NATIONAL TECHNICAL UNIVERSITY OF ATHENS
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Risk analysis of marine accidents derived from inspection mistakes

Diploma Thesis

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Contents

Περίληψη στα ελληνικά

Οι επιθεωρήσεις αποτελούν ένα μεγάλο μέρος της ζωής των πλοίων. Καθορίζουν διαφορετικά προβλήματα και περιοχές που πρέπει να εξεταστούν για την ομαλή λειτουργία των θαλασσίων μεταφορών. Είναι εμφανές ιστορικά ότι πολλά ναυτικά ατυχήματα έγιναν από λάθη επιθεωρητών. Λόγω των πολλών καθηκόντων τους, οι επιθεωρητές κάνουν συχνά σφάλματα που μπορούν να οδηγήσουν σε μεγάλους κινδύνους. Το πρόβλημα αυτό υπογραμμίζει την αναγκαιότητα μιας σωστής ανάλυσης ρίσκου αυτών των τύπων ατυχημάτων που καθαρά να δείχνει τους συντελεστές που συνεισφέρουν σε αυτά και την σύνδεσή τους με τις επιθεωρήσεις.

Η ανάλυση ρίσκου έχει χρησιμοποιηθεί πολλές φορές σε έρευνες για την αναγνώριση και τη μελέτη του ρίσκου και των κινδύνων και είναι ένα σημαντικό στοιχείο για κάθε βιομηχανικό περιβάλλον. Αυτή η έρευνα ερευνά τα χαρακτηριστικά της διαχείρισης και ανάλυσης του ρίσκου και προσπαθεί να παραστήσει ένα χρήσιμο μοντέλο που να μπορεί να χρησιμοποιηθεί στα ατυχήματα που προέρχονται από λάθη επιθεωρητών. Το μοντέλο πρέπει να είναι αρκετά γενικευμένο για να μπορεί να αναπαραστήσει την πλειονότητα των ατυχημάτων.

Διενεργήθηκε μια στατιστική ανάλυση σε πενήντα ατυχήματα για να δειχθεί επαρκώς η ποικιλομορφία των ατυχημάτων που εμπίπτουν στην κατηγορία των προβληματικών επιθεωρήσεων και να υπογραμμιστούν οι διαφορετικές συνέπειες που τα ατυχήματα έχουν. Επίσης οι διαφορετικότητα μεταξύ των ειδών των πλοίων καθορίστηκε στατιστικά. Όλα τα αποτελέσματα παρουσιάστηκαν σε ποικίλα γραφήματα που δίνουν πολλές πληροφορίες για τα ατυχήματα.

Η ανάλυση Bow tie είναι μια νέα έννοια στην εκτίμηση του ρίσκου που μπορεί να περιγράψει την σχέση ανάμεσα σε διαφορετικές παραμέτρους όπως τα αίτια, τους κινδύνους και τις συνέπειες καθώς και να επισημάνει την ύπαρξη ανεπιθύμητων περιστατικών. Αυτή η έρευνα παρουσιάζει πως τα διαγράμματα Bow tie μπορούν να χρησιμοποιηθούν στην ανάλυση του ρίσκου σε ναυτικά ατυχήματα που προέρχονται από προβληματικές επιθεωρήσεις καθώς επίσης και πώς να στέκεται και ως αυτόνομη λεπτομερής ανάλυση ρίσκου.

Ένας μεγάλος αριθμός από διαγράμματα bow tie παρήχθησαν για να παρουσιάσουν τα μεγαλύτερα είδη ατυχημάτων που ήταν λάθη επιθεωρήσεων για διαφορετικούς τύπους πλοίων. Επίσης τα διαγράμματα αυτά εξετάστηκαν με την εφαρμογή τους σε δέκα πραγματικά ατυχήματα. Εν τέλει παρήχθησαν άλλα δώδεκα γενικευμένα σενάρια για να δειχθεί πόσο εύκολα διαφορετικά περιστατικά μπορούν να παρουσιαστούν με αυτήν την μεθοδολογία.

1. Abstract

Inspections are a great part of vessels' lifetime. They define different problems and areas that need to be taken under consideration for orderly functioning of marine operations. It is evident throughout history that many marine accidents occurred because of mistakes done from inspectors and surveyors. Due to their highly demanding duties, inspectors often fall into errors that can lead to major hazards. This problem underlines the necessity of a proper risk analysis of these types of accidents that can clearly show the factors that contribute to accidents and their connection with inspections.

Risk analysis has been used for identification of hazards and their risk in many researches for many decades and it is a crucial element in every industrial environment. This research focuses on the aspects of risk management and analysis and tries to present a useful model that can be used for accidents that derived from inspection mistakes. This model has to be generic in order to be able to represent the majority of the accidents this research focuses on.

A statistical analysis was held in fifty accidents in order to properly show the diversity of accidents that fall into the category of inspection mistakes and to underline the different type of consequences that these accidents have. Also the differentiation between various types of ships is statistically defined for the purpose of the research. All the results are presented in various graphs that give much information about the accidents.

Bow tie analysis is a fairly new concept in risk assessment that can describe the relationships of different parameters, such as causes, hazards and consequences and to underline the occurrence of unwanted incidents. This paper presents how bow tie diagrams can be used for risk analysis in marine accidents derived from inspection errors as well as standing alone as a detailed risk analysis.

A large number of bow tie diagrams were generated in order to represent the major type of accidents that are inspection errors in different types of ships such as Container ships, General cargo ships, Passenger ships etc. Also these diagrams were validated and tested in ten real accidents where their importance and accuracy is clearly demonstrated. Finally, twelve generic scenarios were created that show how easily different incidents and scenarios can be displayed and generated using this methodology.

2. Literature review

2.1 Introduction

The present dynamic society is characterized by rapid change, globalization, fierce competition and the rapid advancement of technology. [1]
It is largely acknowledged that increased complexity in technology, work tasks and organizational structures renders organizations more vulnerable to organizational accident risk due to increased degrees of freedom and ways in which components of complex systems may interact and produce unforeseen situations[1-3].

While outsourcing indeed may involve benefits in terms of increased flexibility, competitiveness, specialized expertise and cost effectiveness, the involvement of multiple organizations adds to the complexity in a system[2]

Accident rates, analyses of risks and hazards, investigations of past accidents and near misses, and analyses of organizational characteristics such as safety culture or safety climate all provide sources of information about different aspects of safety. In the safety literature, a distinction is commonly drawn between individual accidents and organizational accidents[3]

In the well-known Swiss cheese model(Reason 1997), describes how latent conditions dormant in a system may combine with active failures to ultimately breach the defences in depth[4].

Calls have been made for devising risk analysis frameworks, focusing on issues such as how to understand and describe risk, and how to use risk analysis in decision making [5]. Furthermore, there have been calls for devising methods for communicating uncertainty in risk analysis[6]. In the maritime transportation application area, some theoretical frameworks exist, e.g. based on system simulation[7], traffic conflict technique[8] and Bayesian Networks (Bns).[9, 10]

Risk analysis methods for maritime transportation have received a growing interest in recent years, even to the extent that international organizations have provided recommendations on the use of specific risk analysis and management tools[11-13]. Also, there is a recent focus on foundational issues in scientific environments concerned with risk analysis, with calls for intensifying research on issues such as applied terminology, principles and perspectives for analyzing and managing risk[5, 14, 15].

A distinction is made between the science of risk analysis (concerning concepts, principles, methods and models for analyzing risk) and the practice of risk analysis (concerning specific applications)[14].[9]

2.2 Bow tie method

The first precursor of Bow tie diagrams appeared in the (Imperial Chemistry Industry) course notes of a lecture on HAZAN (Hazard Analysis) given at The University of Queensland, Australia[16]. When the first significant hazard assessments were being started in the early 1970s, hazard scenarios were developed in words only. This could result in difficulties of understanding with more complicated scenarios and made communications difficult.

As experience was gained, the presentation was changed to the graphical form as fault trees, using logic symbols to represent 'AND' and 'OR' logic gates. These fault trees were initially drawn by hand and from the earliest stages it was felt in ICI that fault trees using the international standard symbols for 'AND' and 'OR* gates were difficult to draw, inflexible and not easily understood by those designing and operating processes. Furthermore, the Western world reads from left to right, so it was decided that fault trees should also read from left to right. The decision to use a non-standard notation has been shown in practice to be very well received by the most important people - those managing and operating the processes. [16]

Piper Alpha was an oil and gas platform 110 miles from the Coast of Aberdeen in the North Sea that was built in 1976. In June 1998 it produced 10% of the total British North Sea oil.

On July 6, 1988 a gas processor had exploded and set of a chain reaction which led to massive explosions that completely destroyed the platform in 3 hours[17].

The catastrophic incident on the Piper Alpha platform awoke the oil & gas industry. After the report of Lord Cullen, who concluded that there was far too little understanding of Hazards and their accompanying risks that are part of operations, the urge rose to gain more insight in the causality of seemingly independent events and conditions and to develop a systematic/systemic way of assuring control over these Hazards[18].

Bow tie diagrams are gaining greater acceptance in an industry which is moving further towards demonstrable and accountable risk management.

The methodology is proven by track record in the offshore, process and security risk industries and the tool continuously adapted to suite the need[19].

A lot of incidents have triggered the development and application of a series maritime security measures. Among the most significant ones is the implementation of International Shipboard and Port Facility Security (ISPS) Code[20] proposed by the IMO. This is where bow tie analysis comes to fulfill this need for a quantitative approach that is widely used and contributed to the literature of analysis as recommended from Yang and Wang[21]

In 2010, the study of Yi-Chih Yang[22] explore the risk management of Taiwan's maritime supply chain security using extensively the bow tie method.
The purpose of this study is to:

1. Highlight maritime supply chain risk feature and assessment factors.
2. Review current developments and industry insights concerning CSI and the 24-h rule in Taiwan.

3. Perform risk assessment for maritime security risks.
4. Formulate risk management strategies for maritime supply chains

Furthermore a study of Jun Ren, Kambiz Mokhtari, Charles Roberts and Jin Wang refers to Bow tie based risk analysis framework on risk management of sea ports and offshore terminals. This study focuses on the sea ports and offshore terminals and discusses recently emergent RM-related issues with taking into consideration of the externally and internally driven elements[23].

Finally there is the study of Faisal Khan Nima Khakzad and Paul Amyotte that focuses the quantitative risk analysis of offshore drilling operations[24]. This work is aimed at demonstrating the application of BNs in risk analysis of drilling operation s and making a comparison with the bow tie (BT) method.

3. Inspections

3.1 Introduction

This section will provide the necessary informations about ship inspections and surveys. Different kinds of inspection have a huge impact on the maritime industry and the lifetime of vessels. The legal framework is created by three major organizations namely, UN, ILO and the IMO and country specific legislations.

The classification societies provide their expertise during ship building and technical maintenance and also they can be authorized to perform statutory responsibilities on behalf of the flag states that have the responsibility to enforce their legal base which can be a combination of the international conventions of which the flag state is signatory or its own legal base while the ship owner has the ultimate responsibility to comply with the combined legal bases. [25]

Here is a short overview of the different kind of inspections an surveys that are carried out on ships.

The inspections originate from various sources and are as follows:

- Port state control inspections and flag state control inspections
- ISM and ISPS audits due to statutory requirements and which are still sometimes performed by the flag states but most of the time also delegated to recognized classification societies
- Classification surveys on behalf of flag states and to remain in class
- Insurance companies such as P&I Clubs for insurance coverage purposes
- Industry inspections such as vetting inspections performed on oil tankers, chemical tankers, gas carriers and bulk carriers on behalf of oil majors or other cargo owners or on behalf of the ship owner.

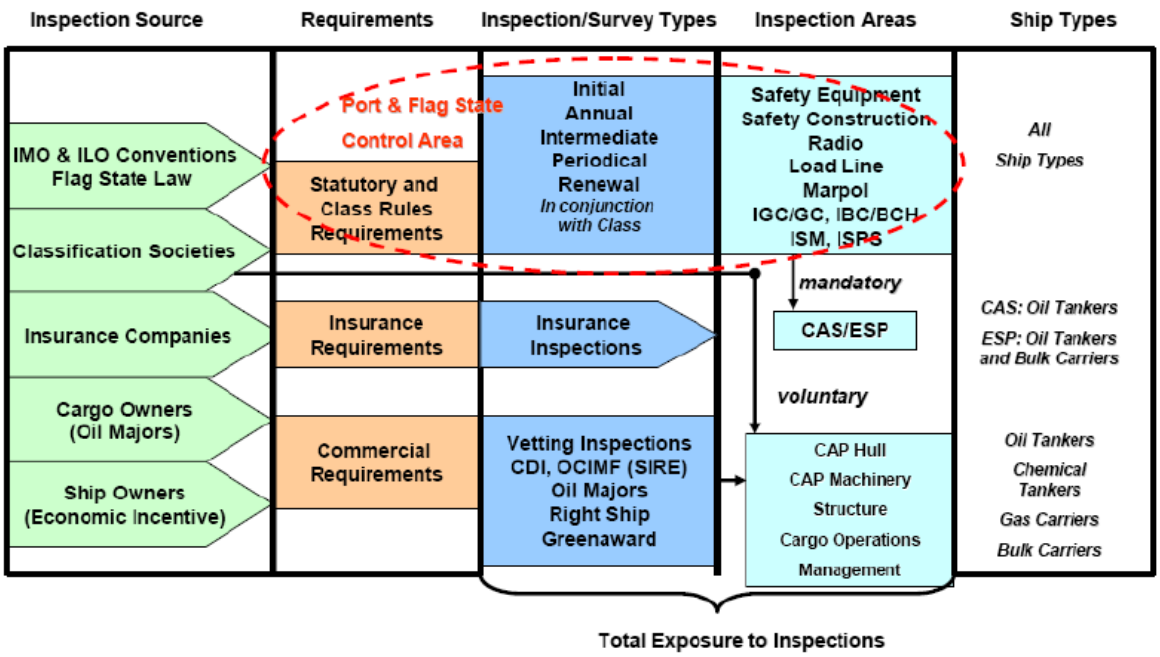

Figure 3.1 – Ship inspections & surveys[25]

3.2 Mandatory Inspections

The IMO has tried to synchronize the various types of inspections and four types of mandatory inspections can be identified.

- Initial: A complete inspection before the vessel comes into service
- Annual: General inspection of the items relating to the certificate to ensure that they have been maintained and remain satisfactory
- Periodical or Intermediate: inspection of the items related to the certificate in order to ensure that they are in satisfactory conditions
- Renewal: same as periodical but more detailed

In order to facilitate the various mandatory inspections/survey types and which need to be carried out, the IMO established the “Harmonized System of Survey’s and Certification” as shown in the next figure. [26]

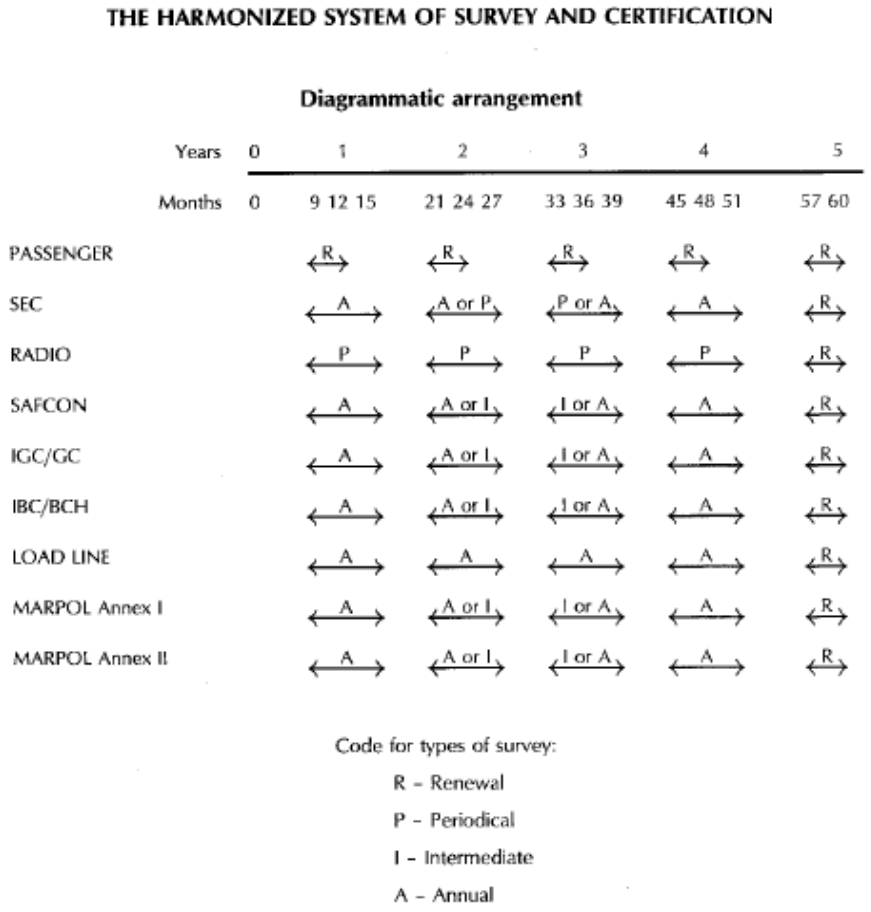

Figure 3.2 – Harmonized System of Survey's and Certification diagram [25]
Abbreviations: SEC = Safety Equipment Cert., SAFCON = Safety Construction Cert., IGC/GC = International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk Cert., IBC/BCH = International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk Cert..

The types of surveys used in the harmonized system are as follows:

3.3 Initial surveys

- SOLAS 74/88 chapter I regulation 7(a)(i)
  chapter I regulation 8(a)(i)
  chapter I regulation 9(a)(i)
  chapter I regulation 10(a)(i)
- LLC 66/88 article 14(1)(a)
- MARPOL Annex I regulation 6.1.1
- MARPOL Annex II regulation 8.1.1
- MARPOL Annex IV regulation 4.1.1
- MARPOL Annex VI regulation 5.1.1
- IBC Code regulation 1.5.2.1.1
- IGC Code regulation 1.5.2.1.1
- BCH Code regulation 1.6.2.1.1

3.4 Periodical surveys

- SOLAS 74/88 chapter I regulation 8(a)(iii)
  chapter I regulation 9(a)(iii)

3.5 Renewal surveys

- SOLAS 74/88 chapter I regulation 7(a)(ii)
  chapter I regulation 8(a)(ii)
  chapter I regulation 9(a)(ii)
  chapter I regulation 10(a)(ii)
- LLC 66/88 article 14(1)(b)
- MARPOL Annex I regulation 6.1.2
- MARPOL Annex II regulation 8.1.2
- MARPOL Annex IV regulation 4.1.2
- MARPOL Annex VI regulation 5.1.2
- IBC Code regulation 1.5.2.1.2
- IGC Code regulation 1.5.2.1.2
- BCH Code regulation 1.6.2.1.2

3.6 Intermediate surveys

- SOLAS 74/88 chapter I regulation 10(a)(iii)
- MARPOL Annex I regulation 6.1.3
- MARPOL Annex II regulation 8.1.3
- MARPOL Annex VI regulation 5.1.3
- IBC Code regulation 1.5.2.1.3
- IGC Code regulation 1.5.2.1.3
- BCH Code regulation 1.6.2.1.3

3.7 Annual surveys

- SOLAS 74/88 chapter I regulations 8(a)(iv) and 10(a)(iv)
- LLC 66/88 article 14(1)(c)
- MARPOL Annex I regulation 6.1.4
- MARPOL Annex II regulation 8.1.4
- MARPOL Annex VI regulation 5.1.4
- IBC Code regulation 1.5.2.1.4
- IGC Code regulation 1.5.2.1.4
- BCH Code regulation 1.6.2.1.4

3.8 Inspection of the outside of the ship's bottom

- SOLAS 74/88 chapter I regulation 10(a)(v)

3.9 Additional surveys

- SOLAS 74/88 chapter I regulation 7(a)(iii)
  chapter I regulation 7(b)(iii)
  chapter I regulation 8(a)(iv)
  chapter I regulation 10(a)(iv)
- LLC 66/88 article 14(1)(c)
- MARPOL Annex I regulation 6.1.5
- MARPOL Annex II regulation 8.1.5
- MARPOL Annex IV regulation 4.1.3
- MARPOL Annex VI regulation 5.1.5
- IBC Code regulation 1.5.2.1.4
- IGC Code regulation 1.5.2.1.4
- BCH Code regulation 1.6.2.1.4

Besides the items listed above, two types of audits are also identified, the *ISM* (International Safety Management) audit and the *ISPS* (International Ship and Port Security) audit which are both SOLAS requirements.
This certification is split into ashipboard part and a company part where the shipboard part has to be completed every five years with one intermediate audit half way). Some flag administrations have not yet authorized classification societies to perform these audits but many flag states have done so and this area is therefore also widely covered by classification societies. [25]

3.10 Classification surveys

- A classification survey is a visual examination that normally consists of:
  an overall examination of the items identified in the Rules for survey;
- detailed checks of selected parts, on a sampling basis;
- witnessing tests, measurements and trials where applicable.

