargo hazards:

- SOLAS II-2/16.2 requires fire safety operational booklets, which are to detail all precautions to be taken when handling the cargo to be carried on-board and the crew’s responsibility in this respect.
  Furthermore, the ISM Code requires that any company operating a ship sets up a safety management system with identified persons in charge of the relevant duties and procedure to report incidents, prepare for and respond to emergency situations;
- SOLAS VI/2 requires that the shipper provides adequate shipping information regarding any cargo loaded on board;
- SOLAS VI/5 requires proper cargo stowage and securing, referring especially to:
    - The Code of Safe Practice for Cargo Stowage and Securing;
    - The IMDG Code for the carriage of dangerous goods.

Chapter 7.5 of the IMDG Code focuses on the stowage and segregation of cargo transport units which are transported in ro-ro cargo spaces. In particular, provisions for segregation between cargo transport units on-board ro-ro ships are given in the table included in Reg. 7.5.3.2 (see **¡Error! No se encuentra el origen de la referencia.**).

Table 102: Table of segregation of cargo transport units on board ro-ro ships

Segregation requirement		Horizontal					
		Closed versus closed		Closed versus open		Open versus open	
		On deck	Under deck	On deck	Under deck	On deck	Under deck
"Away from" .1	Fore and aft	No restriction	No restriction	No restriction	No restriction	At least 3 m	At least 3 m
	Athwartships	No restriction	No restriction	No restriction	No restriction	At least 3 m	At least 3 m
"Separated from" .2	Fore and aft	At least 6 m	At least 6 m or *one bulkhead*	At least 6 m	At least 6 m or *one bulkhead*	At least 6 m	At least 12 m or *one bulkhead*
	Athwartships	At least 3 m	At least 3 m or *one bulkhead*	At least 3 m	At least 6 m or *one bulkhead*	At least 6 m	At least 12 m or *one bulkhead*
"Separated by a complete compartment or hold from" .3	Fore and aft	At least 12 m	At least 24 m + deck	At least 24 m	At least 24 m + deck	At least 36 m	*Two decks or two bulkheads*
	Athwartships	At least 12 m	At least 24 m + deck	At least 24 m	At least 24 m + deck	Prohibited	Prohibited
"Separated longitudinally by an intervening complete compartment or hold from" .4	Fore and aft	At least 36 m	*Two bulkheads* or at least 36 m + *two decks*	At least 36 m	At least 48 m including *two bulkheads*	At least 48 m	Prohibited
	Athwartships	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited

11.4.2.3 Transport of dangerous goods in ro-ro ships with more than 25 passengers

Summary of IMDG rules on dangerous goods that may or may not be carried on board Ro-ro ships with a number of passengers equal to or greater than 25.

Table 103. Dangerous good rules (pax equal to or greater than 25)

DG class	Substance	Weather deck	Open Deck	Close Deck
1	Explosive substances			
2.1	Flammable gases			
2.2	Non-flammable, non-toxic gases			
2.3	Toxic gases			
3	Flammable liquids, PG I , II			
3	Flammable liquids, PG III			
4.1	Flammable solids UN No. 1944, 1945, 2254, 2623 (different types of matches)			
4.1	Flammable solids other UN numbers			
4.2	Substances liable to spontaneous combustion			
4.3	Substances liable to spontaneous combustion			

5.1	Inflammatory substances			
5.2	Organic peroxides			
6.1	Toxic substances, PG I , II			
6.1	Toxic substances, PG III			
6.2	Infectious substances			
7	Radioactive substances			
8	Corrosive substances, PG I oder II			
8	Liquid corrosive substances, PG III			
8	Solid corrosive substances, PG III			
9	Various dangerous substances and objects			

Permitted
Prohibited

Transport of dangerous goods on passenger ships with more than 25 passengers on board, PG = packing group, packing group I: high hazard substances; packing group II: medium hazard substances, packing group III: low hazard substances. * On cargo ferries (no more than 25 passengers on board), the transport of all classes of dangerous goods from class 2 is permitted at least on deck.

11.4.3 Severity

For each type of cargo, the causes that have produced the fire in the load have been analysed, classifying them in causes of origin:

- Electrical
- Overheating
- Leakage of liquids
- Mechanical
- Other

In addition to each type of failure, the severity of the accidents has been analysed, within each category, for the severity the following scale has been used.

According to IMO definitions (IMO’s “Casualty Investigation Code” in its updated version and IMO Circular MSC-MEPC.3/Circ.3), severity is classified into the following levels: Marine accident is considered any marine casualty or marine incident. An accident does not include a deliberate act or omission, with the intention to cause harm to the safety of a ship, an individual or the environment.

