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Procedia Computer Science 180 (2021) 571–580

Procedia Computer Science

www.elsevier.com/locate/procedia

International Conference on Industry 4.0 and Smart Manufacturing

SRTP assessment of passenger ships: a simulation tool

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Abstract

Recent years have seen increasing attention being paid towards the problems related to safety and security onboard ships. As a result, the International Maritime Organization has issued several new Regulations regarding ships' systems that must be considered during the vessel design phases. In particular, one of the most important approaches introduced by this set of rules consists of the Safe Return to Port (SRtP) concept: basically, the ship itself represents its best lifeboat. Essential systems on-board passenger ships shall be designed in order to both guarantee their functionality and allow the return of the ship to the nearest port during specific emergency situations. Consequently, it is evident that designers should pay great attention to these systems since the early stages of the project. In this framework, proper IT design tools able to simulate systems functionality can represent a valuable aid to ensure compliance with the SRtP requirements. In this paper, the basic principles of SRtP Regulations are thoroughly presented. Furthermore, an IT tool, specifically implemented to address the suggested design approach for ship systems, is analyzed.

Keywords: Marine engineering; SRtP; Safety; Passenger ships; Systems assessment

1. Introduction

Increasing safety on-board ships, avoiding human loss of life, and ensuring an effective risk management are constant and fundamental themes in shipbuilding [1, 2]. The necessity of extensive and standardized rules about these issues has brought the International Maritime Organization (IMO) to introduce new requirements within the International Convention for the Safety of Life at Sea (SOLAS). In particular, since 2006, a new set of Regulations commonly known as "Safe Return to Port (SRtP)" has been issued [3, 4, 5]: their primary aim is to ensure that, under specific casualty circumstances, the ship can make a safe return to port with its own systems. Furthermore, when a specific casualty threshold is exceeded, an orderly evacuation and abandonment of the ship shall be ensured [6].

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1877-0509
10.1016/j.procs.2021.01.277

Considering the purpose of SRtP Regulations, it is clear that their application during ship design can have a huge impact on the arrangement and integration of different systems [7]. This is especially true for the so-called "Essential systems" (ESs), for which stricter requirements regarding functionality and redundancy shall be applied. In this regard, previous studies have stressed the difficulty in complying with SRtP rules and have raised criticisms about the benefits of SRtP in terms of systems reliability versus implementation costs [8–11]. Due to these reasons, the availability of simulation tools to be used during early design stages is extremely important [12, 13]. Several IT tools, specifically addressed to deal with SRtP requirements, have been developed. Their operating principles resemble the Regulations logic; furthermore, they are able to simulate the behavior and functionality of ship systems under casualty circumstances. These tools can effectively assist ship system designers in facing and fulfilling Safe Return to Port requirements in a relatively short time [14].

Firstly, the paper gives a brief overview of the Rule Framework currently in force, by deepening the structure of the SRtP Regulation. Then, the paper proceeds with the analysis of the suggested design approach for ship systems and a thorough description of an existing commercial SRtP IT tool, developed by Brookes Bell, able to support such a design phase.

2. Rule framework

The first Safe Return to Port Regulation was introduced in December 2006 as a modification of SOLAS Chapter II-2: the MSC.216(82) (IMO 2006). Successively, its interpretations were issued in MSC.1/Circ.1369 (IMO 2010) and MSC.1/Circ.1437 (IMO 2012).

SRtP Regulations entered into force on the 1st July 2010: they apply to passenger ships with a length of 120 meters or more, or having at least three Main Vertical Zones (MVZs). They are presented in the following subsections.

2.1. Chapter II-1 – Regulation 8.1

Regulation II-1/8.1 provides requirements regarding system capabilities and operational information after a flooding casualty on passenger ships. Specifically, a passenger ship shall be designed so that the systems specified in Regulation II-2/21.4 remain operational when the ship is subject to flooding (due to a pipe failure) of any single main watertight compartment (Figure 1(a)).

2.2. Chapter II-2 – Regulation 21

Regulation II-2/21 provides requirements regarding casualty thresholds, safe areas, and safe return to port. The purpose of this Regulation is to establish design criteria for a ship safe return to port under its own propulsion after a casualty that does not exceed specific casualty thresholds. It also provides functional requirements and performance standards for safe areas.