When a surveyor identifies corrosion, structural defects or damage to hull, machinery and/or piece of equipment which, based on the Society's Rules and in the opinion of the surveyor, affects the ship's class, remedial measures and/or appropriate recommendations/conditions of class are specified in order to retain class.

'Recommendation' and 'condition of class' are different terms used by IACS Societies for the same thing i.e. requirements to the effect that specific measures, repairs, request for surveys etc., are to be carried out within a specified time limit in order to retain class. Each classed vessel is subject to a specified programme of periodic surveys after delivery. The rigour of each specified survey increases with the age of the vessel.

The class renewal surveys/special surveys include extensive in-water and, in most cases,

out-of-water examinations to verify that the structure, main and essential auxiliary machinery, systems and equipment of the ship remain in a condition which satisfies the relevant Rules. The examination of the hull is supplemented, when specified, by ultrasonic thickness measurements and the witnessing of tests as specified in the Rules and as deemed necessary by the attending surveyor. The survey is intended to assess whether the structural integrity remains in conformance with the standards contained in the relevant Rules and to identify areas that exhibit substantial corrosion, significant deformation, fractures, damages or other structural deterioration.

The intermediate survey (held approximately half way between special surveys) includes examinations and checks as specified in the Rules to determine whether the ship remains in a general condition which satisfies the Rule requirements. According to the type and age of the ship, drydocking may be required and the examinations of the hull may be supplemented by ultrasonic thickness measurements as specified in the Rules and where deemed necessary by the attending surveyor.

At the time of annual surveys, the ship is generally examined. The survey includes an external general inspection of the hull, equipment and machinery of the ship and some witnessing of tests, so far as is necessary and practical in order to determine whether the ship remains in a general condition which satisfies the Rule requirements. Older ships of certain types may also be subject to a general examination of some specified internal areas of the hull. Depending upon the age, size, type and condition of the vessel, an annual survey may take from several hours to a few days to complete. [27]

3.11 Port State control

Port State control can be seen as a last resource of safety to eliminate substandard ships from the seas. Worldwide, there are currently ten safety regimes in place to cover most of the coastal states. Those regimes are as follows:

1. Europe and North Atlantic (Paris MoU)
2. Asia and the Pacific (Tokyo MoU)
3. Latin America (Acuerdo de Viña del Mar)
4. Caribbean (Caribbean MoU)
5. West and Central Africa (Abuja MoU)
6. Black Sea (Black Sea MoU)
7. Mediterranean (Mediterranean MoU)
8. Indian Ocean (Indian Ocean MoU)
9. Arab States of the Gulf (Riyadh MoU)
10. US (US Coast Guard)

PSC inspections are carried out under the authority of international conventions to verify that a vessel:

- Maintains valid documents and certificates in accordance with relevant conventions
- Is fit for intended service (e.g. hull and machinery)
- Is not a pollution risk
- Provides the crew a healthy and safe working environment

Initially, the PSC inspection generally consists of a visit on board to verify that necessary

certificates and documents are valid. The initial visit also gives the inspector an opportunity to judge the general appearance and condition of the vessel.

Detailed Inspections are warranted when the vessel does not pass the above criteria to determine whether the ship is substandard and/or not fit for service.

Grounds for a PSC inspectors carrying out a detailed inspection:

- A report or notification received from another authority
- A report or complaint from the master, a crew member (or any person or organization with a legitimate interest in the safe operation of the ship or in the prevention of pollution)
- The finding of serious deficiencies during the preliminary inspection

In many instances, the problems noted by the PCS are rectified while the inspector is still aboard and allowed to leave the port on schedule. Other deficiencies require further action to rectify and the ship is detained.
Once detained, inspectors verify deficiencies are rectified before the ship is allowed to proceed to sea. Additionally, the inspector may:

- Notify flag State of the detention
- Allow the ship to proceed to another port for repairs if it cannot be repaired at the local port, notifying the authority of the vessel's next port of call and the flag State

Numerous Port Authorities throughout the world have implemented Port State Control inspections and are maintaining databases to track owners who are running substandard vessels. Based on the number of times an owner has been entered into the database, it may be targeted as a substandard vessel, with no regard to the severity of the infraction.
The most active Port Authorities are USA, Australia, Canada, The Netherlands, Germany and the UK. Additionally, a PSC may target specific ship types and ages.[28]

3.12 Non Mandatory Inspections

In this section, a short review of non-mandatory inspections will be presented that take place during a vessel's lifetime.

- *CDI (Chemical Industry Institute):* CDI inspections originate from the ship owner and are therefore owned and paid by the ship owner. The owner requests a CDI inspection and the inspector is appointed to the vessel. CDI inspections are primarily performed on chemical tankers.
- *SIRE (Ship Inspection Report Program) and inspection from Oil Majors*: Sire inspections are performed by OCIMF (Oil Companies International Marine Forum) and originate from cargo owners. These types of vetting inspections are primarily for oil tankers. The inspections also cover more or less the same areas as CDI with a heavy influence on cargo operations.
- *Rightship:* Rightship is a ranking system which combines information obtained through vetting inspections, port state control, casualties, ship particular information and ship owner information. The inspections cover tankers and bulk carriers but are primarily for dry bulk carriers.

Greenaward: The last kind of inspection that is performed on vessels (oil tankers) originates from the Greenaward Foundation. These inspections are paid by the ship owner once the vessel is “Greenaward Certified”, it needs to undergo annual or intermediate surveys to remain certified. [25]

4. Risk and bow tie concept

4.1 Risk assessment

Risk and risk assessment have a long history. By understanding risk and its consequences, risk management has been transformed into one of the most important aspect of modern society. The attitude towards risk has changed trough history and the modern lifestyes have great inpact on that.

The ability to define what may happen in the future and to address risk is a key element in a functional system to be able to provide decision support concerning choice of arrangement and measures.[29]

Since 1980, safety barriers have been used in industry process for safety management. The notion of safety barriers was clearly defined by Skelet [30]: “Safety barriers are physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents”.

From ISO 13702, prevention states the reduction of the occurrence related to undesired event, control means limiting duration of an undesired event and mitigation means the reduction of the effects of an undesired event. In addition, this standard defines the undesired events such as; technical failures, human errors, external events or a combination of these occurrences. These events may lead to major accidents such as; environmental damage, material damage and people injuries.

To increase safety at sea, IMO has developed a structured and systematic methodology for a formal safety assessment (FSA), by using risk analysis and an efficient risk management. Formal safety assessment (FSA) represents IMO response to the necessity of a modern approach of the process of establishing regulations in order to improve safety at sea.[31]

In literature, there are several methods for safety management. The well known ones are based on graphical presentation of safety barriers namely; Safety-barrier diagram[32], Event-tree analysis[33] and Bow tie diagram[34].

4.2 Accident risk

Risk is usually associated with accident statistics. There are numerous reports and tables that show the number of fatalitites and injuries as accidents' results.

These statistics may cover the whole number of accidents related with an activity within various consequence categories and they could be related to different accident. Often the statistics are related to time periods, and then time trends can be identified.

Usually, accident statistic are used by industries. They are a tool for management to obtain updates on results and injuries at work.

According to the literature, accident statistics can be used in several ways:

- to monitor the risk and safety level;
- to give input to risk analyses;
- to identify hazards;
- to analyze accident causes;
- to evaluate the effect of risk reducing measures;
- to compare alternative area of efforts and measures. [30]

4.3 Dynamic barrier management

Real-time information from many sources can also have an improvement to safety barrier management, which commonly involves risk-based inspection and maintenance.

Human, technological, organizational or a combination of these reasons can lead to barrier failures. Safety barrier management is well established in the industry. A succession of barriers can be applied to contain the risk below a target level Barrier status is monitored by inspections whose frequency is determined by the additional risk that would be created if a particular barrier failed.

Different risk reduction can be provided by different barriers, so a standard practice is to measure them at different intervals. If barrier failure or weakening goes undetected, risk may as well exceed unwanted target. It is important to understand the actual status of barriers and easily monitor and analyse their performance, their possible degredation and the optimum risk levels.

Dynamic barrier management assessing barrier status so maintenance, repair or replacement can restore risk to target levels. Designing a dynamic barrier management approach involves specifying an appropriate number of barriers to meet the risk target.

While the industry measures barriers, it does so sub-optimally, and status updates and decisions are not always based on risk contribution. Dynamic barrier management can become the main model for barrier management. It can reduce unwanted incidents with frequent sampling of barriers and smarter use of monitoring data. It also supports asset safety and operational efficiency and an early indication of barrier degredation that can provide easiness for scheduling corrective actions.

The value of dynamic barrier management is in the process of evaluating barriers and it is not reduced by the fact that data sources are based on human judgement. People can do it differently or reach different conclusions but they work to the same process, ask the same questions, and make their own decisions.[35]

4.4 Bow tie diagram

The Bowtie method is a risk evaluation method that is used to analyse relationships in high risk scenarios. The method takes its name from the shape of the diagram which looks like a men's bowtie. Bow tie gives a summary of all scenarios around a top event. It displays what should be done to control those scenarios. Once the control measures are identified, the Bowtie method identifies the ways in which control measures fail. [18]

In the early nineties, Bow tie diagram was developed by SHELL company to describe the scenario of an accident. It has proven its efficiency in several real application such as risk management, risk analysis, risk assessment and safety barriers implementation.

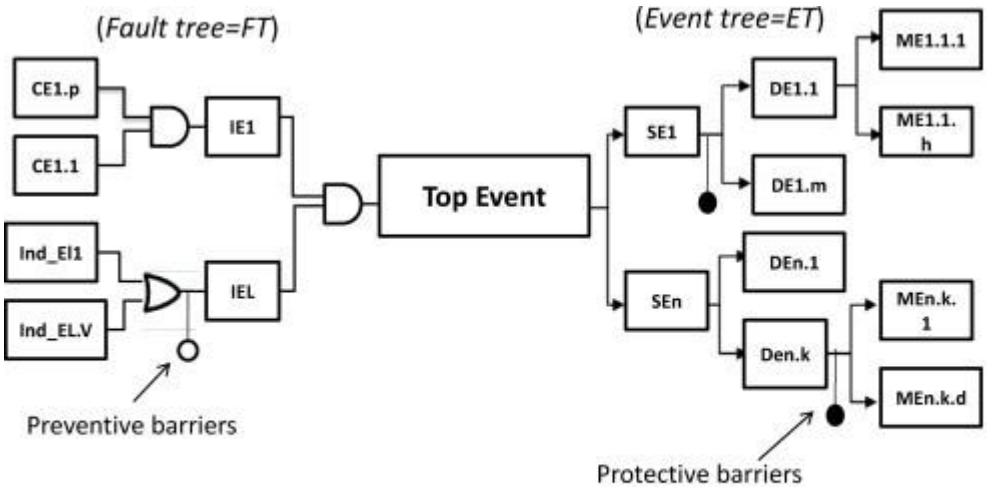

Figure 4.1 – *Generalized bow tie diagram[36]*

This method mainly consists on graphical presentation of the whole scenario of each identified risk named top event via two parts.

The first part represents the fault tree which defines all possible causes of the top event. These causes can be classified into two types namely; the initiator events which define the principal causes of top event. Also, the undesired and critical events which are the causes of initiator events. The relationship between events and causes are represented by logical AND and OR gates. The AND gate means that the frequency of an event requires the happening of all its related causes, whereas the OR gate means that the frequency of an event requires the happening of any of its related causes[14]

Although the Boolean logic gates in Fault Tree Analysis allow the model to be filled with actual numbers about failure probabilities this information is seldom available due to the costs of testing and human influence on the system. [18]

The second part represents the event tree which defines all possible consequences of top event. These consequences can be classified into three types, second events which are the primary consequences of top event, dangerous effects which are the dangerous consequences of second events and major events of each dangerous effects.[36]

The various incidents in fault trees are defined with a specific initial letter (X,I,E,Y,Z etc.). Each letter represents a different level of occurrence in the diagram. The first level of events in a fault tree is called main causes level and all the other levels are, generally, the intermediate causes. Especially in this research, the two levels before the top event are called failure mode(the level just before the top event) and level of causes(the level of events just before the failure mode).

After the top event, specific barriers/gates construct the event tree diagram. The success or failure of these barriers determines if the accident will go further to the next barrier. At the end of every path with its specific barriers there is a an outcome. The severity of this outcome is based on the different barriers that define how the incident continued after the top event. The level of consequences at the end of every path is called ultimate consequences level while all the other levels are the intermediate consequences levels.

The Bowtie method is usually used when the consequence spectrum from the major hazard is so bad that keeping control and analyzing all the possible scenarios is of major importance, regardless of the actual probability of the consequences. In most cases there is little accurate information available about the frequency of these worst-case-scenario consequences. [18]

Bowtie diagrams also define all the possible preventive barrers to limit the occurance of tope event and the protective barriers in event tree section that reduce the severity of the consequenses. These barriers can be classified as active if they require a source of energy or a request (automatic or manual action) to fulfil their function (e.g., safety valve, alarm) or as passive if they do not require a source of energy or a request to fulfil their function (e.g., procedure, retention dike, firewall.[36]

4.4.1 Benefits of the Bowtie Concept

Bow tie concept has many advantages and the main of them is that provides a visual representation of risk, including both applicable elements and the relationships between them. This is the relationship that enables a lot of the pros of this concept when risk analysis is conducted. Also, it allows areas such as inadequately controlled threats or consequences, to be readily identified and subsequently targeted for further treatment.[37]

The linear nature of the Bowtie concept shows the linking of hazards. For instance, one hazard’s outcomes may be a subsequent hazard’s causes depending upon the area of concern[37]

The ability of the Bowtie concept to include elements from domains treated separately, on a single representation is an additional benefit. Threats that can each contribute to a common top event can all be represented on a single Bowtie. Additionally, controls from each of these aspects can be included regardless of the nature of the threat.

Beneath this top level representation of risk, safety engineering techniques can be linked to provide quantification. This is essential as Bowtie does not provide all necessary information for safety analysis.[14]

4.4.2 Practical Uses

5. Logical Structured Approach

The structure of the bow tie shows how effectively all causes are being controlles and how prpepered the management is to recover if things go wrong. This logical approach often identifies gaps and issues that are missed by other techniques.

- Complete Risk Management

The bow tie method highlights the direct link between the controls and elements of the management system . As such, it covers far further than HAZOP study, quantitative risk assessment (QRA), etc.

- Demonstration

Bow ties are commonly used where there is a requirement to demonstrate that hazards are being controlled, and particularly where there is a need to show the link between the controls and elements of the management system.

- Communication

The bow tie can be displayed on posters highlighting key risk control issues. Pocket books and leaflets have also been produced for dissemination of the risk management message.

- Critical Systems

Critical systems can be defined as those which cause, prevent, detect, control or mitigate a top event. The nature of a bow tie diagram allows these critical systems are clearly illustrated along the threat and consequence branches.

- Organizational Improvements

It is possible to use bow ties in conjunction with organizational and cultural survey techniques to highlight where organizational control is weak.

- Specific Risks

Bow ties are of value for their thorough analysis of specific risks to provide reassurance that everything that can reasonably be done to reduce and manage risk is actioned.

- Procedures and Competence

A completed bow tie analysis includes a list of critical tasks undertaken to ensure integrity of the risk controls. A thorough bow tie analysis can also detail, for each task, the input procedures required to undertake the task correctly and any records which verify completion of the task, as well as competence requirements for the role responsible for undertaking the task.

- Layer of Protection Analysis

Bow-tie diagrams have also been used for conducting Layer of Protection Analysis, a risk assessment tool for determining if protection is in acceptable rates and quantifying the risk where it is insufficient. Bow-ties enable conservative estimates of risk to be compared against risk tolerability criteria. The approach tends to work well during design phases. It is also possible to make direct links between the engineered safeguards on the bow ties and specific work orders in a preventive maintenance scheduling and tracking system. In this way, critical hardware systems essential for ongoing risk management are prioritized.[38]

5. Statistical analysis of the accident reports

5.1 Summary

For the purpose of this chapter, a large amount of publicly available accidents were examined if they have the right attributes to be considered as inspection or maintenance mistakes.

From these accidents, a sample of 50 reports were chosen to represent the most clearly defined as this category. Failure of equipment accidents were the highest category followed by fire and structural failure.

This chapter reveals an analysis of the patterns within accident reports and draws conclusions and makes recommendations as appropriate.

5.2 Introduction

This research was conducted using databases such as MAIB,MNZ,MSIU ,NTSB,BSU,TSBC, SHK, DMAIB, HBMCI.

- MAIB (Marine Accident Investigation Branch)

The MAIB investigates marine accidents involving UK vessels worldwide and all vessels in UK territorial waters.[39]

- MNZ (Maritime New Zealand)

Their role is to ensure that all maritime activities are carried out safely, with minimal impact on the environment and on New Zealand's security.[40]

- MSIU (Marine Safety Investigation Unit)

The Marine Safety Investigation Unit (MSIU) is an independent Malta's Government investigation Unit. The MSIU is tasked to contribute to maritime safety by carrying out safety investigations into accidents and incidents, and participate in safety studies and academic research.[41]

- NTSB (National Transportation Safety Board)

The National Transportation Safety Board is an independent American Federal agency charged by Congress with investigating every civil aviation accident the United States and significant accidents in other modes of transportation – railroad, highway, marine and pipeline. The NTSB determines the probable cause of the accidents and issues safety recommendations aimed at preventing future accidents.[42]

- BSU (Federal Bureau of Maritime Casualty Investigation)

The Federal Bureau of Maritime Casualty Investigation (BSU) registers and investigates all types of marine accidents to or on board German flagged ships world-wide. Within the German territorial waters BSU acts regardless of the flag(s) of the ship(s) involved. [43]

- TSBC (Transportation Safety Board of Canada)

The Transportation Safety Board of Canada (TSB) is an independent agency that

advances transportation safety by investigating occurrences in the marine, pipeline, rail and air modes of transportation. [44]

- SHK (Swedish Accident Investigation Authority)

The Swedish Accident Investigation Authority (Statens haverikommission - SHK) is a government authority which investigates accidents and incidents with the aim of improving safety.[45]

- DMAIB (The Danish Maritime Accident Investigation Board)

The Danish Maritime Accident Investigation Board is an independent unit under the Ministry of Business and Growth of Denmark.[46]

- HBMCI (Hellenic Bureau for Marine Casualties Investigation)

HBMCI comprises the new independent and impartial Organization of the Hellenic Republic, competent for conducting safety investigations for marine casualties and incidents that take place in vessels flying the Hellenic flag, other vessels within the Hellenic territorial waters or within the Hellenic Search and Rescue region provided that SAR services were delivered by Greek Authorities, as well as any casualty or incident involves substantial interests of Hellas.[47]

5.3 Data analysis

The following are the results that were extracted from the statistical analysis of the 50 inspection mistakes accidents.

5.3.1 Type of ships

The types of ships that were put under consideration are

- General Cargo ships
- Passenger ships
- Container ships
- Bulk Carrier ships
- Tanker ships
- RoRo Cargo ships
- Cruise ships

Table 5.1 – Type of ships

Type of ship	Number of Accidents
General Cargo	12
Passenger	12
Container	8
Bulk Carrier	6
Tanker	6
RoRo Cargo	3
Cruise	3
SUM	50

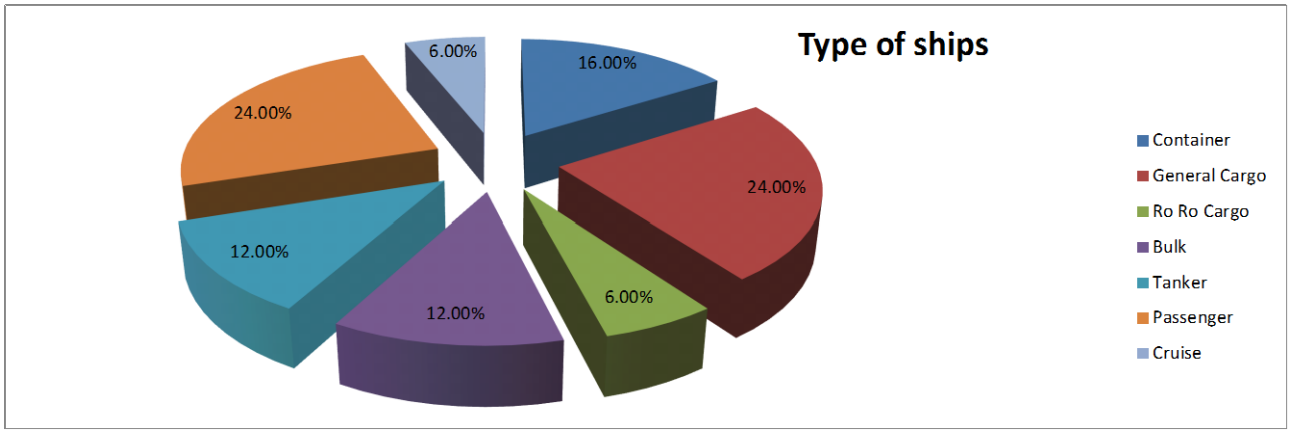

Figure 5.1 – Type of ships

Figure 5.1 reveals that the most common types of ships is General Cargo and Passenger ships followed by Containers, Bulk carriers and Tankers in descending order.