Accidents may be classified (in order of severity) as follows:

- very serious marine casualties
- serious marine casualties
- less serious casualties
- marine incidents
- near miss

Marine casualty means an event, or a sequence of events, that has resulted in any of the following which has occurred directly about the operations of a ship:

- the death of, or serious injury to, a person
- the loss of a person from a ship
- the loss, presumed loss or abandonment of a ship
- material damage to a ship
- the stranding or disabling of a ship, or the involvement of a ship in a collision;
- material damage to marine infrastructure external to a ship, that could seriously endanger the safety of the ship, another ship or an individual
- severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a ship or ships.

<u>Very serious</u> casualties mean a marine casualty involving:

- the total loss of the ship or
- a death or
- severe damage to the environment.

<u>Serious</u> casualties are casualties to ships which do not qualify as very serious casualties and which involve a fire, explosion, collision, grounding, contact, heavy weather damage, ice damage, hull cracking, or suspected hull defect, etc., resulting in:

- immobilization of main engines, extensive accommodation damage, severe structural damage, such as penetration of the hull under water, etc., rendering the ship unfit to proceed∗, or
- pollution (regardless of quantity); and/or
- a breakdown necessitating towage or shore assistance.

<u>Less serious</u> casualties are casualties to ships which do not qualify as very serious casualties or serious casualties.

<u>Marine incident</u> means an event, or sequence of events, other than a marine casualty, which has occurred directly in connection with the operations of a ship that endangered, or, if not corrected, would endanger the safety of the ship, its occupants or any other person or the environment.

<u>Near miss</u> is an unplanned event that did not result in injury or damage - but had the potential to do so.

Material damage in relation to a marine casualty means:

- damage that significantly affects the structural integrity, performance or operational characteristics of marine infrastructure or a ship; and requires major repair or replacement of a major component or components, or

- destruction of the marine infrastructure or ship.

Severe damage to the environment means damage to the environment which, as evaluated by the State(s) affected, or the flag State, as appropriate, produces a major deleterious effect upon the environment.

Serious injury means an injury which is sustained by a person, resulting in incapacitation where the person is unable to function normally for more than 72 hours, commencing within seven days from the date when the injury was suffered.

The proportion of accident severity could be biased by the reporting process depending on the database provider.

However, due to the obligations under Directive 2009/18/EU (EU, 2009), incidents are expected to be well represented in the different databases studied

To analyse the severity of the accidents collected in the Cargo Fire Hazard Database developed in task 2 of WP08 (IR08.03), only accidents occurring on ships from 2003 to 2020 were considered as for the calculation of the frequency of occurrence. The rest of the data were used to identify "cases" not included in this sample that could be of special interest to be considered for the drafting of recommendations to prevent their recurrence, or in other words to avoid their occurrence.

11.5 ANNEX E: Population of the database for generic ships of considered types

Finally, for the development stage of the Stowage Planning Tool, only ro-pax and ro-ro ship types have been considered. The involved tables for the developments carried out are *SHIP, LAYOUT, DECK, LANE, ALLOWED_DG_CARGO, DECK_DEPENDENCY* and *FRAME_SPACING*.

The ship used as a reference for ro-ro ships is the Magnolia Seaways from DFDS and the ship used as a reference for ro-pax ships is the Flavia from STENA. In order to understand the values for the above-mentioned tables, a set of cargo spaces have been defined following the nomenclature as per ANNEX C: Table definition.

For simplification purposes, instead of showing contents for all the tables individually, SHIP, LAYOUT, and DECK are combined into one single table, which is the reason why many rows share the same value for certain columns (this duplication does not exist in the database since data is split in these three tables). Please note that restaurant deck for the Stena Flavia has not been considered.

Table 104. SHIP and LAYOUT tables for all considered ships

IMO	Ship name	Ship Type	Layout	Deck Id	Deck #	Deck name
9259496	DFDS Magnolia Seaways	RO-RO	1	1	1	Tank Top
9259496	DFDS Magnolia Seaways	RO-RO	1	2	2	Main Deck
9259496	DFDS Magnolia Seaways	RO-RO	1	3	3	Upper Deck
9259496	DFDS Magnolia Seaways	RO-RO	1	4	4	Weather Deck
9417919	STENA Flavia	RO-PAX	2	5	1	Lower Hold
9417919	STENA Flavia	RO-PAX	2	6	2	Car Deck
9417919	STENA Flavia	RO-PAX	2	7	3	Main Deck
9417919	STENA Flavia	RO-PAX	2	8	4	Weather Deck

The next two tables show the dependency between decks (only the one immediately below and above have been considered) and the frame spacing, respectively.