2.2.1. Casualty Thresholds

As regards flooding, the casualty threshold is given in Regulation II-1/8.1.

As regards fire, the casualty threshold includes:

1. loss of space of fire origin up to the nearest "A" class boundaries, which may be a part of such a space, if it is protected by a fixed fire-extinguishing system (Figure 1(b)); or
2. loss of the space of fire origin and adjacent spaces up to the nearest "A" class boundaries, which are not part of the space of origin (Figure 1(c)). It is worth noting that, in accordance with MSC.1/Circ.1369 Interpretation 7, only the adjacent spaces within the same MVZ need to be considered and the casualty threshold includes spaces one deck upwards. Therefore, a fire is not intended to spread downwards, but only in upper decks.

2.2.2. Safe Areas

Safe areas are ship zones in which, after a damage not exceeding the casualty threshold and during the return of the ship to port, passengers and crew must stay. Safe areas shall generally be internal spaces; however, the use of an external space as a safe area may be allowed by the Administration on the basis of any restriction due to the area of operation and relevant expected environmental conditions. Furthermore, safe areas shall be above the bulkhead deck and equipped with the following essential systems:

- a minimum space of 1 m^2 or 2 m^2 per person, depending on the duration of safe return to port operations;
- restrooms and potable water, food;
- alternate space for medical care;
- shelter from the weather;
- lighting, air-conditioning and ventilation.

In addition, means of access to live-saving appliances shall be provided from each safe area, taking into account that a MVZ may not be available for internal transit.

2.2.3. Safe Return to Port Essential Systems

When fire damage does not exceed the prescribed casualty threshold, the ship shall be capable of returning to port while providing a safe area. To be deemed capable of returning to port, the following systems shall remain operational in the remaining part of the ship not affected by fire:

- propulsion;
- steering systems and steering-control systems;
- navigational systems;
- systems for fill, transfer and service of fuel oil;
- internal and external communication;
- fire main system, fixed fire-extinguishing systems, and fire and smoke detection system;
- bilge and ballast system;
- power-operated watertight and semi-watertight doors;
- systems intended to support “safe areas”;
- flooding detection systems; and
- other systems determined by the Administration to be vital to damage control efforts.

2.3. Chapter II-2 – Regulation 22

Regulation 22 provides design criteria for systems required to remain operational for supporting the orderly evacuation and abandonment of a ship in case of exceeding the prescribed casualty threshold.

Specifically, in case any one MVZ is unserviceable due to fire, the following systems shall be arranged and segregated in such a way they remain operational:

- fire main;
- internal communications (in support of fire-fighting as required for passenger and crew notifications and evacuation) and means of external communications;
- bilge systems for removal of fire-fighting water;
- lighting along escape routes, at assembly stations and at embarkation stations of life-saving appliances, and guidance systems for evacuation.

The above systems shall be capable of operation for at least 3 hours based on the assumption that there is no damage outside the unserviceable Main Vertical Zone. These systems are not required to remain operational within the unserviceable MVZs.

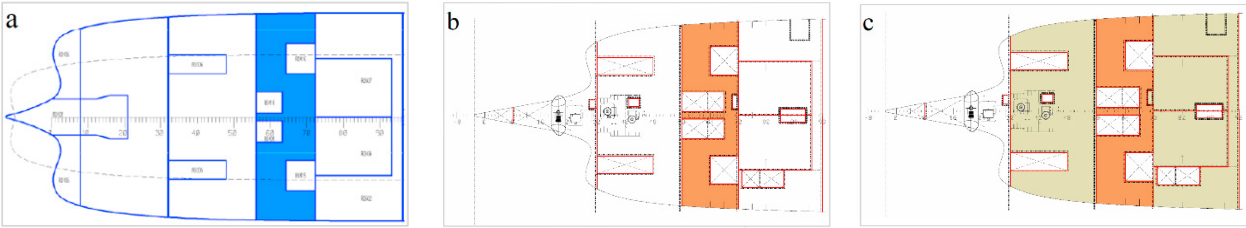

Fig. 1. (a) Flooding of a single watertight compartment; (b) Fire in a protected space; (c) Fire in a non-protected space.