5.3.2 Type of accidents

The types of accidents that were put under consideration are

- Fire
- Explosion
- Failure of Equipment
- Structural Failure
- Machinery Breakdown/Engine Failure
- Personal Accident

Table 5.2 – Type of accidents

Type of accident	Number of Accidents
Fire	8
Explosion	4
Failure of Equipment	25
Structural Failure	6
Machinery Breakdown/Engine Failure	3
Personal Accident	4

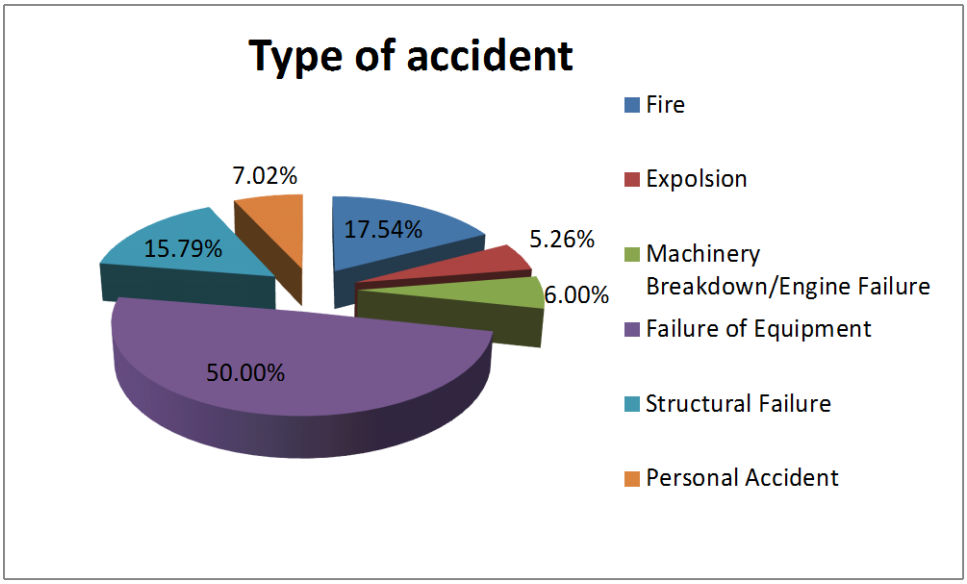

Figure 5.2 – Type of accidents

Figure 5.2 reveals that the largest category of incidents 'Failure of Equipment' (50%), followed by 'Fire' (17.54%), 'Structural Failure' (15.79%) and 'Personal Accident' (7.2%) in descending order. Underlying issues to the accidents reveal the role of design or lack of it, in shipboard equipment, layout and space design as well as poor design of shipboard operations.

5.3.3 Injuries and/or fatalities

As shown in the next graph, the frequencies of Injuries/fatalities in the accidents are somewhat equal to non-injury type of incidents.

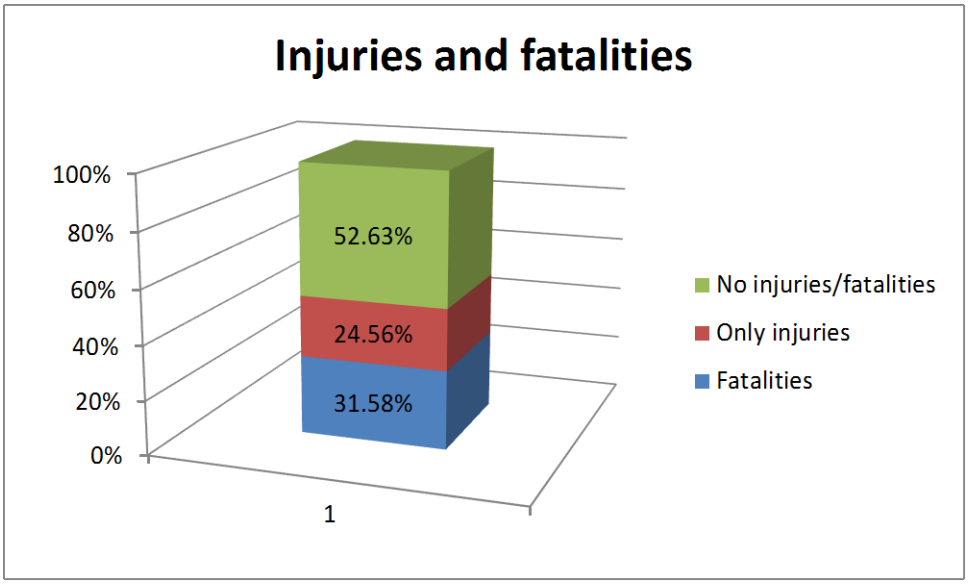

Figure 5.3 – Injuries and fatalities

5.3.4 IMO severity index

IMO is the United Nations' specialized agency responsible for the improving of maritime safety and is directly connected with the promotion of quality and safety in the industry. One of the high-priority objectives of the IMO is "the promotion of the implementation of the international standards and regulations for the improvement of maritime safety and for the prevention and control of marine pollution from ships".[20]

The following table, as given by MSC Circ. 1023, shows an example of a logarithmic severity index, scaled for a maritime safety issue.

Table – Severity Index[20]

Severity Index				
SI	SEVERITY	EFFECTS ON HUMAN SAFETY	EFFECTS ON SHIP	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

According to this table, the different types of accidents were been examined for their severity levels, as listed above in the following graphs.
Personal Accidents were excluded due to their uncommon nature.

- Fire severity

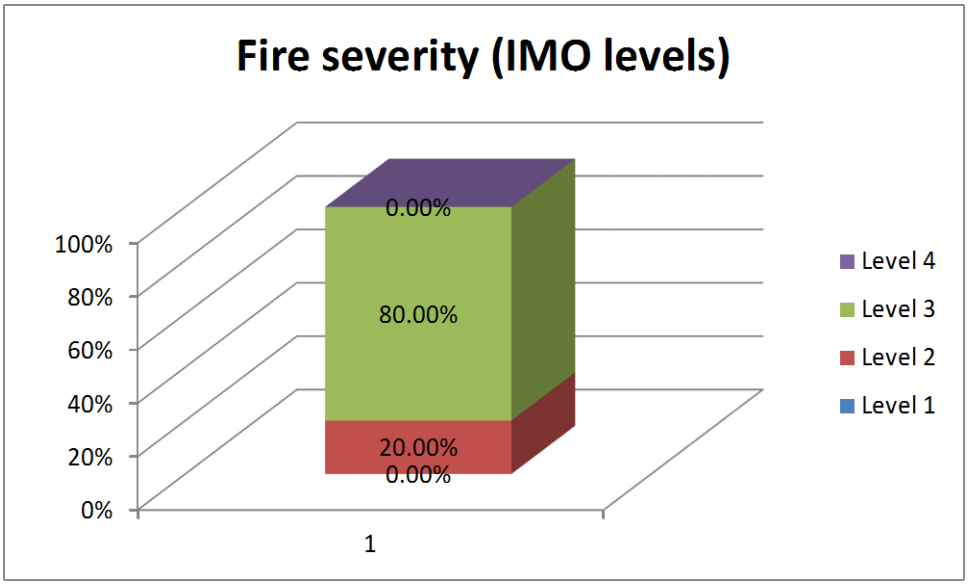

Figure5.4 – Fire severity

The severity levels of fire are high (Level 3) due to catastrophic nature of fire and the difficulty of firefighting process.

- Explosion severity

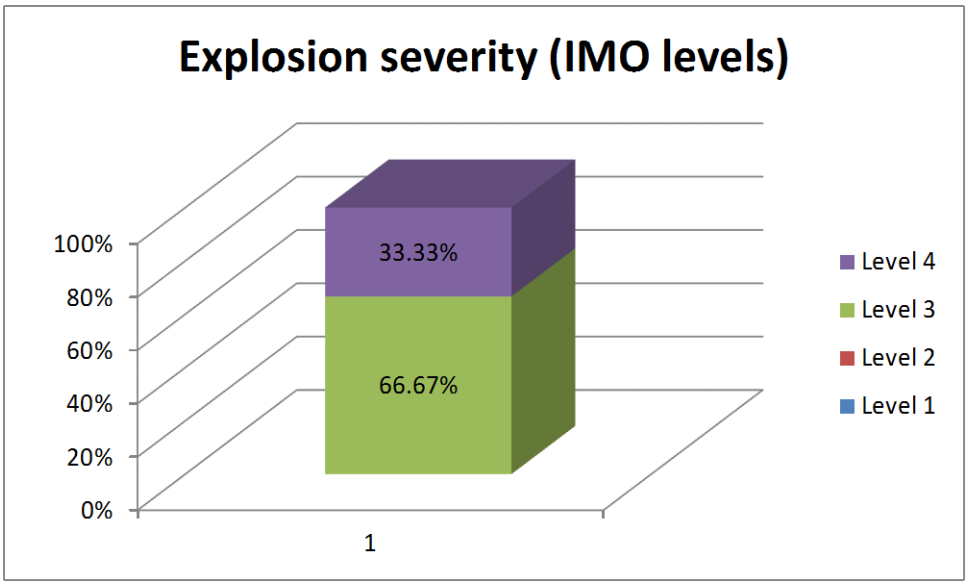

Figure 5.5 – Explosion severity

As seen above, the catastrophic consequences of explosion increase the severity of this type of accident. Severity levels are higher than fire accidents.

- Machinery Breakdown/Engine Failure severity

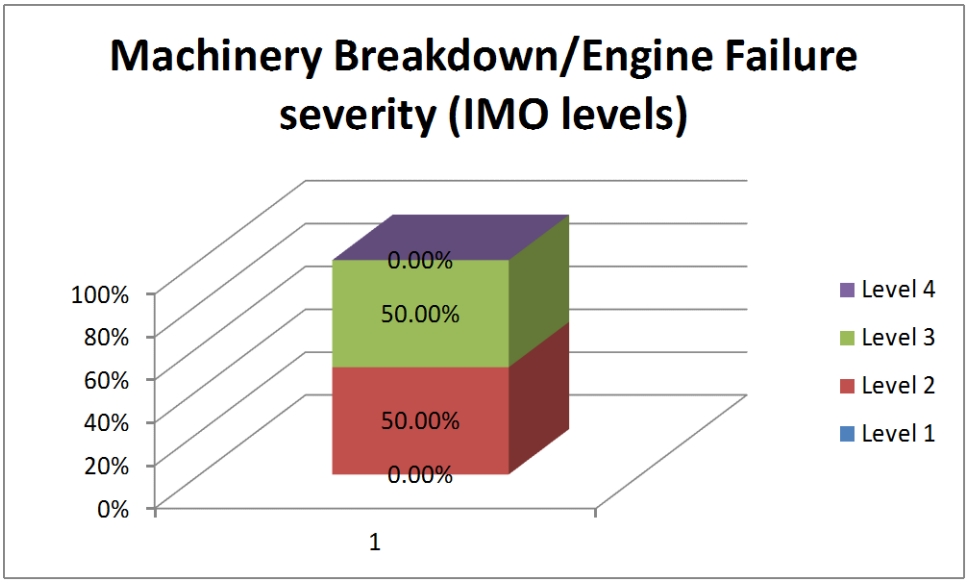

Figure 5.6 – Machinery Breakdown/Engine Failure severity

Machinery Breakdown/Engine Failure accidents have average levels of severity. Because of limited number of these accidents, no actual conclusion can be accurate.

- Failure of Equipment severity

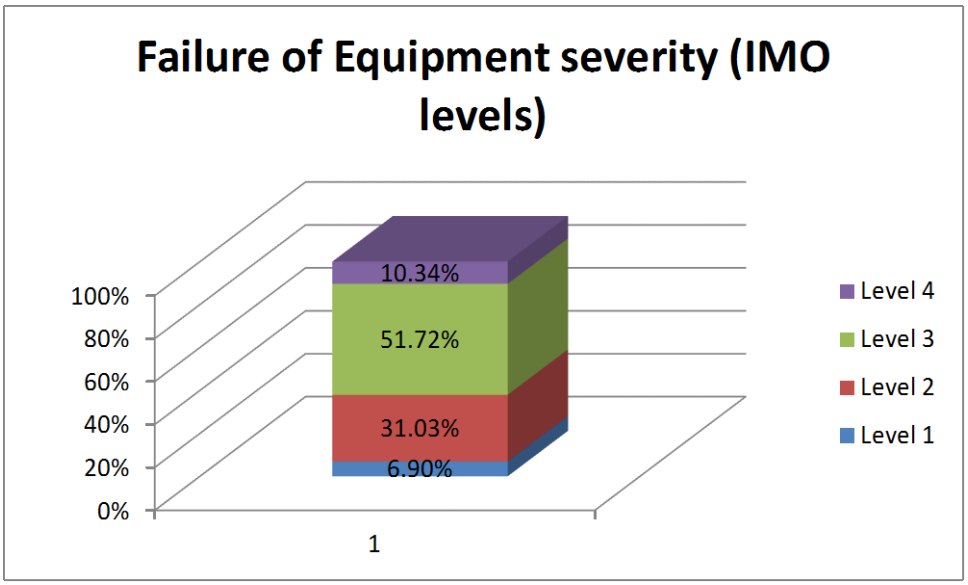

Figure 5.7 – Failure of Equipment severity

There is considerable diversity in severity levels of Failure of Equipment accidents due to the large amount of incidents of this type that derived from the research.

- Structural Failure severity

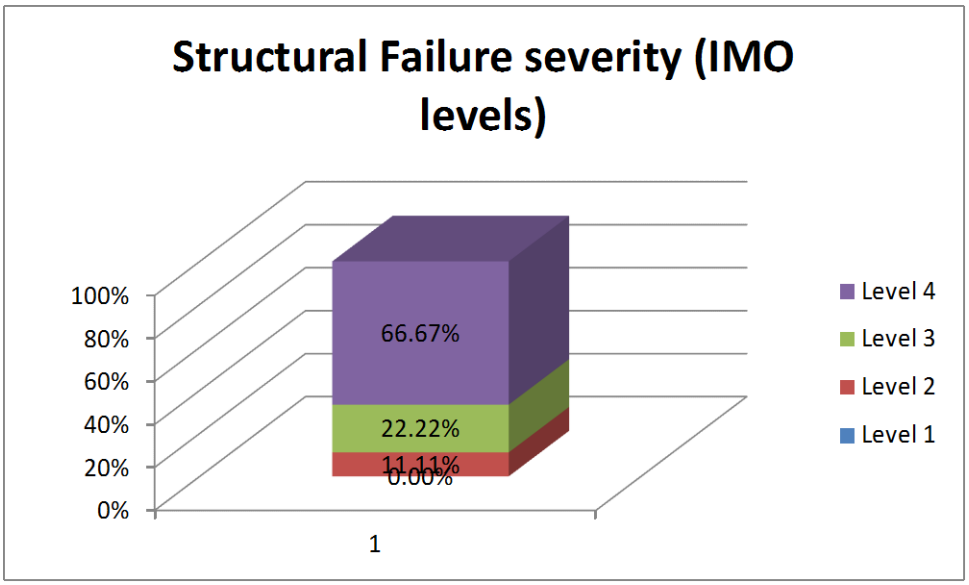

Figure 5.8 – Structural Failure severity

Structural failure accidents usually lead to multiple fatalities and total loss of vessel and they have the highest levels of severity(Level 4).

5.3.5 Time of accidents

This section compares daytime and nighttime involvement rates. In general, nighttime is associated with a higher risk of accident involvement due to factors such as reduced visibility, fatigue etc. Daytime was defined as 6 AM to 9 PM an nighttime as 9 PM to 6 AM.

For each type of accidents, a different figure has been made that shows what time the specific type occurred.