Table 105. Deck dependency and frame spacing

Deck Id	Location	Dep. deck
1	Up (above deck)	2
2	Down (below deck)	1
2	Up (above deck)	3
3	Down (below deck)	2
3	Up (above deck)	4
4	Down (below deck)	3
5	Up (above deck)	6
6	Down (below deck)	5
6	Up (above deck)	7
7	Down (below deck)	6
7	Up (above deck)	8
8	Down (below deck)	7
8	Up (above deck)	9
8	Up (above deck)	10
8	Up (above deck)	11

IMO	Frame start	Frame end	Spacing
9259496	-3	33	600
9259496	33	251	750
9259496	251	274	600
9417919	-9	27	610
9417919	27	175	800
9417919	175	219	700
9417919	219	235	610

11.5.1 Ro-ro lane configuration

The ship used as a reference for ro-ro ships is the Magnolia Seaways from DFDS. In order to understand the values for the above-mentioned tables, a set of cargo spaces have been defined following the nomenclature as per ANNEX C: Table definition; these areas are shown in the next figure.

Figure 43. Cargo space reference for ro-ro generic ship

Table 106. Definition of available lanes for ro-ro the ship

Deck Id	Lane	Frame start	Frame end	Cline start	Cline end	Ship side
1	L-3	98	154	-5,7	-8,55	PORT
1	L-2	98	182	-2,85	-5,7	PORT
1	L-1	98	175	0	-2,85	PORT
1	L+1	98	175	0	2,85	STARBOARD
1	L+2	104	123	3,35	6,2	STARBOARD
1	L+3	124	181	2,85	5,7	STARBOARD
1	L+4	124	161	5,7	8,55	STARBOARD
1	L-4	180	196	0	-3	PORT
1	L+5	187	214	1,425	-1,425	STARBOARD
1	L+6	187	214	4,275	1,425	STARBOARD
2	L+1	-3	20	2	4,85	STARBOARD
2	L+2	-3	20	4,85	7,7	STARBOARD
2	L+3	24	45	3,425	6,275	STARBOARD
2	L+4	24	45	6,275	9,125	STARBOARD
2	L+5	15	95	9,125	11,975	STARBOARD

2	L+6	54	120	3,425	6,275	STARBOARD
2	L+7	54	120	6,275	9,125	STARBOARD
2	L+8	102	120	9,125	11,975	STARBOARD
2	L+9	111	236	0	2,85	STARBOARD
2	L+10	122	217	2,85	5,7	STARBOARD
2	L+11	122	198	5,7	8,55	STARBOARD
2	L+12	122	179	8,55	11,4	STARBOARD
2	L-1	1	45	0	-2,85	PORT
2	L-2	-3	82	-4,85	-7,7	PORT
2	L-3	-3	82	-7,7	-10,55	PORT
2	L-4	95	114	0	-2,85	PORT
2	L-5	122	236	0	-2,85	PORT
2	L-6	95	114	-2,85	-5,7	PORT
2	L-7	122	217	-2,85	-5,7	PORT
2	L-8	84	198	-5,7	-8,55	PORT
2	L-9	84	179	-8,55	-11,4	PORT
3	L+1	14	36	0	2,85	STARBOARD
3	L+2	18	39	2,85	5,7	STARBOARD
3	L+3	18	39	5,7	8,55	STARBOARD
3	L+4	18	39	8,55	11,4	STARBOARD
3	L+5	40	78	2,85	5,7	STARBOARD
3	L+6	40	78	5,7	8,55	STARBOARD
3	L+7	40	78	8,55	11,4	STARBOARD
3	L+8	84	104	2,85	5,7	STARBOARD
3	L+9	84	104	5,7	8,55	STARBOARD
3	L+10	84	104	8,55	11,4	STARBOARD
3	L+11	111	206	0	2,85	STARBOARD
3	L+12	105	144	2,85	5,7	STARBOARD
3	L+13	105	144	5,7	8,55	STARBOARD
3	L+14	105	144	8,55	11,4	STARBOARD
3	L+15	149	206	2,85	5,7	STARBOARD
3	L+16	149	206	5,7	8,55	STARBOARD
3	L+17	149	206	8,55	11,4	STARBOARD
3	L+18	207	246	1,425	4,275	STARBOARD
3	L+19	207	246	4,275	7,125	STARBOARD
3	L+20	207	246	7,125	9,975	STARBOARD
3	L-1	14	36	0	-2,85	PORT
3	L-2	14	36	-2,85	-5,7	PORT
3	L-3	46	104	0	-2,85	PORT
3	L-4	36	113	-3,85	-6,7	PORT
3	L-5	31	107	-7,7	-10,55	PORT
3	L-6	111	206	0	-2,85	PORT
3	L-7	121	206	-2,85	-5,7	PORT
3	L-8	121	139	-5,7	-8,55	PORT
3	L-9	111	148	-8,55	-11,4	PORT