3. Design approach

When a new project starts, shipowner's requirements are the most important input. Indeed, the Technical Specification must contain information regarding ship performances and services available in safe areas during SRtP operations. As an example, SRtP range and speed must be decided in accordance with the shipowner.

3.1. SRtP suggested approach

In order to fulfil requirements, the SRtP Regulation provides four possible approaches:

1. Duplication: to carry out a specific service by using two smaller elements, rather than a single bigger one;
2. Redundancy: to provide at least two identical elements, each capable of ensuring the full service requested by a single component (normally, one element is active while the other is on standby) [15];
3. Segregation: to place various components of a generic system inside different spaces, delimited by "A" class bulkheads or different watertight compartments;
4. Protection: to use special materials able to protect pipes, components, or vital parts of a system, which could be damaged.

However, in order to comply with the ultimate purpose of SRtP Regulation, the perfect design solution consists of a completely redundant vessel, which can be divided into two sub-ships called "Ship A" and "Ship B" (Figure 2). Every Essential System (ES) is therefore divided into two subsystems, each belonging to a specific sub-ship.

Eventually, in order to choose the best design approach possible, it is crucial to understand how each ES works. Based on their operating principles, they can be divided into the following categories:

1. A and B: the system is divided into two completely segregated subsystems (each subsystem is able to perform half the service requested in normal conditions). Moreover, each subsystem must perform the service necessary to face either a SRtP or an evacuation scenario. Some examples are propulsion system and cooling system;
2. Main Vertical Zone: the system is divided into several subsystems, each belonging to a specific MVZ (it is then possible to decouple the subsystem within the lost MVZ). MVZ operating principle is required for systems that are necessary during evacuation and abandonment scenario and some examples are fire main system and lighting;
3. Safe area: the system is divided into several subsystems, each belonging to a specific safe area. Some examples are sanitizing system and potable water distribution;
4. Topographical: the systems must remain available in all spaces not subject to damage. Such systems usually provide their service to various spaces of the ship and some examples are bilge and ballast systems and fixed fire-extinguishing systems.

3.2. Design documents

Safe Return to Port Regulation compliance is assessed through a specific list of documents, which is thoroughly described in the following sections [16].

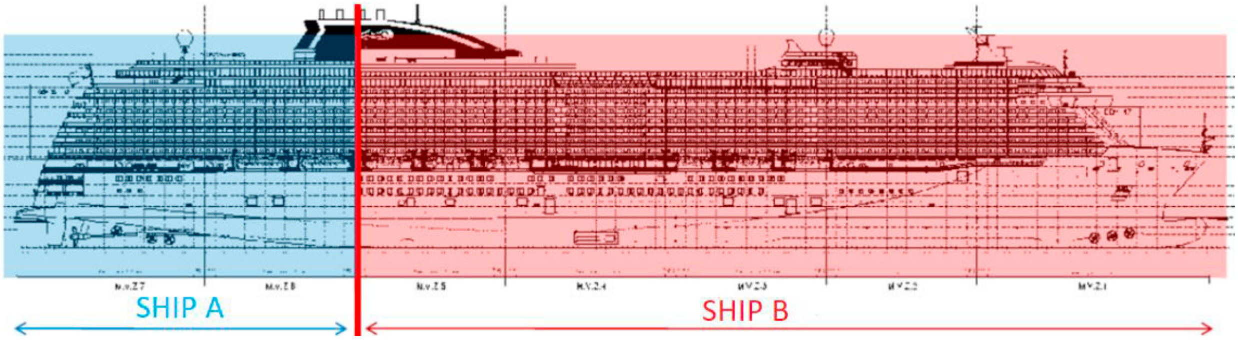

Fig. 2. Subdivision of a completely redundant ship into sub-ships A and B

3.2.1. Ship description

Ship description provides specific information regarding how the ship has been built, in accordance with International Regulations and shipowner's requirements. Furthermore, it provides the basic layout of the vessel, data regarding the minimum speed and the intended operating area, the design criteria for each individual essential system or group of essential systems, criteria adopted for the selection of safe areas and intended locations, and the list of essential systems.