Fire accidents

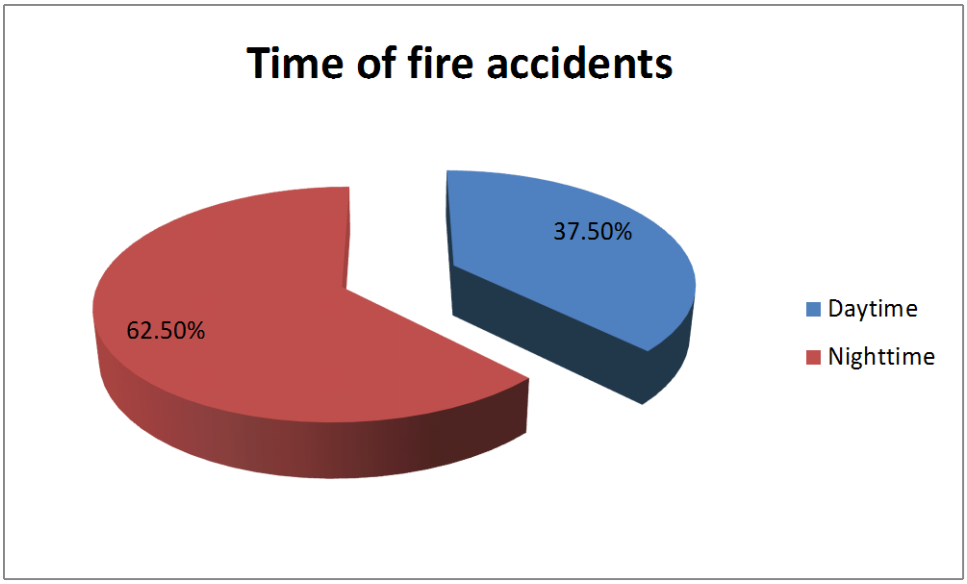

Figure 5.9 – Time of fire accidents

Table 5.9 – Time of fire accidents

	Number of accidents
Daytime	3
Nighttime	5

Explosion accidents

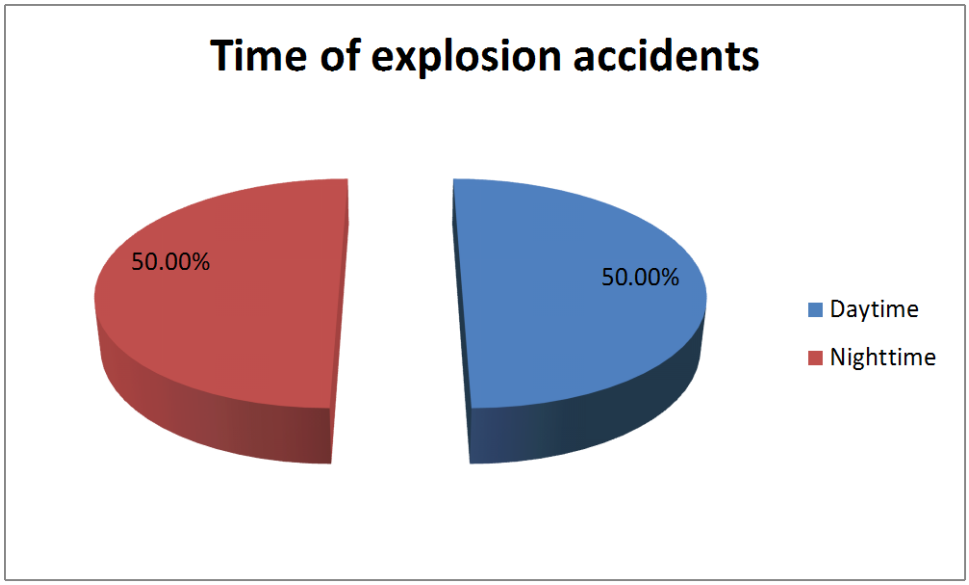

Figure 5.10 – Time of explosion accidens

Machinery Breakdown/Engine Failure accidents

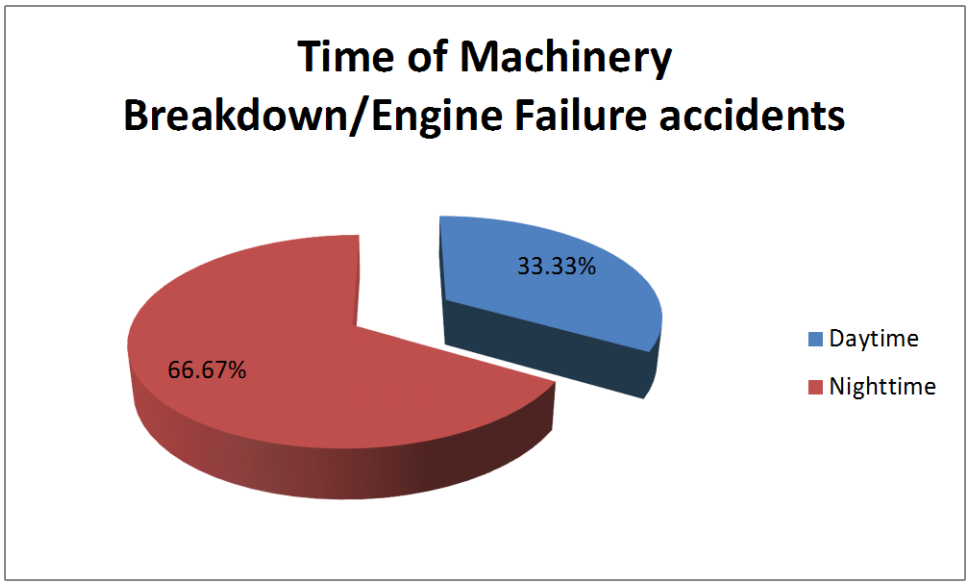

Figure 5.11 – Time of Machinery Breakdown/Engine Failure accidents

Failure of Equipment accidents

Table 5.12 – Time of Failure of Equipment accidents

	Number of accidents
Daytime	15
Nighttime	10

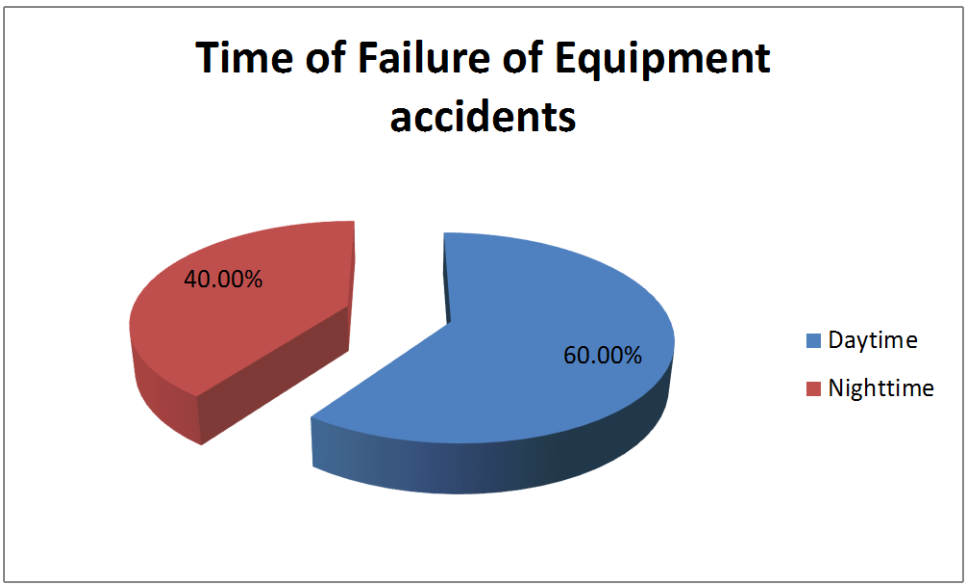

Figure 5.12 – Time of Failure of Equipment accidents

Structural Failure accidents

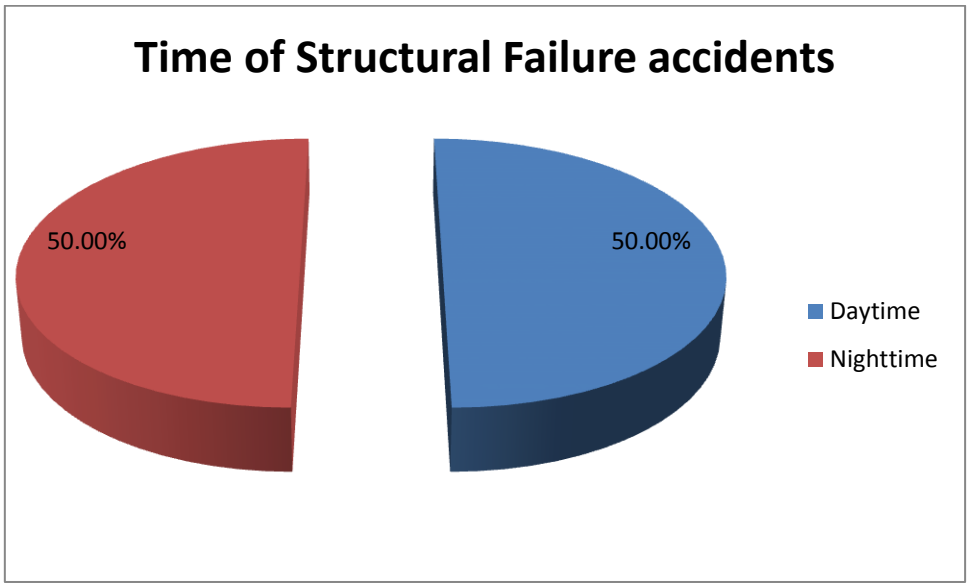

Figure 5.13 – Time of Structural Failure accidents

Nighttime periods appeared to have a high importance when it comes to study the different cases of accidents because in every type except of 'failure of equipment' a respectable amount of incidents happened during the night.

It is a necessity for the risk analysis to take into account of the exact time frame that every type of accident occurred.

5.4 Conclusions

The most important categories of accidents were Failure of Equipment, Structural failure and Fire.

The vessels involved in the incidents were mainly general cargo (24%), passenger vessels (24%) and container vessels (16%). Other vessels involved were bulk carriers (12%), tankers (12%), Ro-ro cargo (6%) and cruise ships (6%).

Non-injury accidents are approximately equal to accidents with minor or major injuries or death, something that is not unsurprising due to the variety of the incidents.

Based on the accident data in the databases, the highest levels of severity,according to IMO's index, are in structural failure accidents followed by explosion, fire, machinery breakdown and failure of equipment in descending order.

Time of day is crucial for the analysis as it seems from the figures above. Machinery breakdown/ engine failure accidents are common in nighttime followed by fire, explosion, structural failure and finally failure of equipment.

6. Bow tie diagrams

6.1 Introduction

In this section, all the Bow tie diagrams which were created during risk analysis of the fifty inspection mistake accidents will be presented thoroughly.

The types of ships wich were put under consideration for this analysis are

6. General cargo ships
7. Container ships
8. Passenger ships
9. Cruise ships

The types of accidents which were examined are

- Failure of equipment accidents
- Structural failure accidents
- Fire accidents
- Explosion accidents

The Bow ties are as general as possible to cover all the different aspects of the accidents and to present with the most accurate way all the possible scenarios within the accidents.
In every bow tie diagram, the role of inspections and maintenance, as initiator events, is clearly defined in the part of fault tree diagrams. Every diagram has been made considering the importance of inspections' mistakes and their consequences.

The various incidents in fault trees are defined with a specific initial letter (X,I,E,Y,Z). Each letter represents a different level of occurrence in the diagram. The last two of these levels before the top event are of high importance and for that reason are underlined with a different color. These levels are:

Z level: Failure mode level
Y level: Level of causes

The importance of Z and Y levels can be clearly understood by the fact that these levels are the most visible conditions in an accident event. The first causes that can be traced before the top event are usually in the top levels of the fault tree diagram.

Inspection and maintenance mistakes on the other hand can be traced back to the first level at the bottom of fault trees. This is due to the nature of these mistakes that can lead to a higher level incident and even to the top event. In addition, this nature of inspection and maintenance mistakes reveals the necessity to be very cautious when a research on these types of accidents is conducted.

Under every diagram, there is a specific table that describes the various contributors of the bow tie in every type of accident.

6.2 Bow tie diagrams of failure of equipment accidents

In failure of equipment accidents, the X level of fault tree part of bow tie diagram was created putting under consideration the initiation factors of the accidents. There is a specific appearance of poor inspections and maintenance that can lead to the top event of this category. Also X level shows other factors such as the human factor, deficiencies in manuals and construction and installation mistakes.

The next levels (I and E levels) show the following events after X level, of the fault tree diagram. They focus mainly in actions and process that were violated and they are transitional stages that lead to failure mode level. In container vessels, there are no I level due to information extracted from the accident reports.

Failure mode level(Y level) presents mostly the type of failure of the equipment that can lead to the main event and a higher level of human errors in case of insufficient personnel, deficiencies of any kind of manual and/or violation of regulations.

Finally, the level of causes is divided in two parts. The first shows the final state of equipment (broken off or loose equipment) before failure and the second the highest human mistake (operational error) before top event. This level leads to the top event of the bow tie diagram.

The construction of fault tree diagrams are similar to any type of vessel that was examined and follow the same rules as explained above.

One of the most important aspects of the construction of the event tree part of bow tie diagrams is the definition of the barriers/gates after the occurrence of the top event.

In failure of equipment accidents, the gates that were used in event tree diagrams are the following:

Location: It determines the location on the vessel (Accommodation, cargo, machinery) where the failure happened.

Operational state: It determines the operational state of vessel (En route, in terminal etc.)

Time of day: It shows when the accident occurred (Nighttime, daytime).

Consequent accident: This barrier determines if there is a following accident after the top event. Possible accidents could be for example fire/explosion incidents, Structural failure etc.

Damage to structure: This barrier controls the integrity of vessel's structure in case of a consequent accident.

Loss of water tightness: Finally, the last barrier determines if there is a possibility of water inflow in case of damaged structure.

The consequences in the end of event trees are explained in the sections below according to each type of ship.
The construction of bow tie diagrams of failure of equipment accidents follows the risk analysis models of the Formal Safety Assessments as submitted by IMO for every type of vessel. [12, 48-51]

6.3 Bow tie diagrams of structural failure accidents

In structural failure accidents, the X level of fault tree part of bow tie diagram was created putting under consideration the initiation factors of the accidents. As well as the other type of accidents in this research, there is a specific appearance of poor inspections and maintenance that can lead to the top event of this category. Also X level shows other factors such as the human factor, deficiencies in manuals and construction and installation mistakes.

The next level (E level) show the following events after X level, of the fault tree diagram. They focus mainly in actions and process that were violated and they are transitional stages that lead to failure mode level.

Failure mode level(Y level) presents mostly the type of failure of the equipment that can lead to the main event and a higher level of human errors(i.e. Navigational failure and inappropriate actions) in case of insufficient personnel, deficiencies of any kind of manual and/or violation of regulations.

Finally, the level of causes is divided in two parts. The first shows the final state of structure (poor condition of structure) before failure and the second the highest human mistake (operational error) before top event. This level leads to the top event of the bow tie diagram.

The construction of fault tree diagrams are similar to any type of vessel that was examined and follow the same rules as explained above.

In structural failure accidents, the gates that were used in event tree diagrams are the following:

Location: It determines the location on the vessel (Accommodation, cargo, machinery) where the failure happened.

Operational state: It determines the operational state of vessel (En route, in terminal etc.)

Time of day: It shows when the accident occurred (Nighttime, daytime).

Consequent accident: This barrier determines if there is a following accident after the top event. Possible accidents could be for example fire/explosion incidents, Structural failure etc.

Loss of water tightness: Finally, the last barrier determines if there is a possibility of water inflow. This is a very important barrier because it increases dramatically the severity level of the accident.

The consequences in the end of event trees are explained in the sections below according to each type of ship.

The construction of bow tie diagrams of structural failure accidents follows the risk analysis models of the Formal Safety Assessments as submitted by IMO for every type of vessel. [12, 48-51]

6.4 Bow tie diagrams of fire/explosion accidents

The X level of fault tree part of bow tie diagram in fire/explosion accidents was created by the examination of the initiation factors of the accidents. As well as the other type of accidents in this research, poor inspections and maintenance have a major role in this level. Also X level shows other factors such as the human factor, deficiencies in manuals and construction and installation mistakes.

As mentioned in the previous chapters, the next level (E level) show the following events after X level, of the fault tree diagram. They focus mainly in actions and process that were violated and they are transitional stages that lead to failure mode level.

Failure mode level(Y level) presents the type of failure that can lead to the main event and also a higher level of human errors.

Finally, the level of causes shows the final state (leakage, high inappropriate temperatures etc.) before fire/explosion and the highest level of human mistake (operational error) before top event.

The construction of fault tree diagrams are similar to any type of vessel that was examined and follow the same rules as explained above.

In structural failure accidents, the gates that were used in event tree diagrams are the following:

Location: It determines the location on the vessel (Accommodation, cargo, machinery) where the failure happened.

Time of day: It shows when the accident occurred (Nighttime, daytime).

Automatic firefighting: It displays the effectiveness of an automatic firefighting system.

Manual firefighting: It displays the effectiveness of manual firefighting systems.
Fire spread to accommodation: This barrier determines if there is a fire in accommodation areas. This is a very important barrier because it increases dramatically the severity level of the accident.

Firefighting assistance from other vessel or land: It shows the effectiveness of assistance from other sources.

Fire extinguishing, vessel towing: It shows if there is an effective fire extinguishing and/or vessel towing.

Ship evacuation/ Rescue of crew: In extreme cases, this barrier determines if total loss of cargo and crew can be avoided or not.

The construction of bow tie diagrams of fire/explosion accidents follows the risk analysis models of the Formal Safety Assessments as submitted by IMO for every type of vessel. Especially, Formal Safety Assessment for container vessels had a major impact in creation of barriers for the event tree parts of bow tie diagrams [12, 48-51]

6.5 Bow tie diagrams in General Cargo ships

6.5.1 Failure of Equipment accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.1.1 *– Pattern of consequences in Failure of Equipment accidents of General Cargo ships*

Minor repairable damage to accident area
Extended damage to accident area
Serious damage to accident area
Very serious damage to accident area / Damage to vessel

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

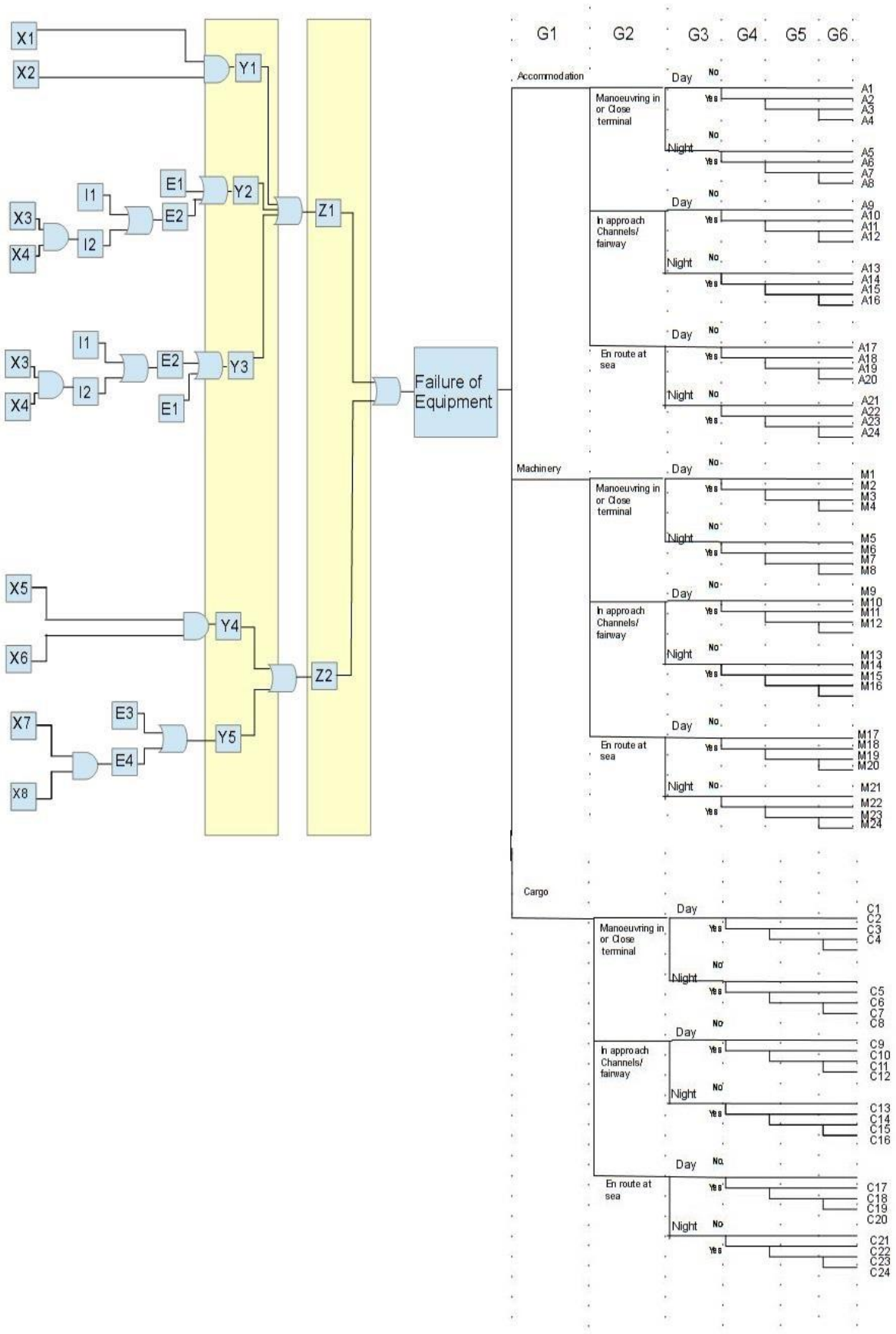

Figure 6.1 *– Bow tie diagram in Failure of Equipment accidents of General Cargo ships*

In failure of equipment accidents of cargo ships there is a variety of contributors that can lead to the top event. This is due to the nature of these accidents that are different from case to case.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.1.2 – *X level in Failure of Equipment accidents of General Cargo ships*

X1	Poor installation
X2	Poor supervision from the crew
X3	Poor maintenance
X4	Poor inspection
X5	Inexperienced personnel
X6	Untrained personnel
X7	Crew did not pay attention
X8	Deficiencies of manuals

I and E levels are presented in the next table.