3	L-10	149	168	-8,05	-10,9	PORT
4	L-9	168	207	-8,4	-11,25	PORT
3	L-11	207	246	1,425	-1,425	PORT
3	L-12	207	246	-1,425	-4,275	PORT
3	L-13	207	246	-4,275	-7,125	PORT
3	L-14	219	238	-7,125	-9,975	PORT
4	L+1	0	44	0	2,85	STARBOARD
4	L+2	0	44	2,85	5,7	STARBOARD
4	L+3	12	44	5,7	8,55	STARBOARD
4	L+4	12	44	8,55	11,4	STARBOARD
4	L+5	44	83	3	5,85	STARBOARD
4	L+6	44	83	5,85	8,7	STARBOARD
4	L+7	44	83	8,7	11,55	STARBOARD
4	L+8	87	105	3	5,85	STARBOARD
4	L+9	87	105	5,85	8,7	STARBOARD
4	L+10	87	105	8,7	11,55	STARBOARD
4	L+11	106	220	0	2,85	STARBOARD
4	L+12	106	220	2,85	5,7	STARBOARD
4	L+13	106	220	5,7	8,55	STARBOARD
4	L+14	106	220	8,55	11,4	STARBOARD
4	L+15	227	246	0	2,85	STARBOARD
4	L+16	227	246	2,85	5,7	STARBOARD
4	L+17	224	244	5,7	8,55	STARBOARD
4	L+18	224	244	8,55	11,4	STARBOARD
4	L-1	0	217	0	-2,85	PORT
4	L-2	0	217	-2,85	-5,7	PORT
4	L-3	0	131	-5,7	-8,55	PORT
4	L-4	17	134	-8,55	-11,4	PORT
4	L-5	227	246	0	-2,85	PORT
4	L-6	227	246	-2,85	-5,7	PORT
4	L-7	214	244	-5,7	-8,55	PORT
4	L-8	211	230	-8,55	-11,4	PORT

Table 107. Definition of allowed DG cargo for ro-ro the ship

Deck id	DG class	Package	Frame start	Frame end	Flashpoint	State	Flammable
1	1.4	P	97	217			
1	2.2	P	97	217			
1	2.3	P	97	217			0
1	3	P	97	217	III		
1	4.1	P	97	217			
1	4.2	P	97	217			
1	4.3	P	97	217		L	
1	4.3	P	97	217		S	
1	5.1	P	97	217			

1	6.1	P	97	217		S	
1	8	P	97	217	III	L	
1	8	P	97	217		L	0
1	8	P	97	217		S	
1	9	P	97	217			
2	1.4	P	3	237			
2	2.2	P	3	237			
2	2.3	P	3	237			0
2	3	P	3	237	III		
2	4.1	P	3	237			
2	4.2	P	3	237			
2	4.3	P	3	237		L	
2	4.3	P	3	237		S	
2	5.1	P	3	237			
2	6.1	P	3	237		S	
2	8	P	3	237	III	L	
2	8	P	3	237		L	0
2	8	P	3	237		S	
2	9	P	3	237			
3	1.4	P	3	246			
3	2.2	P	3	246			
3	2.3	P	3	246			0
3	3	P	3	246	III		
3	4.1	P	3	246			
3	4.2	P	3	246			
3	4.3	P	3	246		L	
3	4.3	P	3	246		S	
3	5.1	P	3	246			
3	6.1	P	3	246	III	L	
3	6.1	P	3	246		L	0
3	6.1	P	3	246		S	
3	8	P	3	246	III	L	
3	8	P	3	246		L	0
3	8	P	3	246		S	
3	9	P	3	246			
4	1.1	P	0	75			
4	1.1	P	136	246			
4	1.2	P	0	75			
4	1.2	P	136	246			
4	1.3	P	0	75			
4	1.3	P	136	246			
4	1.4	P	0	246			
4	1.5	P	0	75			
4	1.5	P	136	246			
4	1.6	P	0	75			