3.2.2. Overall assessment of essential systems

An overall structured assessment of all essential systems should be carried out, in order to demonstrate their functionality and highlight interdependences among them. The systems assessment can be performed in qualitative terms; quantitative analysis may be required as part of the detailed systems assessment as described in the following section.

3.2.3. Detailed assessment of critical systems

A detailed assessment must be performed for each system whose functionality could be affected after a damage. The document should contain the following information:

- remaining functionality of the system;
- details of pipes, cables or other devices connecting the components of the critical system, or connecting different critical systems including their location within the affected area;
- details of any manual action providing the required ship systems functionality; and
- details of any operational solution forming part of the design criteria.

3.2.4. Operation manual

The operation manual must be developed for every possible damage scenario on-board the ship and it is part of the on-board documentation. It provides all the information regarding the consequences of a generic damage on all essential systems and highlights any necessary manual actions. In general, tests or drills, as applicable, should demonstrate feasibility of manual actions.

3.2.5. Test program

The test program represents a structured procedure whose purpose is to demonstrate what has been stated through the design documents (Figure 3(a)). It consists of different types of tests including the memoranda test and the scenario test, both described below:

- memoranda test: it verifies that every single essential system fulfils requirements;
- scenario test: it verifies that, following a damage in a specific room, all the essential systems work simultaneously.

3.3. Topographic schemes

In order to perform systems assessment and elaborate all the design documents previously described, topographic schemes of essential systems are necessary.

First, all the SRtP spaces delimited by "A" class or watertight bulkheads must be identified through an unequivocal acronym.

Then, all the systems must be described by reporting technical and location information of all the components (machinery, tanks, pipes, cables, etc.) belonging to them.

Furthermore, also the adopted assessment criteria should be specified.

Systems topographic schemes display all the components in their correct location, in order to allow manual actions identification. To summarise, these schemes show SRtP pipes and cables route, valves position, machinery position, and potential reinforced connections. It is not necessary to locate every component in the precise position: selecting the correct room is sufficient.

3.4. Failure Mode Effect Analysis

The tool to assess systems functionality after damages is the Failure Mode Effect Analysis (FMEA) [17–22].

FMEA is a technique in which systems are defined in terms of functions or hardware. Each item in the system is identified at a required level of analysis. The effects of item failure at that level and at higher levels are analyzed to determine their severity on the system as a whole. Any compensating or mitigating provisions in the system are taken account of and recommendations for the reduction of the severity are determined. The analysis indicates single failure modes that may cause system failure.

The FMEA report outlines the results regarding failure modes that can have significant effects on the system and classifies them into categories, e.g., catastrophic, critical.

4. Tools for SRtP assessment

As previously seen, SRtP requirements are not immediate and easy to implement. Designers have to deal with several aspects and difficulties while defining systems arrangements. Hence, IT tools can represent valuable instrument to support design.

In particular, Systema is a tool for the design and assessment of ship systems able to ensure compliance with SRtP requirements. Systema allows the design of systems within a vessel General Arrangement plan (GA), by placing components and relevant routing cables and piping through multiple spaces. The functionality of systems may be defined, as well as vessel subdivisions and damages, in accordance with SRtP Regulations. Systema operating principle is based on the approach issued within SRtP Regulation. This consideration represents also the basis for the methodology developed in terms of systems assessment and described in the following (Figure 3(b)). In particular, the analysis is performed through the following four steps:

1. set up of the ship model: layout of spaces, definition of damages, MVZs, safe areas, and SRtP spaces;
2. definition of the models of the systems: layout, topography, functions of the components, and functionality of the systems;
3. calculation of the damages' effects: failure of functionality, individual components failure;
4. detailed overview of failure mechanism: redesign options, manual actions.

4.1. Ship model

In order to start modelling systems, Systema must be provided with the ship geometry, represented by the longitudinal profile and decks views and containing all the “SRtP spaces” to be analyzed (Figure 4). Systema stores the relevant position of each space, thereby allowing to route cables/pipes and generate damages. Within Systema, “SRtP spaces” represent the smallest portions of a deck, and are called “Rooms”. When contiguous Rooms are grouped in a whole entity it is formed the so-called “Space”. “Spaces” in turn can be collected into four different categories:

watertight (WT), A-CLass (ACL), Main Vertical Zone (MVZ) and Safe Area (SA). On the basis of the Spaces category, “damage” is defined as a collection of Rooms where all the elements of the present systems are unavailable. It is possible to generate both the prescribed SRtP Regulation damages and designer custom damages.