Table 6.1.3 – *I and E levels in Failure of Equipment accidents of General Cargo ships*

I1	Insufficient attention to repairs
I2	Inattentions
E1	Weather conditions
E2	Poor condition of equipment
E3	Violation of regulations
E4	Process not followed

Z level (Failure mode level) and Y level (Level of causes) are presented below

Table 6.1.4 – *Z and Y levels in Failure of Equipment accidents of General Cargo ships*

Y1	Deficient equipment
Y2	Corrosion
Y3	Cracking
Y4	Insufficient quality of personnel
Y5	Inappropriate actions
Z1	Broken off or loose equipment
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.1.5 – *Gates/Barriers of the event tree diagram in Failure of Equipment accidents of General Cargo ships*

G1	Location
G2	Operational state
G3	Time of day
G4	Consequent accident
G5	Damage to structure
G6	Loss of water tightness

- Consequences

Table 6.1.6 – *Consequences in Failure of Equipment accidents of General Cargo ships*

A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A8	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Minor repairable damage to accommodation/ Possible injuries
A10	Extended damage to accommodation/ Injuries and possible fatalities
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Injuries
A14	Extended damage to accommodation/ Injuries and possible fatalities
A15	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A16	Very serious damage to accommodation/ Damage to

	vessel/ Injuries and fatalities
A17	Minor repairable damage to accommodation/ Possible injuries
A18	Extended damage to accommodation/ Injuries and possible fatalities
A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
M6	Extended damage to machinery/ Possible injuries
M7	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M8	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Minor repairable damage to machinery
M10	Extended damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery/ Possible injuries
M14	Extended damage to machinery/ Possible injuries
M15	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M16	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M17	Minor repairable damage to machinery
M18	Extended damage to machinery/ Possible injuries
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all crew

M21	Minor repairable damage to machinery/ Possible injuries
M22	Extended damage to machinery/ Possible injuries
M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to cargo
C2	Extended damage to cargo/ Possible injuries
C3	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C4	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C5	Minor repairable damage to cargo/ Possible injuries
C6	Extended damage to cargo/ Possible injuries
C7	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C8	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C9	Minor repairable damage to cargo
C10	Extended damage to cargo/ Possible injuries
C11	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to cargo/ Possible injuries
C14	Extended damage to cargo/ Possible injuries
C15	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C16	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C17	Minor repairable damage to cargo
C18	Extended damage to cargo/ Possible injuries
C19	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C20	Worst case: Loss of vessel/Loss of all crew
C21	Minor repairable damage to cargo/ Possible injuries
C22	Extended damage to cargo/ Possible injuries
C23	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C24	Worst case: Loss of vessel/Loss of all crew

6.5.2 Structural Failure accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.2.1 *– Pattern of consequences in Structural Failure accidents of General Cargo ships*

Minor repairable damage to damaged area
Serious damage to damaged area/ Damage to vessel
Very serious damage to damaged area/ Damage to vessel

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

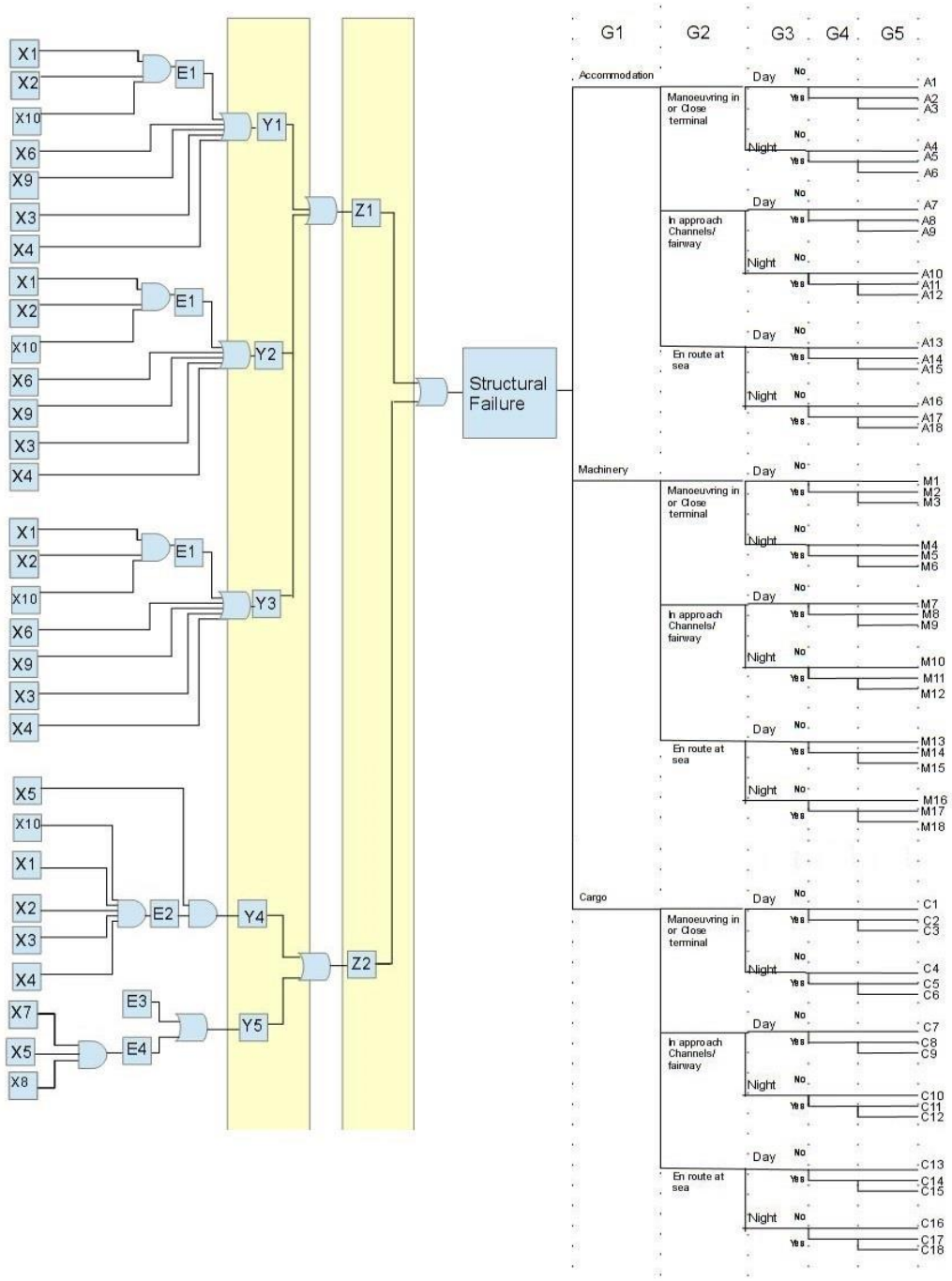

Figure 6.2 – *Bow tie diagram in Structural Failure accidents of General Cargo ships*

In structural failure accidents of cargo ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is more serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.2.2 – *X level in Structural Failure accidents of General Cargo ships*

X1	Poor design calculations
X2	Poor endurance tests
X3	Poor maintenance
X4	Poor inspection
X5	Inadequate personnel
X6	Insufficient attention to repairs
X7	Crew did not pay attention
X8	Deficiencies of manuals
X9	Adverse weather conditions
X10	Poor construction/ purchase of equipment

I and E levels are presented in the next table.

Table 6.2.3 – *E level in Structural Failure accidents of General Cargo ships*

E1	Inferior quality of structure
E2	Poor condition of equipment
E3	Violation of regulations
E4	Misuse of equipment

Z level (Failure mode level) and Y level (Level of causes) are presented below.

Table 6.2.4 – *Z and Y levels in Structural Failure accidents of General Cargo ships*

Y1	Corrosion
Y2	Cracking
Y3	Deformation
Y4	Navigational failure
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.2.5 – *Gates/Barriers of the event tree diagram in Structural Failure accidents of General Cargo ships*

G1	Location
G2	Operational state
G3	Time of day
G4	Consequent accident
G5	Loss of water tightness

- Consequences

Table 6.2.6 – *Consequences in Structural Failure accidents of General Cargo ships*

A1	Minor repairable damage to accommodation/ Possible injuries
A2	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A3	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Minor repairable damage to accommodation/ Injuries
A5	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A6	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A7	Minor repairable damage to accommodation/ Possible injuries
A8	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A10	Minor repairable damage to accommodation/ Injuries
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Possible injuries
A14	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A15	Worst case: Loss of vessel/Loss of all crew
A16	Minor repairable damage to accommodation/ Injuries

A17	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A18	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M3	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Minor repairable damage to machinery/ Possible injuries
M5	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M6	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M7	Minor repairable damage to machinery
M8	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M10	Minor repairable damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery
M14	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M15	Worst case: Loss of vessel/Loss of all crew
M16	Minor repairable damage to machinery/ Possible injuries
M17	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M18	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to cargo
C2	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C3	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C4	Minor repairable damage to cargo/ Possible injuries
C5	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C6	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C7	Minor repairable damage to cargo
C8	Serious damage to cargo/ Damage to vessel/ Injuries

	and fatalities
C9	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C10	Minor repairable damage to cargo/ Possible injuries
C11	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to cargo
C14	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C15	Worst case: Loss of vessel/Loss of all crew
C16	Minor repairable damage to cargo/ Possible injuries
C17	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C18	Worst case: Loss of vessel/Loss of all crew

6.5.3 Fire accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

***Table** 6.3.1 – Pattern of consequences in Fire accidents of General Cargo ships*

Minor damage to damaged area
Extended damage to damaged area/ Possible damage to vessel
Serious damage to damaged area/ Damage to vessel/ Crew injuries
Very serious cargo damage/Very serious vessel damage/ Crew injuries and fatalities
Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

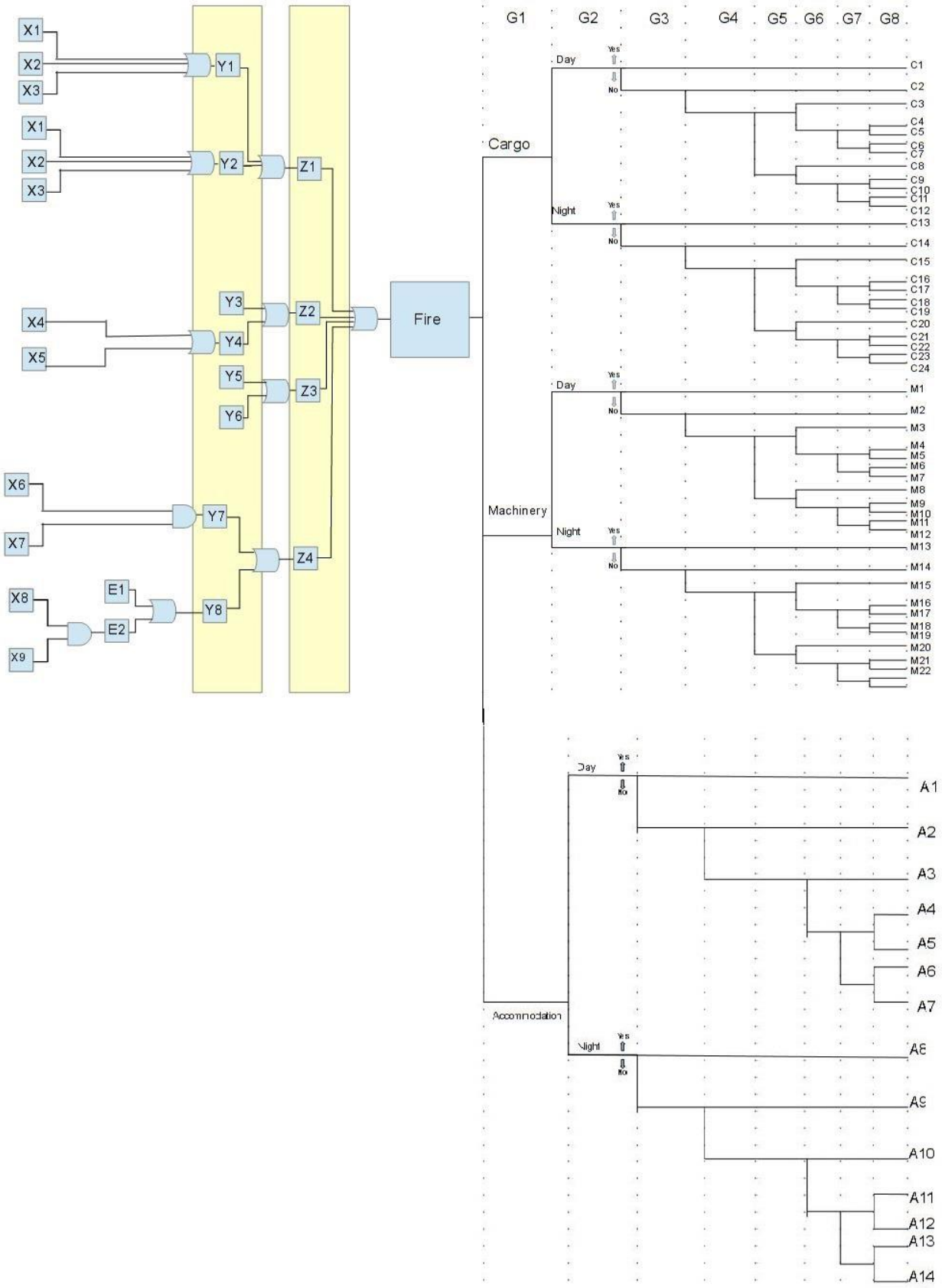

Figure 6.3 – *Bow tie diagram in Fire accidents of General Cargo ships*

In fire accidents of general cargo ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is rather serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.3.1 – *X level in Fire accidents of General Cargo ships*

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Poor design
X5	Poor supervision from the crew
X6	Inexperienced personnel
X7	Untrained personnel
X8	Crew did not pay attention
X9	Deficiencies of manuals

E levels are presented in the next table.

Table 6.3.2– *E level in Fire accidents of General Cargo ships*

E1	Violation of regulations
E2	Process not followed

Z level (Failure mode level) and Y level (Level of causes) are presented below.

Table 6.3.3 – *Z and Y levels in Fire accidents of General Cargo ships*

Y1	Corrosion
Y2	Cracking
Y3	Overheating machine
Y4	Hot surfaces
Y5	Incorrect tightening
Y6	Use of unauthorised spare part
Y7	Insufficient quality of personnel
Y8	Inappropriate actions
Z1	Leakage
Z2	Inappropriate temperature
Z3	Crankcase explosion
Z4	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.3.4 – *Gates/Barriers of the event tree diagram in Fire accidents of General Cargo ships*

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting
G5	Fire spread to accommodation
G6	Firefighting assistance from other vessel or land
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew

- Consequences

Table 6.3.5 – *Consequences in Fire accidents of General Cargo ships*

C1	Minor damage to cargo
C2	Extended damage to cargo/ Possible damage to vessel
C3	Serious damage to cargo/ Damage to vessel/ Crew injuries
C4	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C5	Very serious cargo damage/Loss of vessel/ Crew injuries and fatalities
C6	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C8	Serious damage to cargo/ Damage to vessel
C9	Very serious cargo damage/serious damage to vessel
C10	Very serious cargo damage/Loss vessel/ Crew injuries fatalities
C11	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C13	Minor damage to cargo
C14	Extended damage to cargo/ Possible damage to vessel
C15	Serious damage to cargo/ Damage to vessel/ Crew injuries and possible fatalities
C16	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities

C17	Very serious cargo damage/Loss vessel/ Crew injuries fatalities
C18	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C20	Serious damage to cargo/ Damage to vessel
C21	Very serious cargo damage/serious damage to vessel
C22	Very serious cargo damage/Loss vessel/ Crew injuries fatalities
C23	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M5	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
M9	Very serious damage to machinery/serious damage to vessel
M10	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M11	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M13	Minor damage to machinery
M14	Extended damage to machinery/ Possible damage to vessel
M15	Serious damage to machinery/ Damage to vessel/ Crew injuries and possible fatalities
M16	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M17	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M18	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage

M19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M20	Serious damage to machinery/ Damage to vessel
M21	Very serious damage to machinery/serious damage to vessel
M22	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M23	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A1	Minor repairable damage to accommodation
A2	Extended damage to accommodation/ Possible damage to vessel
A3	Serious damage to accommodation/ Damage to vessel/ Possible crew injuries
A4	Very serious damage to accommodation/serious damage to vessel/ Injuries and possible fatalities/
A5	Crew casualties/ Very serious damage to accommodation / Loss of vessel
A6	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A8	Minor repairable damage to accommodation
A9	Extended damage to accommodation/ Possible damage to vessel/ Injuries
A10	Serious damage to accommodation/ Damage to vessel/ Crew injuries and possible fatalities
A11	Very serious damage to accommodation/serious damage to vessel/ Injuries and fatalities
A12	Crew casualties/ Very serious damage to accommodation / Loss of vessel/
A13	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A14	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew

There was no data for explosions in general cargo ships to allow the production of a Bow tie diagram for fire accidents.

6.6 Bow tie diagrams in Container ships

6.6.1 Failure of Equipment accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.4.1 – *Pattern of consequences in Failure of Equipment accidents of Containe ships*

Minor repairable damage to accident area
Extended damage to accident area
Serious damage to accident area
Very serious damage to accident area / Damage to vessel

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

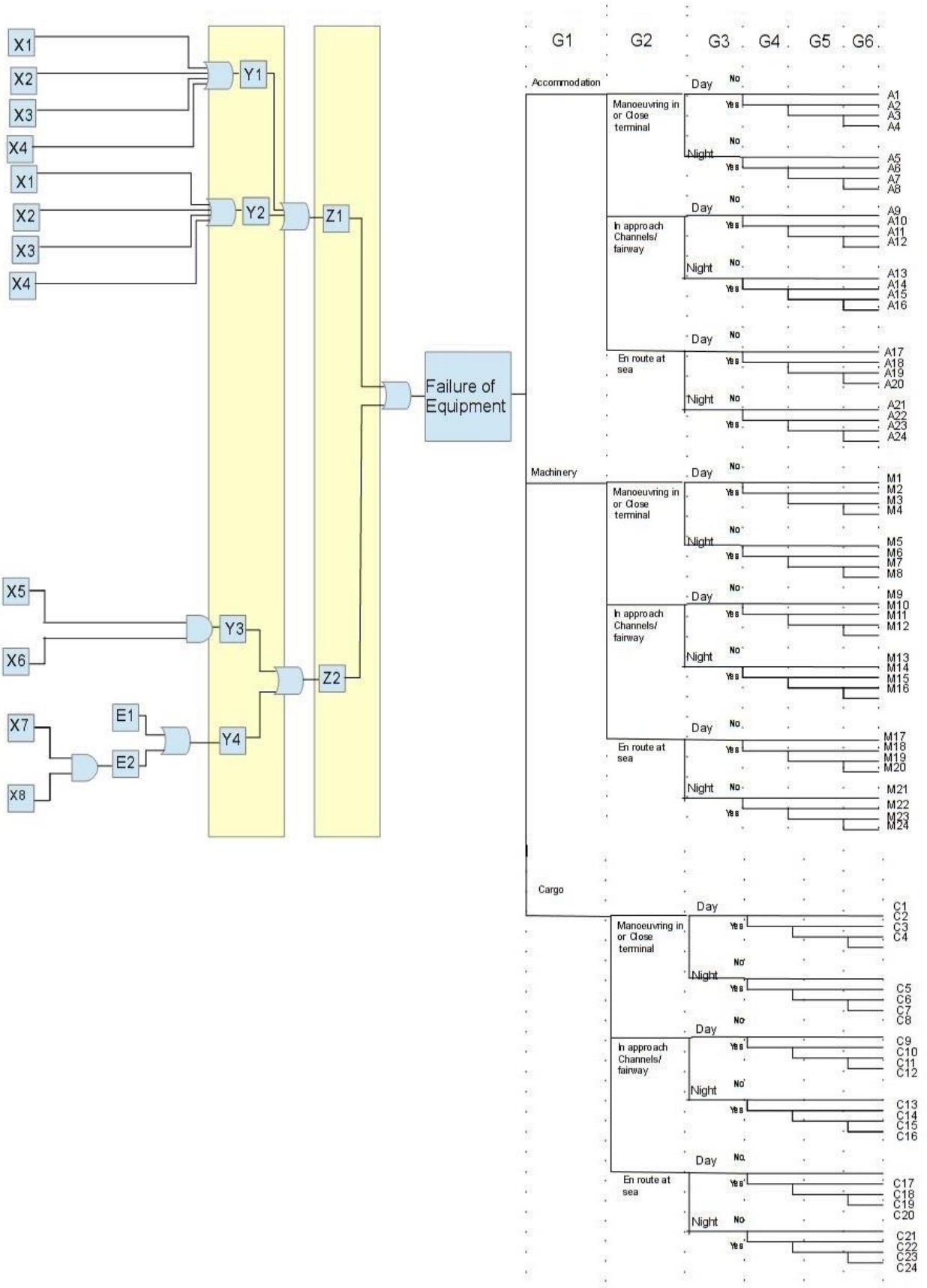

Figure 6.4 *– Bow tie diagram in Failure of Equipment accidents of Container ships*

In failure of equipment accidents of container ships there is a variety of contributors that can lead to the top event.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.4.2 – *X level in Failure of Equipment accidents of Container ships*

X1	Poor maintenance
X2	Poor inspection
X3	Poor repairs
X4	Poor design
X5	Inexperienced personnel
X6	Untrained personnel
X7	Crew did not pay attention
X8	Deficiencies of manuals

E level are presented in the next table.