4	1.6	P	136	246			
4	2.1	P	0	75			
4	2.1	P	136	246			
4	2.2	P	0	246			
4	2.3	P	0	246			0
4	3	P	0	75	II		
4	3	P	136	246	II		
4	3	P	0	246	III		
4	4.1	P	0	246			
4	4.2	P	0	246			
4	4.3	P	0	246		L	
4	4.3	P	0	246		S	
4	5.1	P	0	246			
4	5.2	P	0	75		L	
4	5.2	P	136	246		L	
4	6.1	P	0	75	II	L	
4	6.1	P	136	246	II	L	
4	6.1	P	0	246	III	L	
4	6.1	P	0	246		L	0
4	6.1	P	0	246		S	
4	8	P	0	75	II	L	
4	8	P	136	246	II	L	
4	8	P	0	246	III	L	
4	8	P	0	246		L	0
4	8	P	0	246		S	
4	9	P	0	246			

11.5.2 Ro-pax lane configuration

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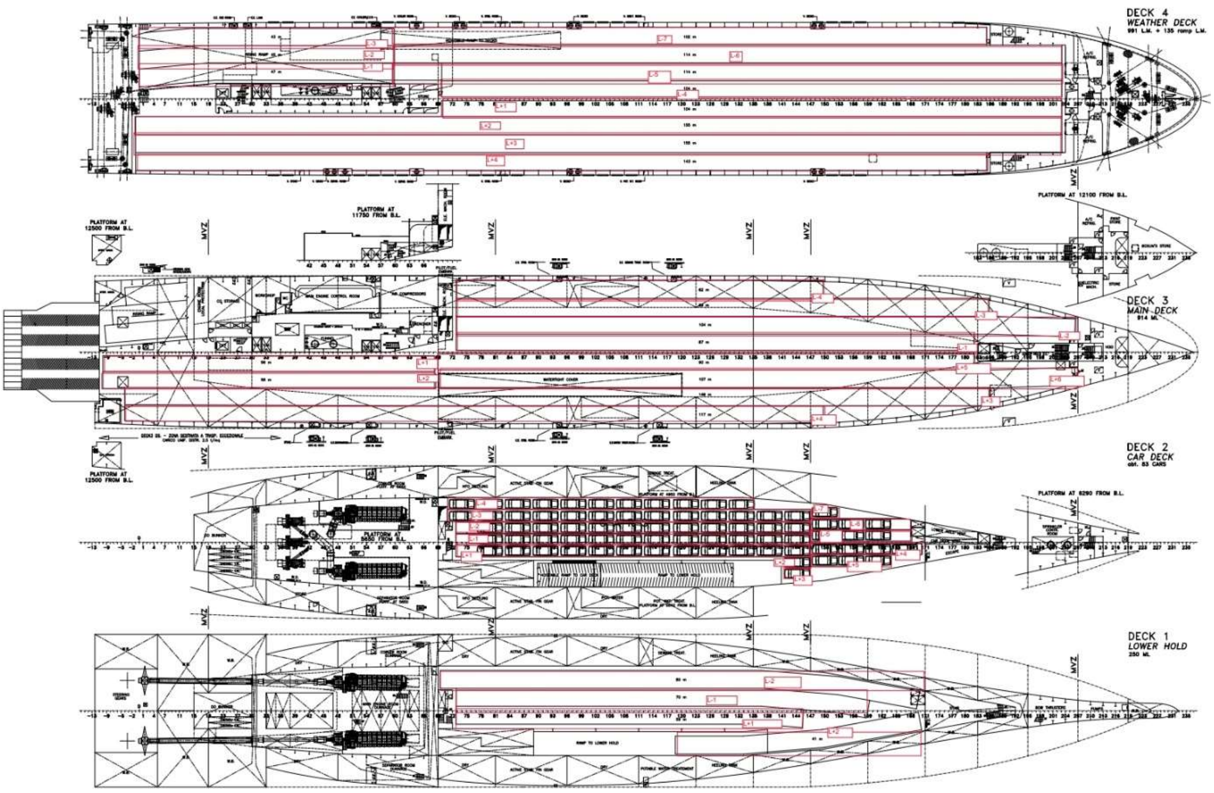

Figure 44. Cargo space reference for ro-pax generic ship

Table 108. Definition of available lanes for ro-pax the ship

Deck Id	Lane	Frame start	Frame end	Cline start	Cline end	Ship side
5	L-2	69	169	-3	-6	PORT
5	L-1	73	159	0	-3	PORT
5	L+1	73	145	0	3	STARBOARD
5	L+2	119	169	3	6	STARBOARD
6	L-1	72	147	0	-2	PORT
6	L-2	72	147	-2	-4	PORT
6	L-3	70	147	-4	-6	PORT
6	L-4	70	135	-6	-8	PORT
6	L-5	147	168	0	-2	PORT
6	L-6	147	168	-2	-4	PORT
6	L-7	147	153	-4	-6	PORT
6	L+1	72	147	0	2	STARBOARD
6	L+2	141	147	2	4	STARBOARD
6	L+3	141	147	4	6	STARBOARD
6	L+4	147	169	0	2	STARBOARD
6	L+5	147	164	2	4	STARBOARD
7	L-1	72	181	0	-3	PORT