4.2. Models of the systems

Once the ship model has been set up, it is possible to start modelling systems: Systema provides a default list of SRtP Essential Systems, and customized systems can be added. Each ES can be subdivided into several subsystems, in order to both facilitate modelling and perform reporting and analysis stages as well. Of course, Systema allows the connection between subsystems in order to simulate their working state.

Subsystems are modelled through block-line diagrams, in which components (blocks) and connections (lines) must be drawn (Figure 5(a)). Elements in these diagrams are placed in their correct location by means of the ship model.

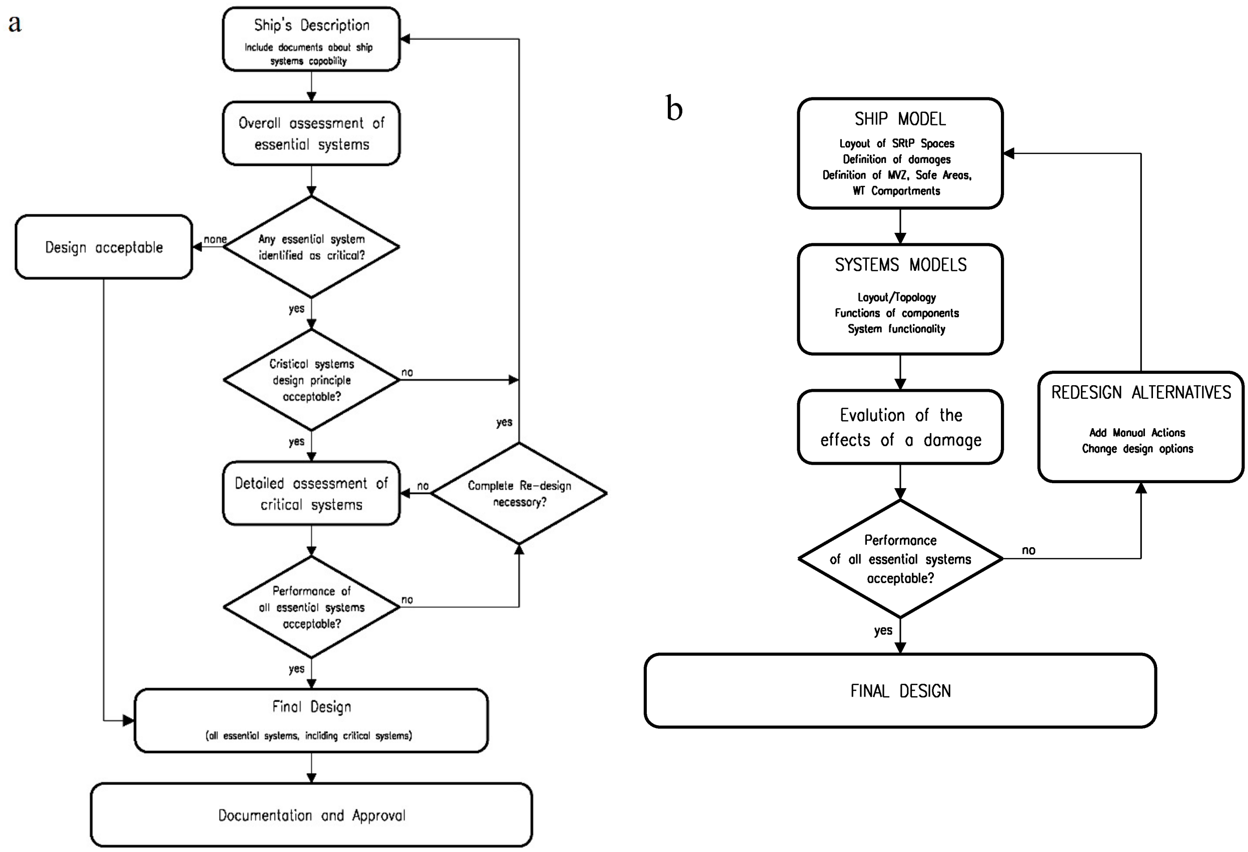

Fig. 3. (a) Assessment flowchart; (b) Systema methodology for systems assessment

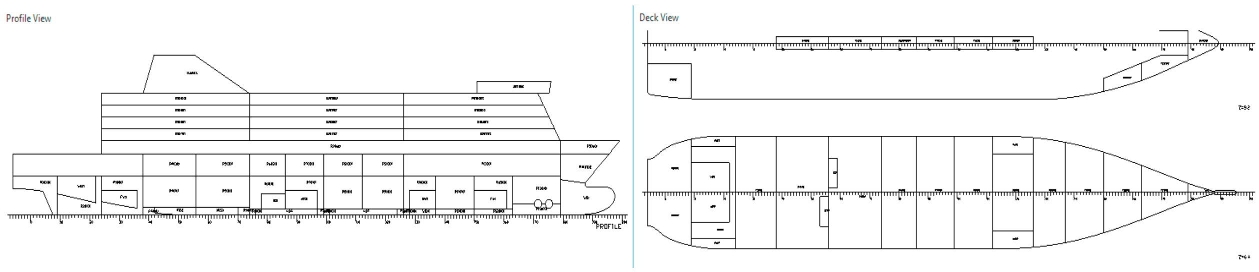

Fig. 4. Longitudinal profile and deck views

4.2.1. Models of the systems – Components

Components represent the physical entities of systems, e.g., engines, propellers, tanks.

Since all components in a damaged space are assumed to be unavailable, each component must be placed in the correct Room. Furthermore, other information regarding vulnerability can be added.

Every component in a system has some functionality associated with it. This is the basis of defining the functionality of a component: in general, the model creator can consider output dependent on the input as set up. When a component is damaged, it is assumed that all output fail, whether or not the input have failed.

4.2.2. Models of the systems – Connections

Connections represent the physical links between components, e.g., cables and pipes.

As for components, two-component connections must be routed through the correct Rooms. Moreover, it is possible to add further information regarding vulnerability.

Connections are responsible for defining the links between outputs of one component to the inputs of another. This allows to analyze the impact of the failure of a single (or multiple) component(s) on the functionality of all other linked components. Therefore, the availability of the different systems can be assessed.

4.2.3. Models of the systems – Functions