Table 6.4.3 – *E levels in Failure of Equipment accidents of Container ships*

E1	Violation of regulations
E2	Process not followed

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table 6.4.4 – *Z land Y levels in Failure of Equipment accidents of Container ships*

Y1	Corrosion
Y2	Cracking
Y3	Insufficient quality of personnel
Y4	Inappropriate actions
Z1	Broken off or loose equipment
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.4.5 – *Gates/Barriers of the event tree diagram in Failure of Equipment accidents of Container ships*

G1	Location
G2	Operational state
G3	Time of day
G4	Consequent accident
G5	Damage to structure
G6	Loss of water tightness

- Consequences

Table 6.4.6 – *Consequences in Failure of Equipment accidents of Container ships*

A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A8	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Minor repairable damage to accommodation/ Possible injuries
A10	Extended damage to accommodation/ Injuries and possible fatalities
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Injuries
A14	Extended damage to accommodation/ Injuries and possible fatalities
A15	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A16	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities

A17	Minor repairable damage to accommodation/ Possible injuries
A18	Extended damage to accommodation/ Injuries and possible fatalities
A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
M6	Extended damage to machinery/ Possible injuries
M7	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M8	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Minor repairable damage to machinery
M10	Extended damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery/ Possible injuries
M14	Extended damage to machinery/ Possible injuries
M15	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M16	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M17	Minor repairable damage to machinery
M18	Extended damage to machinery/ Possible injuries
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all crew
M21	Minor repairable damage to machinery/ Possible

	injuries
M22	Extended damage to machinery/ Possible injuries
M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to containers
C2	Extended damage to containers/ Possible injuries
C3	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C4	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C5	Minor repairable damage to containers/ Possible injuries
C6	Extended damage to containers/ Possible injuries
C7	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C8	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C9	Minor repairable damage to containers
C10	Extended damage to containers/ Possible injuries
C11	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to containers/ Possible injuries
C14	Extended damage to containers/ Possible injuries
C15	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C16	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C17	Minor repairable damage to containers
C18	Extended damage to containers/ Possible injuries
C19	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C20	Worst case: Loss of vessel/Loss of all crew
C21	Minor repairable damage to containers/ Possible injuries
C22	Extended damage to containers/ Possible injuries
C23	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C24	Worst case: Loss of vessel/Loss of all crew

6.6.2 Structural Failure accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.5.1 *– Pattern of consequences in Structural Failure accidents of Container ships*

Minor repairable damage to damaged area
Serious damage to damaged area/ Damage to vessel
Very serious damage to damaged area/ Damage to vessel

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

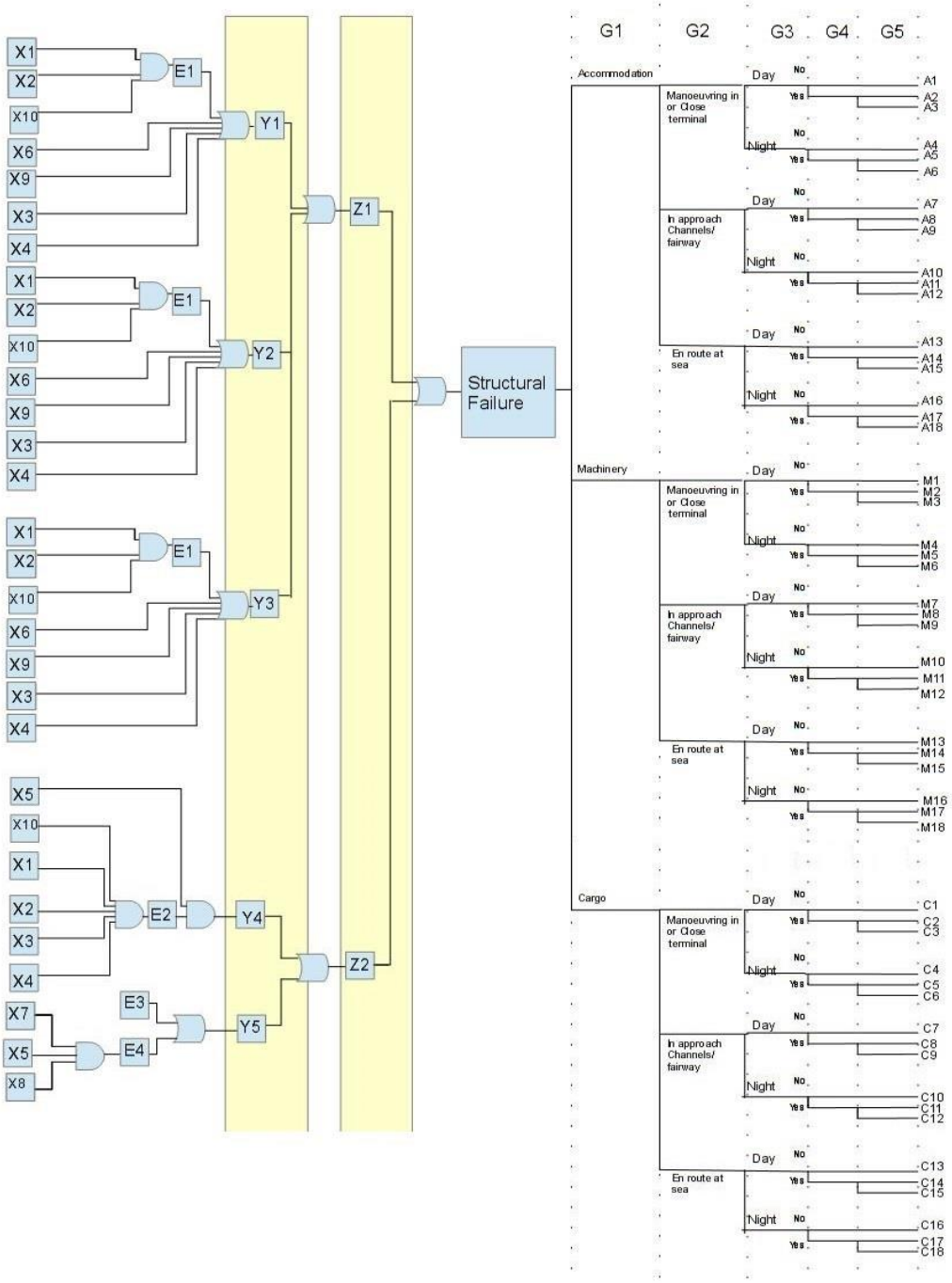

Figure 6.5 – Bow tie diagram in Structural Failure accidents of Container ships

In structural failure accidents of container ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is more serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.5.2 – *X level in Structural Failure accidents of General Cargo ships*

X1	Poor design calculations
X2	Poor endurance tests
X3	Poor maintenance
X4	Poor inspection
X5	Inadequate personnel
X6	Insufficient attention to repairs
X7	Crew did not pay attention
X8	Deficiencies of manuals
X9	Adverse weather conditions
X10	Poor construction/ purchase of equipment

I and E levels are presented in the next table.

Table 6.5.3 – *E level in Structural Failure accidents of General Cargo ships*

E1	Inferior quality of structure
E2	Poor condition of equipment
E3	Violation of regulations
E4	Misuse of equipment

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table6.5.4 – *Z and Y levels in Structural Failure accidents of General Cargo ships*

Y1	Corrosion
Y2	Cracking
Y3	Deformation
Y4	Navigational failure
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.5.5 – *Gates/Barriers of the event tree diagram in Structural Failure accidents of Container ships*

G1	Location
G2	Operational state
G3	Time of day
G4	Consequent accident
G5	Loss of water tightness

- Consequences

Table 6.5.6 – *Consequences in Structural Failure accidents of Container ships*

A1	Minor repairable damage to accommodation/ Possible injuries
A2	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A3	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Minor repairable damage to accommodation/ Injuries
A5	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A6	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A7	Minor repairable damage to accommodation/ Possible injuries
A8	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A10	Minor repairable damage to accommodation/ Injuries
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Possible injuries
A14	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A15	Worst case: Loss of vessel/Loss of all crew
A16	Minor repairable damage to accommodation/ Injuries
A17	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities

A18	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M3	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Minor repairable damage to machinery/ Possible injuries
M5	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M6	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M7	Minor repairable damage to machinery
M8	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M10	Minor repairable damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery
M14	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M15	Worst case: Loss of vessel/Loss of all crew
M16	Minor repairable damage to machinery/ Possible injuries
M17	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M18	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to containers
C2	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C3	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C4	Minor repairable damage to containers/ Possible injuries
C5	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C6	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C7	Minor repairable damage to container
C8	Serious damage to containers/ Damage to vessel/

	Injuries and fatalities
C9	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C10	Minor repairable damage to containers/ Possible injuries
C11	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to containers
C14	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C15	Worst case: Loss of vessel/Loss of all crew
C16	Minor repairable damage to containers/ Possible injuries
C17	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C18	Worst case: Loss of vessel/Loss of all crew

6.6.3 Explosion accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.6.1 – *Pattern of consequences in Explosion accidents of Container ships*

Minor damage to damaged area
Extended damage to damaged area/ Possible damage to vessel
Serious damage to damaged area/ Damage to vessel/ Crew injuries
Very serious cargo damage/Very serious vessel damage/ Crew injuries and fatalities
Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

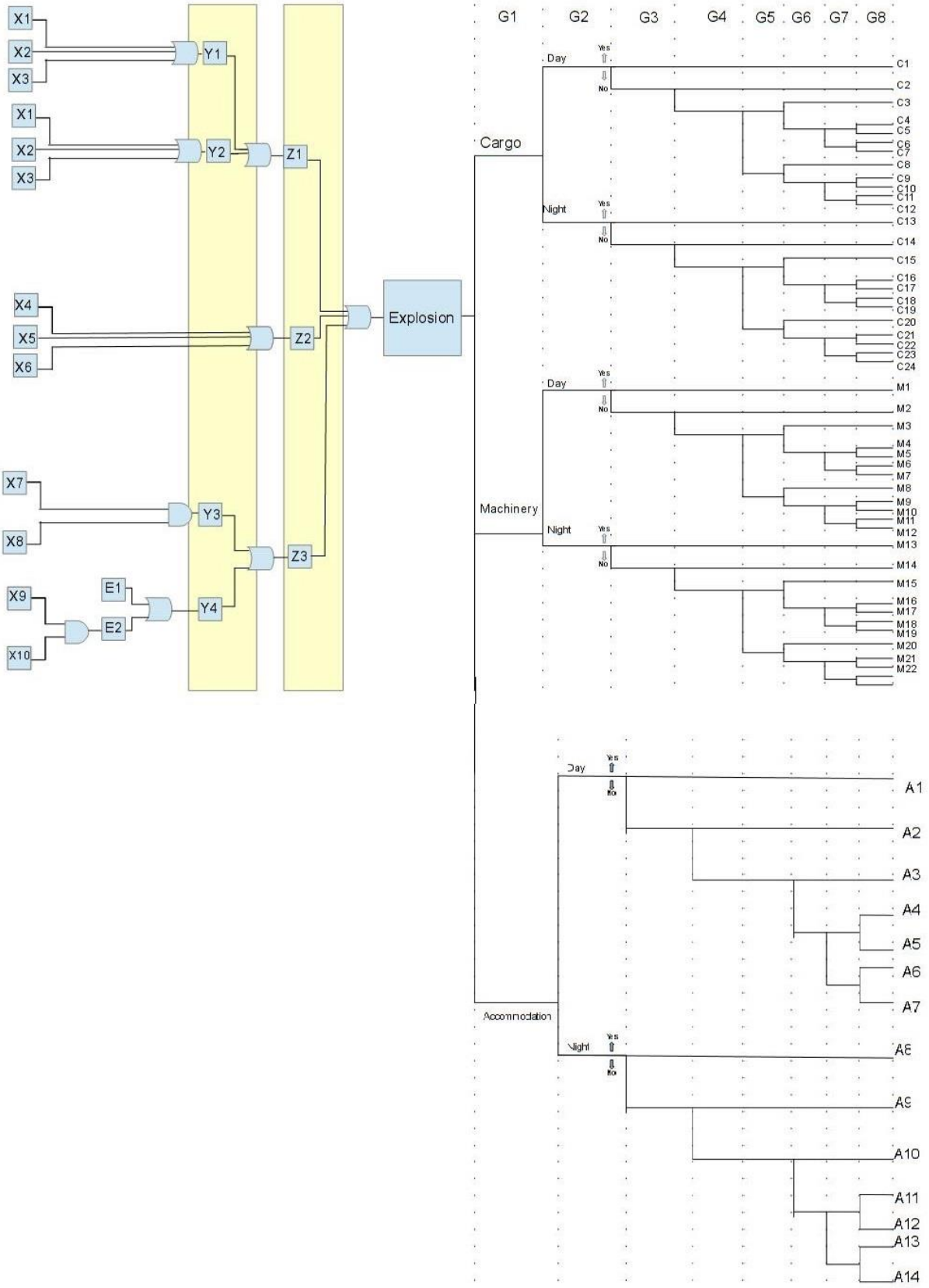

Figure 6.6 – *Bow tie diagram in Explosion accidents of Container ships*

In explosion accidents of container ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is rather serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.6.2 – *X level in Explosion accidents of Container ships*

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Incautious practice of metalworking
X5	Electrical malfunction
X6	Mechanical malfunction
X7	Untrained personnel
X8	Inexperienced personnel
X9	Crew did not pay attention
X10	Deficiencies of manuals

E level are presented in the next table.

Table 6.6.3 – *E level in Explosion accidents of Container ships*

E1	Violation of regulations
E2	Process not followed

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table 6.6.4 – *Z and Y levels in Explosion accidents of Container ships*

Y1	Corrosion
Y2	Cracking
Y3	Insufficient quality of personnel
Y4	Inappropriate actions
Z1	Leakage of explosive mixture of materials
Z2	Sparks
Z3	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.6.5 – *Gates/Barriers of the event tree diagram in Explosion accidents of Container ships*

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting
G5	Fire spread to accommodation
G6	Firefighting assistance from other vessel or land
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew

- Consequences

Table 6.6.6 – *Consequences in Explosion accidents of Container ships*

C1	Minor damage to cargo
C2	Extended damage to cargo/ Possible damage to vessel
C3	Serious damage to cargo/ Damage to vessel/ Crew injuries
C4	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C5	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C6	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C8	Serious damage to cargo/ Damage to vessel
C9	Very serious cargo damage/serious damage to vessel
C10	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C11	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C13	Minor damage to cargo
C14	Extended damage to cargo/ Possible damage to vessel
C15	Serious damage to cargo/ Damage to vessel/ Crew injuries and possible fatalities
C16	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities

C17	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C18	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C20	Serious damage to cargo/ Damage to vessel
C21	Very serious cargo damage/serious damage to vessel
C22	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C23	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M5	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
M9	Very serious damage to machinery/serious damage to vessel
M10	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M11	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M13	Minor damage to machinery
M14	Extended damage to machinery/ Possible damage to vessel
M15	Serious damage to machinery/ Damage to vessel/ Crew injuries and possible fatalities
M16	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M17	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M18	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage

M19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M20	Serious damage to machinery/ Damage to vessel
M21	Very serious damage to machinery/serious damage to vessel
M22	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M23	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A1	Minor repairable damage to accommodation
A2	Extended damage to accommodation/ Possible damage to vessel
A3	Serious damage to accommodation/ Damage to vessel/ Possible crew injuries
A4	Very serious damage to accommodation/serious damage to vessel/ Injuries and possible fatalities/
A5	Crew casualties/ Very serious damage to accommodation / Serious damage to vessel/
A6	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A8	Minor repairable damage to accommodation
A9	Extended damage to accommodation/ Possible damage to vessel/ Injuries
A10	Serious damage to accommodation/ Damage to vessel/ Crew injuries and possible fatalities
A11	Very serious damage to accommodation/serious damage to vessel/ Injuries and fatalities
A12	Crew casualties/ Very serious damage to accommodation / Serious damage to vessel/
A13	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A14	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew

There was no data for fire in container ships to allow the production of a Bow tie diagram for fire accidents.

6.7 Bow tie diagrams in Passenger ships

6.7.1 Failure of Equipment accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.7.1 *– Pattern of consequences in Failure of Equipment accidents of Passenger ships*

Minor repairable damage to accident area
Extended damage to accident area
Serious damage to accident area
Very serious damage to accident area / Damage to vessel

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

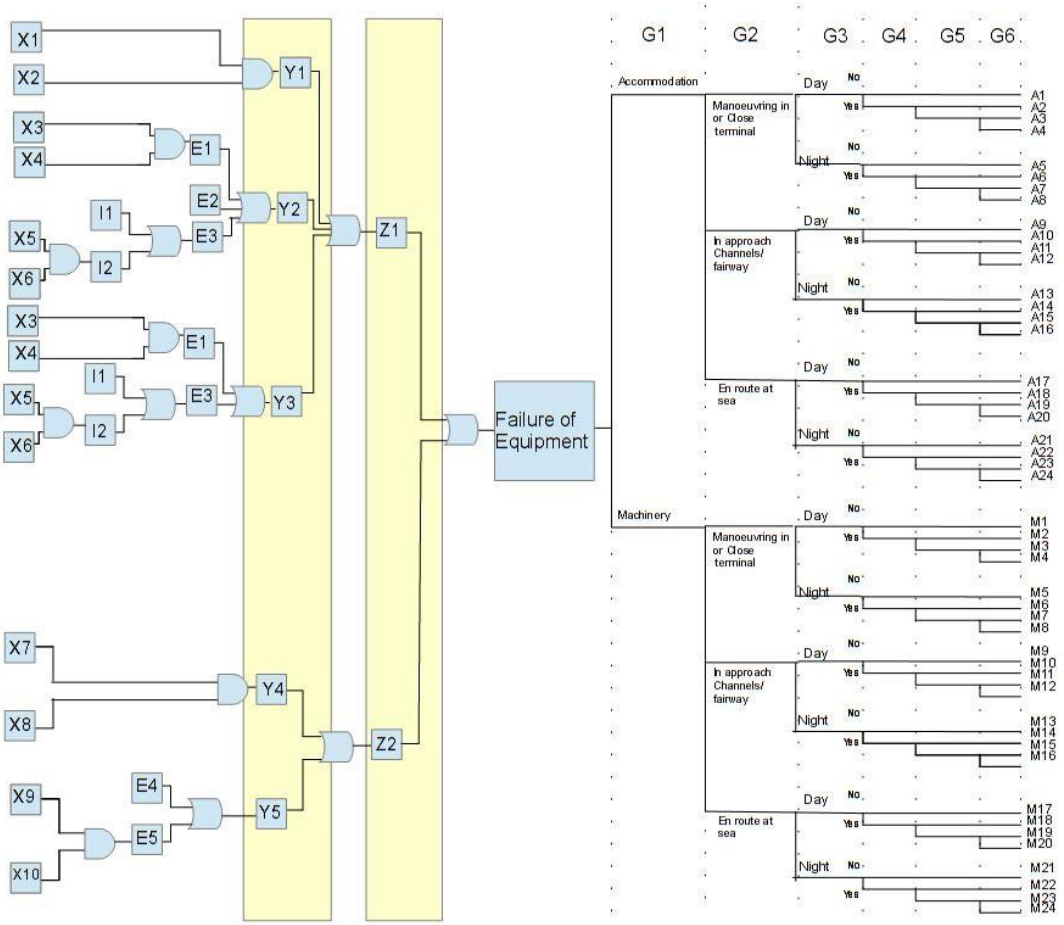

Figure 6.7 – *Bow tie diagram in Failure of Equipment accidents of Passenger ships*

In failure of equipment accidents in passenger ships there is a variety of contributors that can lead to the top event.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.7.2 – *X level in Failure of Equipment accidents of Passenger ships*

X1	Poor instalation
X2	Poor supervision from the crew
X3	Poor design calculations
X4	Poor endurance tests
X5	Poor maintenance
X6	Poor inspection
X7	Inexperienced personnel
X8	Untrained personnel
X9	Crew did not pay attention
X10	Deficiencies of manuals

I and E levels are presented in the next table.