7	L-2	72	206	-3	-6	PORT
7	L-3	72	186	-6	-9	PORT
7	L-4	72	149	-9	-12	PORT
7	L+1	-9	68	0	3	STARBOARD
7	L+2	-9	68	3	6	STARBOARD
7	L+3	-4	186	6	9	STARBOARD
7	L+4	-4	149	9	12	STARBOARD
7	L+5	69	182	0	3	STARBOARD
7	L+6	69	207	3	6	STARBOARD
8	L-1	0	59	-3	-6	PORT
8	L-2	0	59	-6	-9	PORT
8	L-3	0	59	-9	-12	PORT
8	L-4	69	203	0	-3	PORT
8	L-5	59	203	-3	-6	PORT
8	L-6	59	203	-6	-9	PORT
8	L-7	59	185	-9	-12	PORT
8	L+1	69	203	0	3	STARBOARD
8	L+2	-1	203	3	6	STARBOARD
8	L+3	-1	203	6	9	STARBOARD
8	L+4	-1	184	9	12	STARBOARD
9	L-1	15	99	-4	-6	PORT
9	L-2	15	99	-6	-8	PORT
9	L-3	15	53	-8	-10	PORT
9	L-4	15	53	-10	-12	PORT
9	L-5	71	100	0	-2	PORT
9	L-6	71	100	-2	-4	PORT
9	L-7	57	95	-9	-11	PORT
9	L+1	28	68	2	4	STARBOARD
9	L+2	28	68	4	6	STARBOARD
9	L+3	28	68	6	8	STARBOARD
9	L+4	28	68	8	10	STARBOARD
9	L+5	71	100	0	2	STARBOARD
9	L+6	71	100	2	4	STARBOARD
9	L+7	71	100	4	6	STARBOARD
9	L+8	71	100	6	8	STARBOARD
9	L+9	71	100	8	10	STARBOARD
10	L+1	0	13	-2	10	STARBOARD
11	L+1	0	13	-4	8	STARBOARD
11	L+2	0	13	-4	8	STARBOARD
11	L+3	0	13	-4	8	STARBOARD
11	L+4	0	7	-4	4	STARBOARD

Table 109. Definition of allowed DG cargo for ro-pax the ship

Deck Id	Lane	Frame start	Frame end	Cline start	Cline end	Ship side	Deck Id
5	1.4	P	72	183			
5	2.2	P	72	183			
5	3	P	72	183	III		
5	4.1	P	72	183			
5	4.2	P	72	183			
5	4.3	P	72	183			
5	5.1	P	72	183			
5	6.1	P	72	183	I		
5	6.1	P	72	183	III	L	
5	8	P	72	183	I	L	
5	8	P	72	183	III	L	
5	8	P	72	183		S	
5	9	P	72	183			
5	8	P	72	83	II	L	
6	4.3	P	75	140	I	S	0
7	1.4	P	0	183			
7	2.2	P	0	183			
7	3	P	0	183	III		
7	4.1	P	0	183			
7	4.2	P	0	183			
7	4.3	P	0	183			
7	5.1	P	0	183			
7	6.1	P	0	183	III	L	
7	8	P	0	183	I	L	
7	8	P	0	183	III	L	
7	8	P	0	183		S	
7	9	P	0	183			
7	8	P	0	183	II	L	
8	1.1	P	0	19			
8	1.2	P	0	19			
8	1.3	P	0	19			
8	1.4	P	0	19			
8	1.5	P	0	19			
8	1.6	P	0	19			
8	2.1	P	0	19			
8	2.2	P	0	19			
8	2.3	P	0	19			
8	3.0	P	0	19	II		
8	4.1	P	0	19			
8	4.2	P	0	19			
8	4.3	P	0	19			
8	5.1	P	0	19			