"Functions" in Systema are used to assess systems and check if they are working properly. These are crucial when carrying out assessment of SRtP requirements of the ship systems. Therefore, Functions are generally created as dependent on an output or an input of a component.

It is possible to define the following five different types of Functions (or "assessment criteria"):

1. ESS – Ship Wide Essential: to be available under all damage conditions;
2. ESW – WT Space Essential: to be available within each WT space not affected by the damage;
3. EST – ACL Space Essential: to be available within each ACL space not affected by the damage;
4. ESX – MVZ Space Essential: to be available within each MVZ except for the one where the damage occurred;
5. ESA – Safe Area Essential: to be available within each Safe Area except for the one where the damage occurred.

Function types are very important, as they are the basis for defining the scope of a "Function" and, therefore, its criticality level. For example, an ESS type function would be the propulsion, which must be available no matter where the damage has occurred.

4.3. Calculation of the damages effects

Systems assessment is performed based on damage scenarios, connections/dependencies between various systems, and functions. Systema expresses connections and functions as Boolean variables, applies the damage (i.e., simulates the damage of the components inside spaces), and finally obtains and analyses the output results. The software interface can display the results in the relevant system diagrams, GA, and damage results views (Figure 5(b)). Designers can examine all the damage scenarios and analyze the functionality of systems and components involved.

Furthermore, Systema can elaborate a FMEA report, in which output results and significant information regarding ship and systems are collected. A single report is generated for each of the subsystems specified. Within each report, damages that do not affect a particular subsystem are not included.

4.4. Detailed overview of failure mechanism

After simulating damages to a system, Systema is able to determine how to restore a function. Only functions resulted as "critical" can be restored. Restoration is carried out through operations on valves and switches, which can be opened or closed. On the basis of the restoration instructions given by Systema, manual actions for the crew can be issued.