Table 6.7.3 – *I and E levels in Failure of Equipment accidents of Passenger ships*

I1	Insufficient attention to repairs
I2	Inattentions
E1	Inferior quality of materials
E2	Weather conditions
E3	Poor condition of equipment
E4	Violation of regulations
E5	Process not followed

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table 6.7.4 – *Z and Y levels in Failure of Equipment accidents of Passenger ships*

Y1	Deficient equipment
Y2	Corrosion
Y3	Cracking
Y4	Insufficient quality of personnel
Y5	Inappropriate actions
Z1	Broken off or loose equipment
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.7.5 – *Gates/Barriers of the event tree diagram in Failure of Equipment accidents of Passenger ships*

G1	Location
G2	Operational state
G3	Time of day
G4	Consequent accident
G5	Damage to structure
G6	Loss of water tightness

- Consequences

Table 6.7.6 – *Consequences in Failure of Equipment accidents of Passenger ships*

A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A8	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Minor repairable damage to accommodation/ Possible injuries
A10	Extended damage to accommodation/ Injuries and possible fatalities
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Injuries
A14	Extended damage to accommodation/ Injuries and possible fatalities
A15	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A16	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A17	Minor repairable damage to accommodation/ Possible injuries

A18	Extended damage to accommodation/ Injuries and possible fatalities
A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all passengers and crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all passengers and crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
M6	Extended damage to machinery/ Possible injuries
M7	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M8	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Minor repairable damage to machinery
M10	Extended damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery/ Possible injuries
M14	Extended damage to machinery/ Possible injuries
M15	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M16	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M17	Minor repairable damage to machinery
M18	Extended damage to machinery/ Possible injuries
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all passengers and crew
M21	Minor repairable damage to machinery/ Possible injuries

M22	Extended damage to machinery/ Possible injuries
M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all passengers and crew

6.7.2 Fire/Explosion accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.8.1 *– Pattern of consequences in Fire/Explosion accidents of Passenger ships*

Minor repairable damage to damaged area/Possible injuries
Extended damage to damaged area/ Possible damage to vessel/ Crew and passengers injuries
Serious damage to damaged area/ Damage to vessel/ Crew and passengers injuries
Very serious damage to damaged area/Serious damage to vessel/ Crew, passengers injuries and fatalities
Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

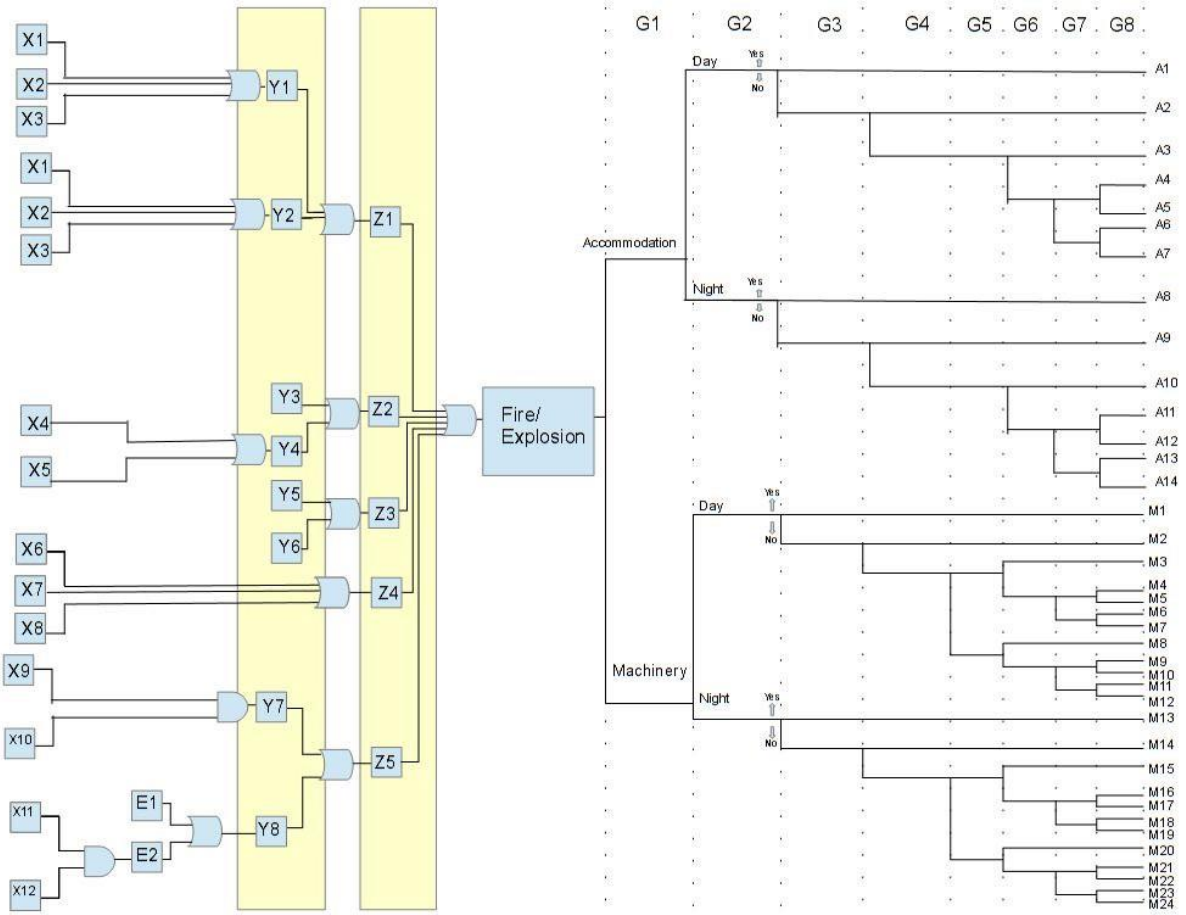

Figure 6.8 – *Bow tie diagram in Fire/Explosion accidents of Passenger ships*

In fire/explosion accidents in passenger ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is rather serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.8.2 – *X level in Fire/Explosion accidents of Passenger ships*

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Poor design
X5	Poor supervision from the crew
X6	Incautious practice of metalworking
X7	Electrical malfunction
X8	Mechanical malfunction
X9	Inexperienced personnel
X10	Untrained personnel
X11	Crew did not pay attention
X12	Deficiencies of manuals

E level is presented in the next table.

Table 6.8.3 – *E level in Fire/Explosion accidents of Passenger ships*

E1	Violation of regulations
E2	Process not followed

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table 6.8.4 – *Z and Y levels in Fire/Explosion accidents of Passenger ships*

Y1	Corrosion
Y2	Cracking
Y3	Overheating machine
Y4	Hot surfaces
Y5	Incorrect tightening
Y6	Use of unauthorised spare part
Y7	Insufficient quality of personnel
Y8	Inappropriate actions
Z1	Leakage
Z2	Inappropriate temperature
Z3	Crankcase explosion
Z4	Sparks
Z5	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.8.5 – *Gates/Barriers of the event tree diagram in Fire/Explosion accidents of Passenger ships*

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting
G5	Fire spread to accommodation
G6	Assistance from other vessel or land/ Rescue of passengers
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew

- Consequences

Table 6.8.6 – *Consequences in Fire/Explosion accidents of Passenger ships*

A1	Possible Injuries

A2	Injuries and possible fatalities
A3	Injuries/fatalities and damage to vessel
A4	Injuries and fatalities/ Serious damage to vessel
A5	Many fatalities/Loss of crew and loss of vessel
A6	Many passangers and crew fatalities
A7	Worst case: Loss of vessel/ Loss of passengers and crew
A8	Injuries and possible fatalities
A9	Injuries/fatalities and damage to vessel
A10	Injuries and fatalities/ Serious damage to vessel
A11	Injuries and fatalities/ Serious damage to vessel
A12	Many fatalities/Loss of crew and loss of vessel
A13	Many passangers and crew fatalities
A14	Worst case: Loss of vessel/ Loss of passengers and crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew and passengers injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew,passengers injuries and possible fatalities
M5	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
M9	Very serious damage to machinery/serious damage to vessel
M10	Very serious damage to machinery/Loss vessel/ Crew, passengers fatalities
M11	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M12	Worst case: Loss of vessel/ Loss of passengers and crew
M13	Minor damage to machinery
M14	Extended damage to machinery/ Possible damage to vessel
M15	Serious damage to machinery/ Damage to vessel/ Crew, passengers injuries and possible fatalities
M16	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities

M17	Very serious damage to machinery/Loss vessel/ Crew, passengers fatalities
M18	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M19	Worst case: Loss of vessel/ Loss of passengers and crew
M20	Serious damage to machinery/ Damage to vessel
M21	Very serious damage to machinery/serious damage to vessel
M22	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M23	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of passengers and crew

There was no data for structural failures in passenger ships to allow the production of a Bow tie diagram for structural failure accidents. Also due to the similar nature of fire an explosion accidents, a merged diagram was created.

6.8 Bow tie diagrams in Cruise ships

6.8.1 Failure of Equipment accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.9.1 *– Pattern of consequences in Failure of Equipment accidents of Cruise ships*

Minor repairable damage to accident area
Extended damage to accident area
Serious damage to accident area
Very serious damage to accident area / Damage to vessel

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

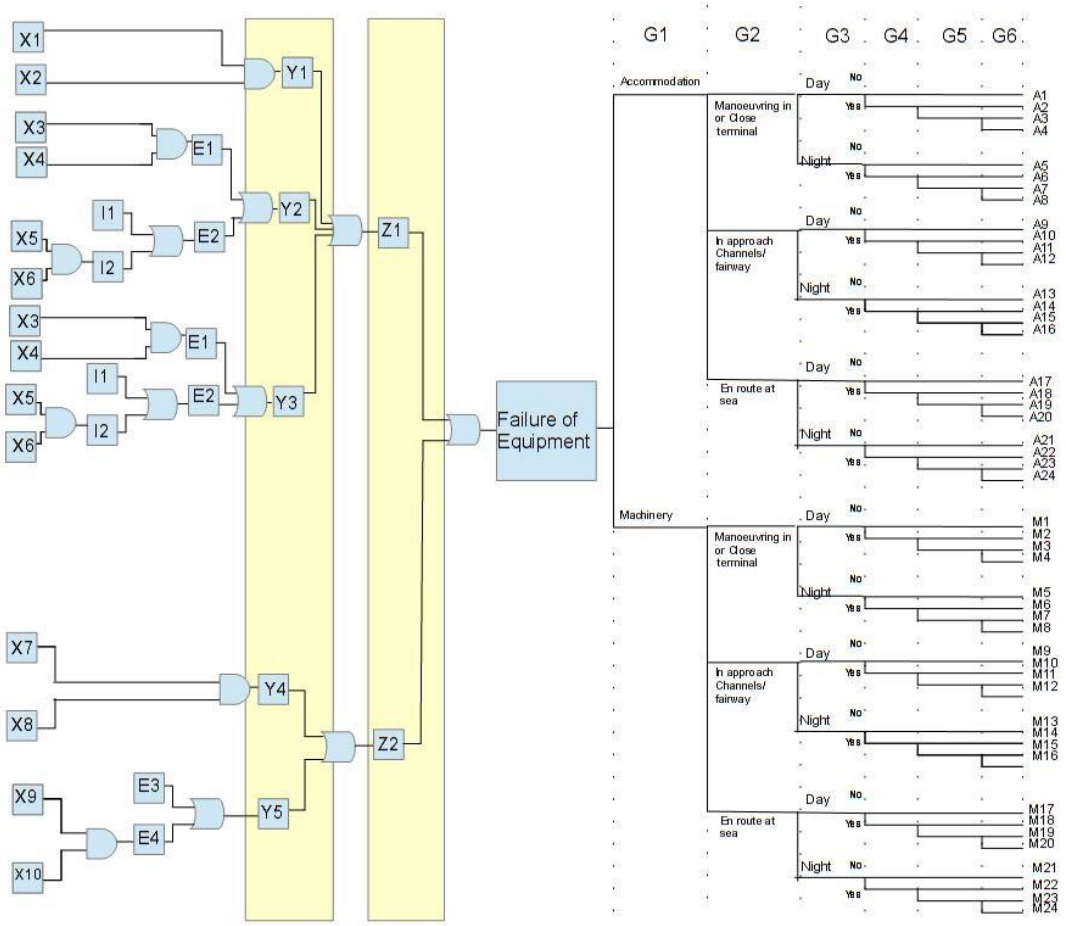

Figure 6.9 – Bow tie diagram in Failure of Equipment accidents of Cruise ships

In failure of equipment accidents in cruise ships there is a variety of contributors that can lead to the top event.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.9.2 – *X level in Failure of Equipment accidents of Cruise ships*

X1	Poor instalation
X2	Poor supervision from the crew
X3	Poor design calculations
X4	Poor endurance tests
X5	Poor maintenance
X6	Poor inspection
X7	Inexperienced personnel
X8	Untrained personnel
X9	Crew did not pay attention
X10	Deficiencies of manuals

I and E levels are presented in the next table.

Table 6.9.3 – *I and E levels in Failure of Equipment accidents of Cruise ships*

I1	Insufficient attention to repairs
I2	Inattentions
E1	Inferior quality of materials
E2	Poor condition of equipment
E3	Violation of regulations
E4	Process not followed

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table 6.9.4 – *Z and Y levels in Failure of Equipment accidents of Cruise ships*

Y1	Deficient equipment
Y2	Corrosion
Y3	Cracking
Y4	Insufficient quality of personnel
Y5	Inappropriate actions
Z1	Broken off or loose equipment
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.9.5 – *Gates/Barriers of the event tree diagram in Failure of Equipment accidents of Cruise ships*

G1	Location
G2	Operational state
G3	Time of day
G4	Consequent accident
G5	Damage to structure
G6	Loss of water tightness

- Consequences

Table 6.9.6 – *Consequences in Failure of Equipment accidents of Cruise ships*

A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A8	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Minor repairable damage to accommodation/ Possible injuries
A10	Extended damage to accommodation/ Injuries and possible fatalities
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Injuries
A14	Extended damage to accommodation/ Injuries and possible fatalities
A15	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A16	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A17	Minor repairable damage to accommodation/ Possible injuries
A18	Extended damage to accommodation/ Injuries and possible fatalities

A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all passengers and crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all passengers and crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
M6	Extended damage to machinery/ Possible injuries
M7	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M8	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Minor repairable damage to machinery
M10	Extended damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery/ Possible injuries
M14	Extended damage to machinery/ Possible injuries
M15	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M16	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M17	Minor repairable damage to machinery
M18	Extended damage to machinery/ Possible injuries
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all passengers and crew
M21	Minor repairable damage to machinery/ Possible injuries

M22	Extended damage to machinery/ Possible injuries
M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all passengers and crew

6.8.2 Explosion accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.10.1 *– Pattern of consequences in Explosion accidents of Cruise ships*

Minor repairable damage to damaged area/Possible injuries
Extended damage to damaged area/ Possible damage to vessel/ Crew and passengers injuries
Serious damage to damaged area/ Damage to vessel/ Crew and passengers injuries
Very serious damage to damaged area/Serious damage to vessel/ Crew, passengers injuries and fatalities
Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

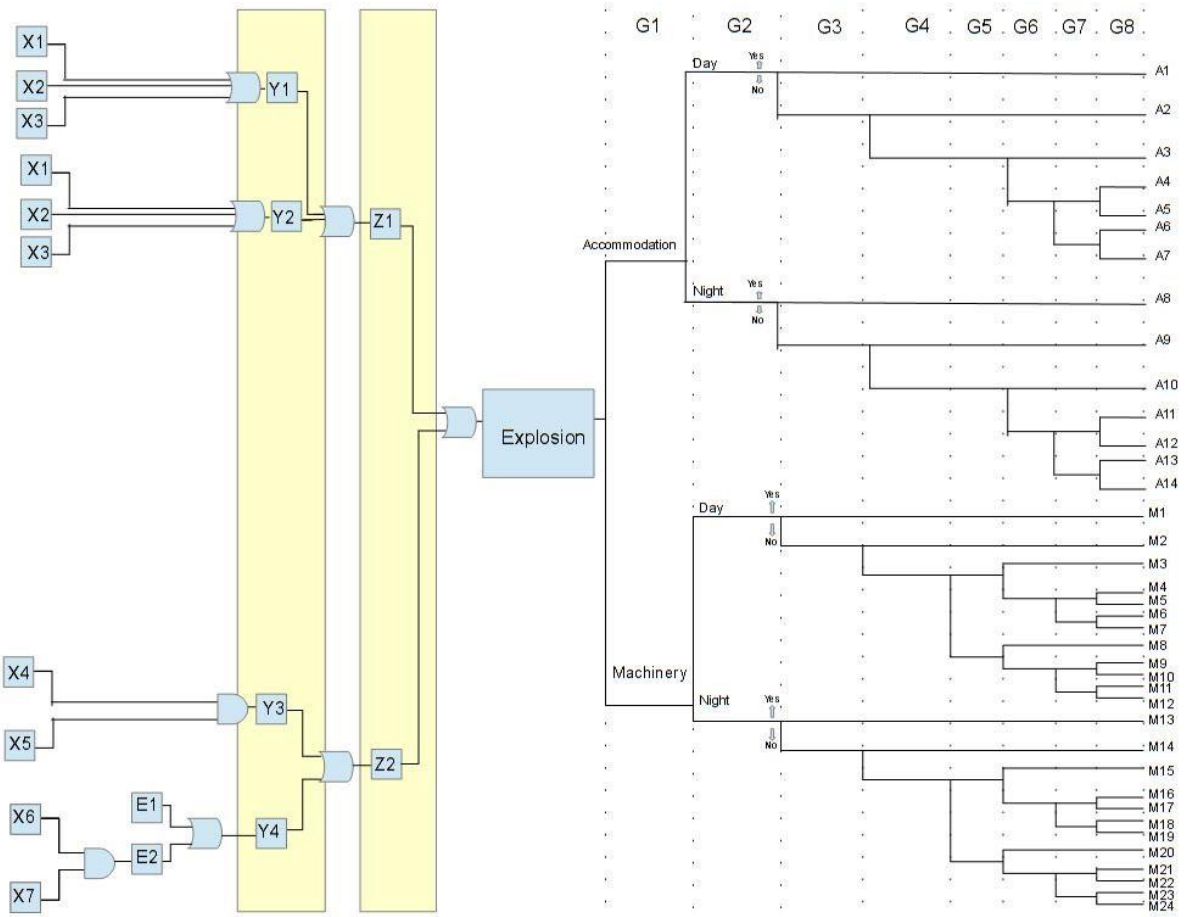

Figure 6.10 – *Bow tie diagram in Explosion accidents of Cruise ships*

In fire/explosion accidents in cruise ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is rather serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.10.2 – *X level in Explosion accidents of Cruise ships*

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Inexperienced personnel
X5	Untrained personnel
X6	Crew did not pay attention
X7	Deficiencies of manuals

E level are presented in the next table.

Table 6.10.3 – *E level in Explosion accidents of Cruise ships*

E1	Violation of regulations

E2	Process not followed

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table 6.10.4 – *Z and Y levels in Explosion accidents of Cruise ships*

Y1	Corrosion
Y2	Cracking
Y3	Insufficient quality of personnel
Y4	Inappropriate actions
Z1	Leakage
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.10.5 – *Gates/Barriers of the event tree diagram in Explosion accidents of Cruise ships*

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting
G5	Fire spread to accommodation
G6	Assistance from other vessel or land/ Rescue of passengers
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew

- Consequences

Table 6.10.6 – *Consequences in Explosion accidents of Cruise ships*

A1	Possible Injuries
A2	Injuries and possible fatalities
A3	Injuries/fatalities and damage to vessel
A4	Injuries and fatalities/ Serious damage to vessel
A5	Many fatalities/Loss of crew and loss of vessel
A6	Many passangers and crew fatalities
A7	Worst case: Loss of vessel/ Loss of passengers and crew
A8	Injuries and possible fatalities
A9	Injuries/fatalities and damage to vessel
A10	Injuries and fatalities/ Serious damage to vessel
A11	Injuries and fatalities/ Serious damage to vessel
A12	Many fatalities/Loss of crew and loss of vessel

A13	Many passangers and crew fatalities
A14	Worst case: Loss of vessel/ Loss of passengers and crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew and passengers injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew,passengers injuries and possible fatalities
M5	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
M9	Very serious damage to machinery/serious damage to vessel
M10	Very serious damage to machinery/Loss vessel/ Crew, passengers fatalities
M11	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M12	Worst case: Loss of vessel/ Loss of passengers and crew
M13	Minor damage to machinery
M14	Extended damage to machinery/ Possible damage to vessel
M15	Serious damage to machinery/ Damage to vessel/ Crew, passengers injuries and possible fatalities
M16	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M17	Very serious damage to machinery/Loss vessel/ Crew, passengers fatalities
M18	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M19	Worst case: Loss of vessel/ Loss of passengers and crew
M20	Serious damage to machinery/ Damage to vessel
M21	Very serious damage to machinery/serious damage to vessel
M22	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M23	Injuries, fatalities/ Very serious damage to

	machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of passengers and crew

There was no data for structural failures and fire in cruise ships to allow the production of a Bow tie diagram for structural failure and fire accidents.

6.9 Bow tie diagrams in LNG ships

Due to the limited accidents related to LNG ships, this section tries to present a risk evaluation method using mostly the approach of IMO's FSA for these vessels(IMO 2007). Also some hazard and their information have been taken from Li and Huang's work(Li and Huang 2012).