8	5.2	P	0	19			
8	6.1	P	0	19	I	L	
8	6.1	P	0	19	III	L	
8	6.1	P	0	19		S	
8	8	P	0	19	I	L	
8	8	P	0	19	III	L	
8	8	P	0	19		S	
8	9	P	0	19			
8	1.4	P	19	204			
8	2.2	P	19	204			
8	3	P	19	204	III		
8	4.1	P	19	204			
8	4.2	P	19	204			
8	4.3	P	19	204			
8	5.1	P	19	204			
8	6.1	P	19	204	I	L	
8	6.1	P	19	204	III	L	
8	6.1	P	19	204		S	
8	8	P	19	204	I	L	
8	8	P	19	204	III	L	
8	8	P	19	204		S	
8	9	P	19	204			
8	6.1	P	0	19	II	L	
8	6.1	P	19	204	II	L	
8	8	P	19	204	II	L	
8	8	P	0	19	II	L	

11.6 ANNEX F Cargo distribution recommendations

Main author of the chapter: África Marrero, CIM

Table 110. Recommendations for the cargo

ID	Recommendations
RR1	Athwartships - Separated from access at least 12 metres
RR2	Athwartships - Separated from access at least 24 metres
RR3	Athwartships - Separated from access at least 3 metres
RR4	Athwartships - Separated from access at least 6 metres
RR5	Athwartships - Separated from access ramps exits at least 3 metres
RR6	Athwartships - Separated from access ramps exits at least 6 metres
RR7	Athwartships - Separated from at least 12 metres
RR8	Athwartships - Separated from at least 24 metres
RR9	Athwartships - Separated from at least 3 metres
RR10	Athwartships - Separated from at least 6 metres
RR11	Athwartships - Separated from DDGG at least 12 metres
RR12	Athwartships - Separated from DDGG at least 24 metres
RR13	Athwartships - Separated from DDGG at least 3 metres
RR14	Athwartships - Separated from DDGG at least 6 metres
RR15	Athwartships - Separated from emergency exits at least 12 metres
RR16	Athwartships - Separated from emergency exits at least 24 metres
RR17	Athwartships - Separated from emergency exits at least 3 metres
RR18	Athwartships - Separated from emergency exits at least 6 metres
RR19	Athwartships - Separated from LSA at least 12 metres
RR20	Athwartships - Separated from LSA at least 24 metres
RR21	Athwartships - Separated from LSA at least 3 metres
RR22	Athwartships - Separated from LSA at least 6 metres
RR23	Athwartships - Separated from mechanical ventilation at least 12 metres
RR24	Athwartships - Separated from mechanical ventilation at least 24 metres
RR25	Athwartships - Separated from mechanical ventilation at least 3 metres
RR26	Athwartships - Separated from mechanical ventilation at least 6 metres
RR27	Athwartships - Separated from natural ventilation openings at least 3 metres
RR28	Athwartships - Separated from natural ventilation openings at least 6 metres
RR29	Athwartships - Separated from natural ventilation openings at least 12 metres
RR30	Athwartships - Separated from natural ventilation openings at least 24 metres
RR31	Athwartships - Separated from ramp at least 12 metres
RR32	Athwartships - Separated from ramp at least 24 metres
RR33	Athwartships - Separated from ramp at least 3 metres
RR34	Athwartships - Separated from ramp at least 6 metres
RR35	Athwartships - Separation of 0.5m with respect to adjacent loads
RR36	Do not locate on ramps
RR37	Fore and Aft - Separated from access at least 12 metres
RR38	Fore and Aft - Separated from access at least 24 metres
RR39	Fore and Aft - Separated from access at least 3 metres
RR40	Fore and Aft - Separated from access at least 6 metres
RR41	Fore and Aft - Separated from access ramps exits at least 3 metres
RR42	Fore and Aft - Separated from access ramps exits at least 6 metres
RR43	Fore and Aft - Separated from at least 12 metres
RR44	Fore and Aft - Separated from at least 24 metres