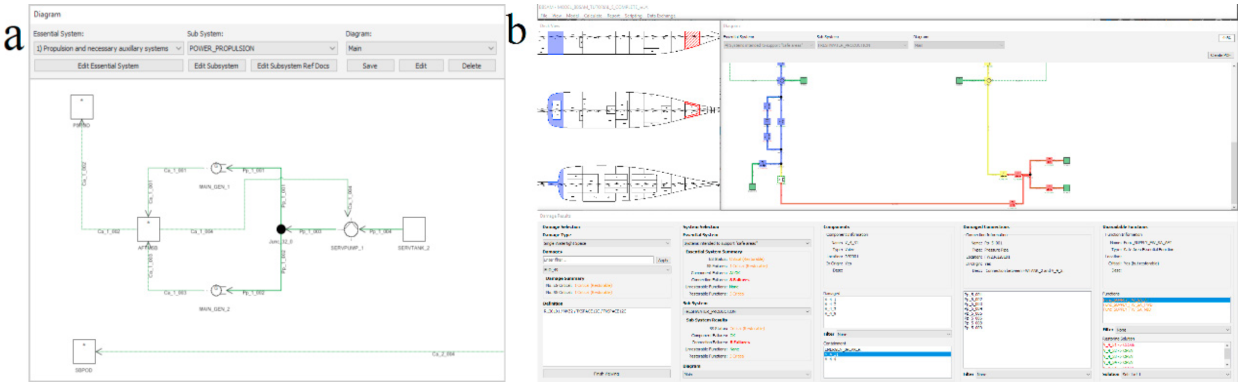

Fig. 5. (a) Example of propulsion system diagram; (b) GA, diagram, and damage results view.

4.5. Design documents

As seen in the previous sections, Systema is able to elaborate a FMEA report. Furthermore, a valuable feature called "SRtP Submission Documents" has been developed in accordance with suggestions and feedbacks from various Parties. The submission documents are split into one summary document and six detailed volumes:

- Availability Analysis: summary of failures for all systems and all damages;
- Volume I: ship space definition, plots on GA;
- Volume II: Casualty scenarios, plots on GA;
- Volume III: essential system details including reference documents, extent of system, components, connections, assessment criteria, summary of failure;
- Volume IV: subsystem report detailing;
- Volume V: model description detailing the physical and functional model by summarizing information;
- Volume VI: crew manuals (details of each damage and extent, lost functions and restoring actions).

Furthermore, another significant feature called "SRtP Test Programme Report" allows to generate documentation to support audit, and verify the systems during both harbour and sea trial acceptance tests. The report is split into four additional volumes.

5. Results and Discussion

The paper provides a thorough analysis of the SRtP Regulation and an extensive description of the suggested design approach. Furthermore, it gives a detailed explanation of the structure of Systema, a simulation tool able to support ship systems design and assessment. In this regard, it is worth noting that Systema is one of the few available IT tools addressing the matter. Its architecture accurately resembles the approach described in SRtP Regulation, but the correct methodology to use is the innovative aspect presented in the paper. Indeed, the tool has been tested and applied on several case studies and the results obtained have been validated. Surely, systems designer must generate the most important contribution, which is the precise modeling of the ship and its systems; once done, the tool is able to perform all the necessary calculation to assess systems functionality and provide restoring actions, when necessary. Therefore, ship designers must stick to a definite procedure in order to instruct Systema in the best way possible.

6. Conclusions

The IMO Safe Return to Port Regulation introduced new challenges for ship system designers, which has to deal with stricter rules regarding systems arrangement and functionality. As a result, design time could extend and the availability of IT tools for SRtP compliance can represent a great aid. Indeed, by simulating systems working processes, it is possible to identify potential criticalities already during design phases. Furthermore, they can also elaborate preliminary versions of documents for submission and test phases.

In particular, the Systema software presented in this paper appears to be a promising and valuable tool for ship designers. Indeed, the authors have tested the tool on several case studies that will be presented in future works. The application of Systema allowed to define a clear and definite methodology for systems assessment.

The effective benefits of the tool will be further investigated within other ship designs. Moreover, a comparison with other available SRtP tools could be carried out: by the differences stemming, it will be possible to understand their capabilities and effectiveness.

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