RR45	Fore and Aft - Separated from at least 3 metres
RR46	Fore and Aft - Separated from at least 6 metres
RR47	Fore and Aft - Separated from DDGG at least 12 metres
RR48	Fore and Aft - Separated from DDGG at least 24 metres
RR49	Fore and Aft - Separated from DDGG at least 3 metres
RR50	Fore and Aft - Separated from DDGG at least 6 metres
RR51	Fore and Aft - Separated from emergency exits at least 12 metres
RR52	Fore and Aft - Separated from emergency exits at least 24 metres
RR53	Fore and Aft - Separated from emergency exits at least 3 metres
RR54	Fore and Aft - Separated from emergency exits at least 6 metres
RR55	Fore and Aft - Separated from LSA at least 12 metres
RR56	Fore and Aft - Separated from LSA at least 24 metres
RR57	Fore and Aft - Separated from LSA[7] at least 3 metres
RR58	Fore and Aft - Separated from LSA at least 6 metres
RR59	Fore and Aft - Separated from mechanical ventilation at least 12 metres
RR60	Fore and Aft - Separated from mechanical ventilation at least 24 metres
RR61	Fore and Aft - Separated from mechanical ventilation at least 3 metres
RR62	Fore and Aft - Separated from mechanical ventilation at least 6 metres
RR63	Fore and Aft - Separated from natural ventilation openings at least 3 metres
RR64	Fore and Aft - Separated from natural ventilation openings at least 6 metres
RR65	Fore and Aft - Separated from natural ventilation openings at least 12 metres
RR66	Fore and Aft - Separated from natural ventilation openings at least 24 metres
RR67	Fore and Aft - Separated from ramp at least 12 metres
RR68	Fore and Aft - Separated from ramp at least 24 metres
RR69	Fore and Aft - Separated from ramp at least 3 metres
RR70	Fore and Aft - Separated from ramp at least 6 metres
RR71	Fore and Aft - Separation of 0.5m with respect to adjacent cargo
RR72	Highly safety-controlled areas
RR73	Isolated from other cargoes
RR74	Near electrical connections
RR75	Near security openings (patrol access)
RR76	Near to safety equipment
RR77	Place on close deck
RR78	Place on open deck
RR79	Place on weather deck
RR80	Transport disconnected
RR81	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 12 metres
RR82	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 24 metres
RR83	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 3 metres

[7] Life-saving appliances (LSA) considered in setting the recommendations include:

- Lifebuoys and life-jackets
- Lifeboats
- Life-rafts
- Rescue boats
- Rocket parachute flares
- Launching and embarkation appliances
- Marine evacuation systems

RR84	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 6 metres
RR85	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 12 metres + Deck
RR86	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 24 metres + Deck
RR87	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 3 metres + Deck
RR88	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 6 metres + Deck
RR89	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 12 metres + 2 Decks
RR90	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 24 metres + 2 Decks
RR91	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 3 metres + 2 Decks
RR92	Close deck VS Close deck – Under deck – Fore and Aft - Separated from at least 6 metres + 2 Decks
RR93	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 12 metres
RR94	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 24 metres
RR95	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 3 metres
RR96	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 6 metres
RR97	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 12 metres + Deck
RR98	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 24 metres + Deck
RR99	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 3 metres + Deck
RR100	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 6 metres + Deck
RR101	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 12 metres + 2 Decks
RR102	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 24 metres + 2 Decks
RR103	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 3 metres + 2 Decks
RR104	Close deck VS Open deck – Under deck – Fore and Aft - Separated from at least 6 metres + 2 Decks
RR105	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 12 metres
RR106	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 24 metres
RR107	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 3 metres
RR108	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 6 metres
RR109	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 12 metres + Deck
RR110	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 24 metres + Deck
RR111	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 3 metres + Deck
RR112	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 6 metres + Deck
RR113	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 12 metres + 2 Decks
RR114	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 24 metres + 2 Decks
RR115	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 3 metres + 2 Decks

RR116	Open deck VS Open deck – Under deck – Fore and Aft - Separated from at least 6 metres + 2 Decks
RR117	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 12 metres
RR118	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 24 metres
RR119	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 3 metres
RR120	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 6 metres
RR121	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 12 metres + Deck
RR122	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 24 metres + Deck
RR123	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 3 metres + Deck
RR124	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 6 metres + Deck
RR125	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 12 metres + 2 Decks
RR126	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 24 metres + 2 Decks
RR127	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 3 metres + 2 Decks
RR128	Close deck VS Close deck – Under deck – Athwartships - Separated from at least 6 metres + 2 Decks
RR129	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 12 metres
RR130	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 24 metres
RR131	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 3 metres
RR132	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 6 metres
RR133	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 12 metres + Deck
RR134	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 24 metres + Deck
RR135	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 3 metres + Deck
RR136	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 6 metres + Deck
RR137	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 12 metres + 2 Decks
RR138	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 24 metres + 2 Decks
RR139	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 3 metres + 2 Decks
RR140	Close deck VS Open deck – Under deck – Athwartships - Separated from at least 6 metres + 2 Decks
RR141	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 12 metres
RR142	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 24 metres
RR143	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 3 metres
RR144	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 6 metres
RR145	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 12 metres + Deck
RR146	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 24 metres + Deck
RR147	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 3 metres + Deck
RR148	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 6 metres + Deck

RR149	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 12 metres + 2 Decks
RR150	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 24 metres + 2 Decks
RR151	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 3 metres + 2 Decks
RR152	Open deck VS Open deck – Under deck – Athwartships - Separated from at least 6 metres + 2 Decks