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

6.9.1 Fire/Explosion accidents

Table 6.11.1 *– Pattern of consequences in Fire/Explosion accidents of LNG ships*

Minor damage to damaged area
Extended damage to damaged area/ Possible damage to vessel
Serious damage to damaged area/ Damage to vessel/ Crew injuries/Possible environmental pollution
Very serious damage to damaged area/serious damage to vessel/ Crew injuries and possible fatalities/ Possible environmental pollution
Very serious damage to damaged area /Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

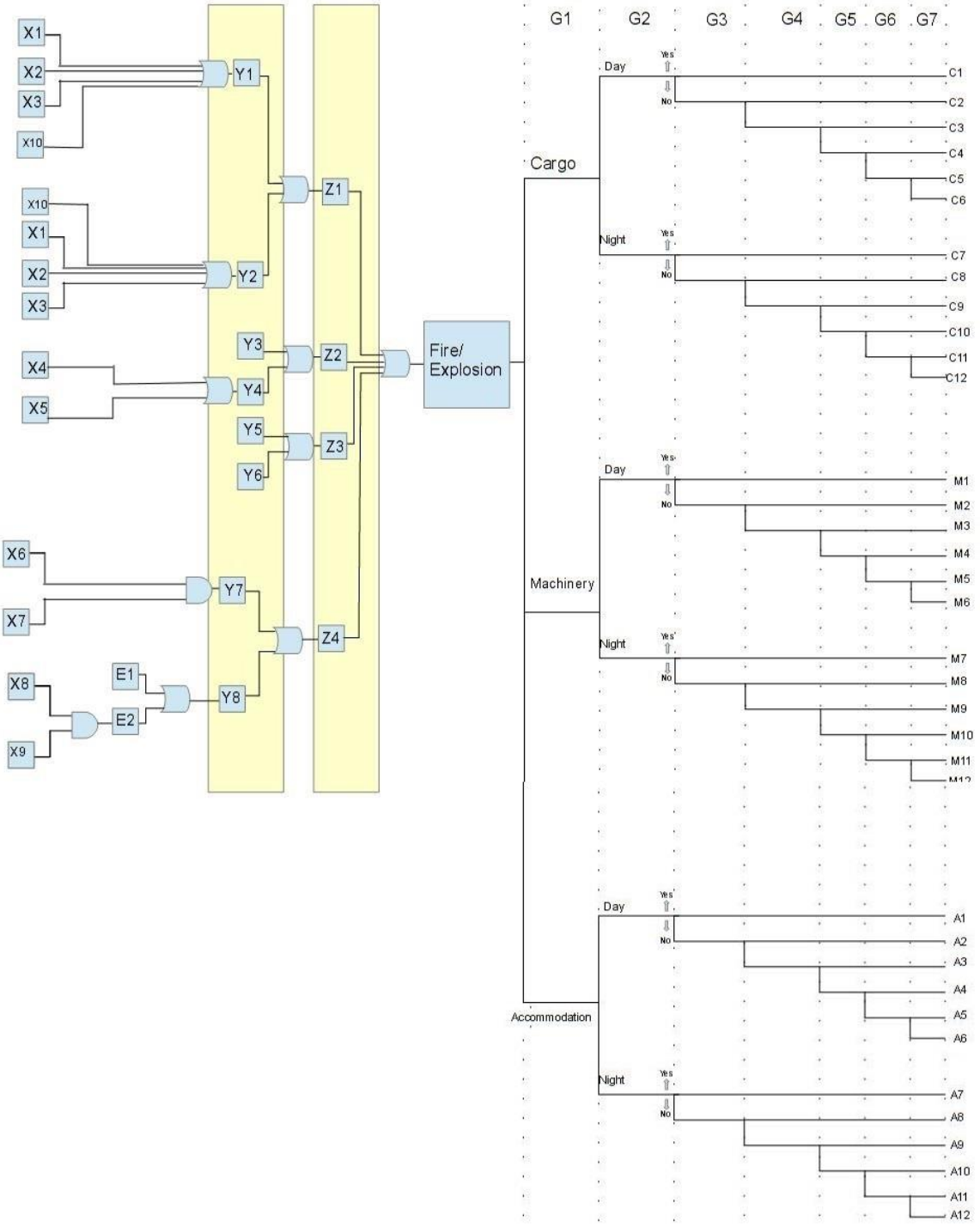

Figure 6.11 – *Bow tie diagram in Fire/Explosion accidents of LNG ships*

In fire/explosion accidents in LNG ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is rather serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.11.2 – *X level in Fire/Explosion accidents of LNG ships*

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Poor design
X5	Poor supervision from the crew
X6	Inexperienced personnel
X7	Untrained personnel
X8	Crew did not pay attention
X9	Deficiencies of manuals
X10	Sloshing of partially filled tank

E level is presented in the next table.

Table 6.11.3 – *E level in Fire/Explosion accidents of LNG ships*

E1	Violation of regulations
E2	Process not followed

Z level(Failure mode level) and Y level(Level of causes) are presented below.

Table 6.11.4 – *Z and Y levels in c*

Y1	Corrosion
Y2	Cracking
Y3	Overheating machine
Y4	Hot surfaces
Y5	Incorrect tightening
Y6	Use of unauthorised spare part
Y7	Insufficient quality of personnel
Y8	Inappropriate actions
Z1	Leakage
Z2	Inappropriate temperature
Z3	Crankcase explosion
Z4	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.11.5 – *Gates/Barriers of the event tree diagram in Fire/Explosion accidents of LNG ships*

G1	Location
G2	Time of day
G3	Successful fire fighting systems
G4	No LNG leakage
G5	No pool fire
G6	Fire extinguishing, vessel towing
G7	Ship evacuation/ Rescue of crew

- Consequences

Table 6.11.6 – *Consequences in Fire/Explosion accidents of LNG ships*

C1	Minor damage to cargo area
C2	Extended damage to cargo area/ Possible damage to vessel
C3	Serious damage to cargo area/ Damage to vessel/ Crew injuries/Possible environmental pollution
C4	Very serious damage to cargo area/serious damage to vessel/ Crew injuries and possible fatalities/ Possible environmental pollution
C5	Very serious damage to cargo area /Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
C6	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
C7	Damage to cargo area/Possible injuries
C8	Extended damage to cargo area/ Possible damage to vessel/ Crew injuries
C9	Serious damage to cargo area/ Damage to vessel/ Crew injuries/Possible environmental pollution
C10	Very serious damage to cargo area/serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
C11	Very serious damage to cargo area/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
C12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
M1	Minor damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel

M3	Serious damage to machinery/ Damage to vessel/ Crew injuries/Possible environmental pollution
M4	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities/ Possible environmental pollution
M5	Very serious damage to machinery/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
M6	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
M7	Damage to machinery/Possible injuries
M8	Extended damage to machinery/ Possible damage to vessel/ Crew injuries
M9	Serious damage to machinery/ Damage to vessel/ Crew injuries/Possible environmental pollution
M10	Very serious damage to machinery/serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
M11	Very serious damage to machinery/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
M12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
A1	Minor damage to accommodation
A2	Extended damage to accommodation/ Possible damage to vessel
A3	Serious damage to accommodation/ Damage to vessel/ Crew injuries/Possible environmental pollution
A4	Very serious damage to accommodation/serious damage to vessel/ Crew injuries and possible fatalities/ Possible environmental pollution
A5	Very serious damage to accommodation/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
A6	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
A7	Damage to accommodation/Possible injuries
A8	Extended damage to accommodation/ Possible damage to vessel/ Crew injuries
A9	Serious damage to accommodation/ Damage to vessel/ Crew injuries/Possible environmental pollution
A10	Very serious damage to accommodation/serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
A11	Very serious damage to accommodation/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
A12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution

6.9.2 Structural Failure accidents

In the following diagram, the consequences produced by event tree were extracted putting under consideration the IMO's severity index, as shown in previous chapter, and follow a specific pattern.

Table 6.12.1 *– Pattern of consequences in Structural Failure accidents of LNG ships*

Minor repairable damage to cargo area
Extended damage to cargo area/ Possible injuries
Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
Worst case: Loss of vessel/Loss of all crew

There is a difference in injuries/ fatalities severity according to time of day, damaged area and operational state. Due to the fact that in nighttime, in accommodation area and en route operational state the severity levels are higher, the consequences in human life are greater.

Finally, there is a consequence that describes the worst case scenario of the event tree. This consequence is derived from the most severe path in the diagram after the occurrence of top event.

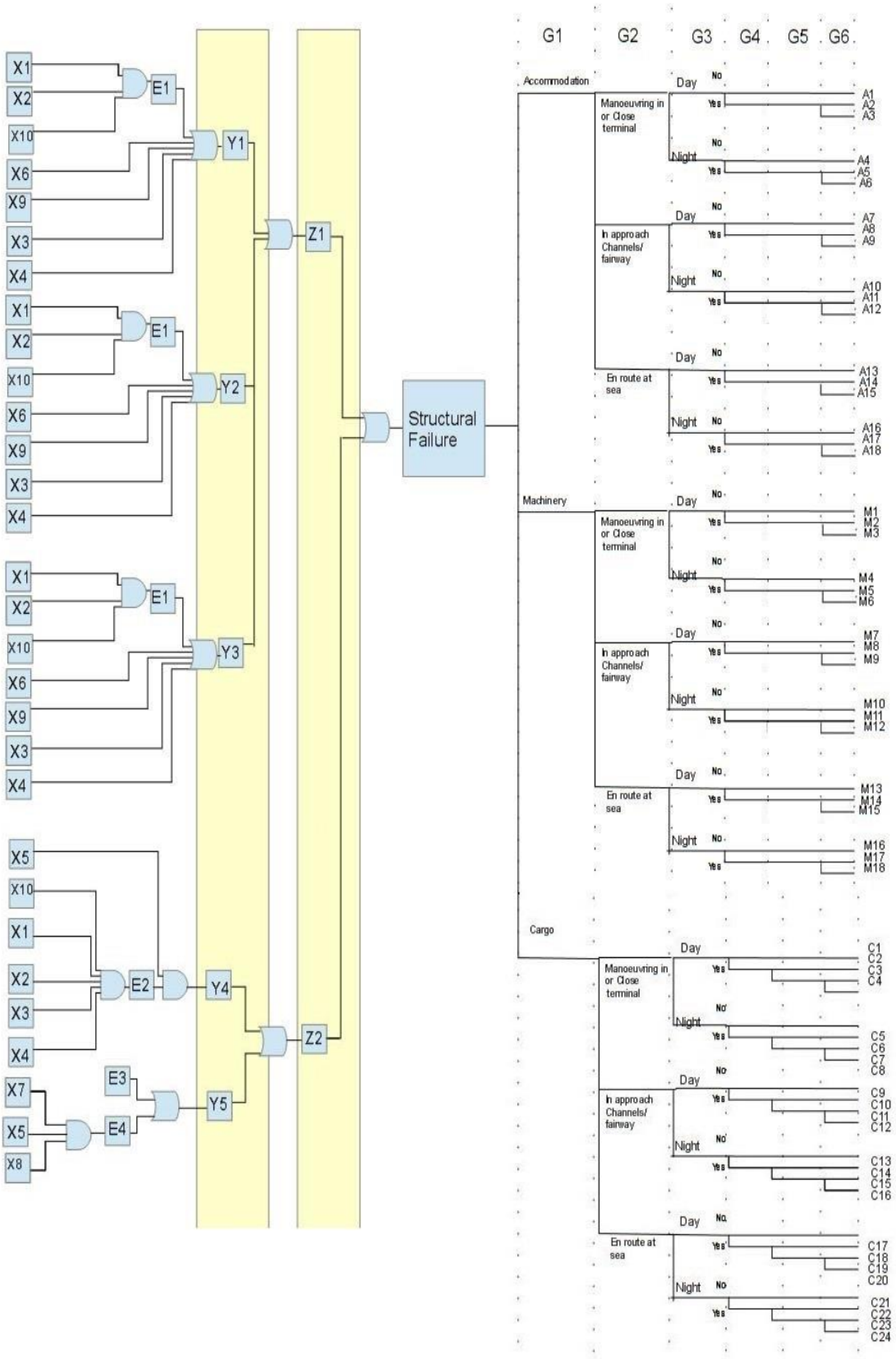

Figure 6.12 *– Bow tie diagram in Structural Failure accidents of LNG ships*

In structural failure accidents of LNG ships there is a variety of contributors that can lead to the top event. Also due to the greater severity levels of this type of accidents the consequences after the occurrence of top event is more serious.

X level, the critical events that can lead to the next levels is presented in the next table.

Table 6.12.2 – *X level in Structural Failure accidents of LNG ships*

X1	Poor design calculations
X2	Poor endurance tests
X3	Poor maintenance
X4	Poor inspection
X5	Inadequate personnel
X6	Insufficient attention to repairs
X7	Crew did not pay attention
X8	Deficiencies of manuals
X9	Adverse weather conditions
X10	Poor construction/ purchase of equipment

I and E levels are presented in the next table.

Table 6.12.3 – *E level in Structural Failure accidents of LNG ships*

E1	Inferior quality of structure
E2	Poor condition of equipment
E3	Violation of regulations
E4	Misuse of equipment

Z level (Failure mode level) and Y level (Level of causes) are presented below.

Table 6.12.4 – *Z and Y levels in Structural Failure accidents of LNG ships*

Y1	Corrosion
Y2	Cracking
Y3	Deformation
Y4	Navigational failure
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational error

In the tables below, the gates and the different consequences of the event tree diagram are presented thoroughly.

- Gates/Barriers

Table 6.12.5 – *Gates/Barriers of the event tree diagram in Structural Failure accidents of LNG ships*

G1	Location
G2	Operational state
G3	Time of day
G4	Consequent accident
G5	Leakage of LNG
G6	Loss of water tightness

- Consequences

Table 6.12.6 – *Consequences in Structural Failure accidents of LNG ships*

A1	Minor repairable damage to accommodation/ Possible injuries
A2	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A3	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Minor repairable damage to accommodation/ Injuries
A5	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A6	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A7	Minor repairable damage to accommodation/ Possible injuries
A8	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A10	Minor repairable damage to accommodation/ Injuries
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Possible injuries
A14	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A15	Worst case: Loss of vessel/Loss of all crew
A16	Minor repairable damage to accommodation/ Injuries

A17	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A18	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M3	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Minor repairable damage to machinery/ Possible injuries
M5	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M6	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M7	Minor repairable damage to machinery
M8	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M10	Minor repairable damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery
M14	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M15	Worst case: Loss of vessel/Loss of all crew
M16	Minor repairable damage to machinery/ Possible injuries
M17	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M18	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to cargo area
C2	Extended damage to cargo area/ Possible injuries
C3	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C4	Very serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/ Possible environmental pollution
C5	Minor repairable damage to cargo area/ Possible injuries
C6	Extended damage to cargo area/ Possible injuries

C7	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C8	Very serious damage to cont cargo area / Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C9	Minor repairable damage to cargo area
C10	Extended damage to cargo area/ Possible injuries
C11	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C12	Very serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C13	Minor repairable damage to cargo area/ Possible injuries
C14	Extended damage to cargo area/ Possible injuries
C15	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C16	Very serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C17	Minor repairable damage to cargo area
C18	Extended damage to cargo area/ Possible injuries
C19	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C20	Worst case: Loss of vessel/Loss of all crew/Environmental pollution
C21	Minor repairable damage to cargo area/ Possible injuries
C22	Extended damage to cargo area/ Possible injuries
C23	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C24	Worst case: Loss of vessel/Loss of all crew/Environmental pollution

7. Real accidents

7.1 Introduction

In this section, ten incidents were chosen to represent each accident category as shown in previous sections. Each incident is easily defined as inspection mistake accident and each bow tie diagram that was created can clearly present the specific path that led to the top event as well as its consequences.

7.2 Mv Sonia accident on 1 September 1999

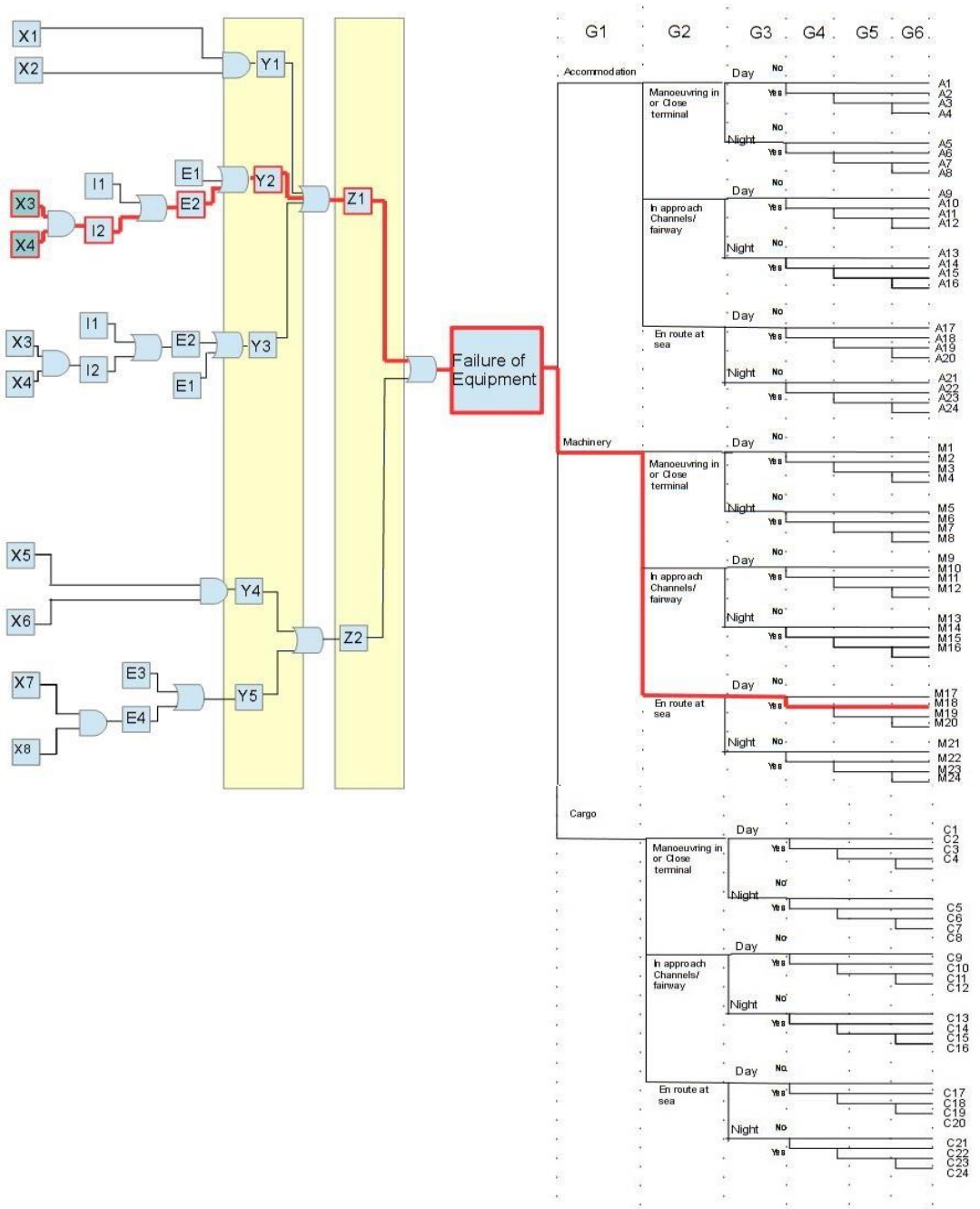

Figure 7.1 – Representation on bow tie diagram of Mv Sonia accident

On 1 September 1999 at 1718, the Solent Coastguard notified the Marine Accident Investigation Branch (MAIB) that the engine room of the cargo ship *Sonia* had flooded. Initially the situation was monitored, and the following day an MAIB inspector started an investigation.

Sonia was a 1968 built, 4,659gt, four hold, single screw general cargo vessel, with a crew of15. She was registered in St Vincent and The Grenadines, and operated worldwide by the managers, Balthellas Chartering SA. She arrived alongside No 47 berth in Southampton docks on 27 August and started loading a bulk cargo of grain later that day. Loading was completed by 1955 on 3 1 August, and at 2240 the pilot boarded and *Sonia* left Southampton for Greece.

The cause of the water ingress was a corroded seawater pipe connecting the sea chest to a system isolating valve. This 7mm thick pipe wall had suffered galvanic corrosion adjacent to the isolating valve flange over two-thirds of the pipe circumference. This level of corrosion reflected some years of neglect and suggested that the required inspections and surveys on a 31 year old vessel were not as thorough as they should have been. Given her age and the extent of the water damage in the engine room, *Sonia* was subsequently scrapped.

There were no injuries to sea staff but the MoD salvage master suffered shock after falling into the sea.[52]

Table 7.1 – Components in bow tie diagram of Mv Sonia accident

X3	Poor maintenance of seawater pipe
X4	Poor inspection of seawater pipe
I2	Inattention of the condition of seawater pipe
E2	Poor condition of seawater pipe
Y2	Corrosion of seawater pipe
Z1	Broken off seawater pipe
Top event	Failure of seawater pipe
G1	Engine room
G2	En route
G3	Day
G4	Flooding
M18	Ship flooded/ No injuries

7.3 Structural failure and foundering of the general cargo ship Swanland on 27 November 2011

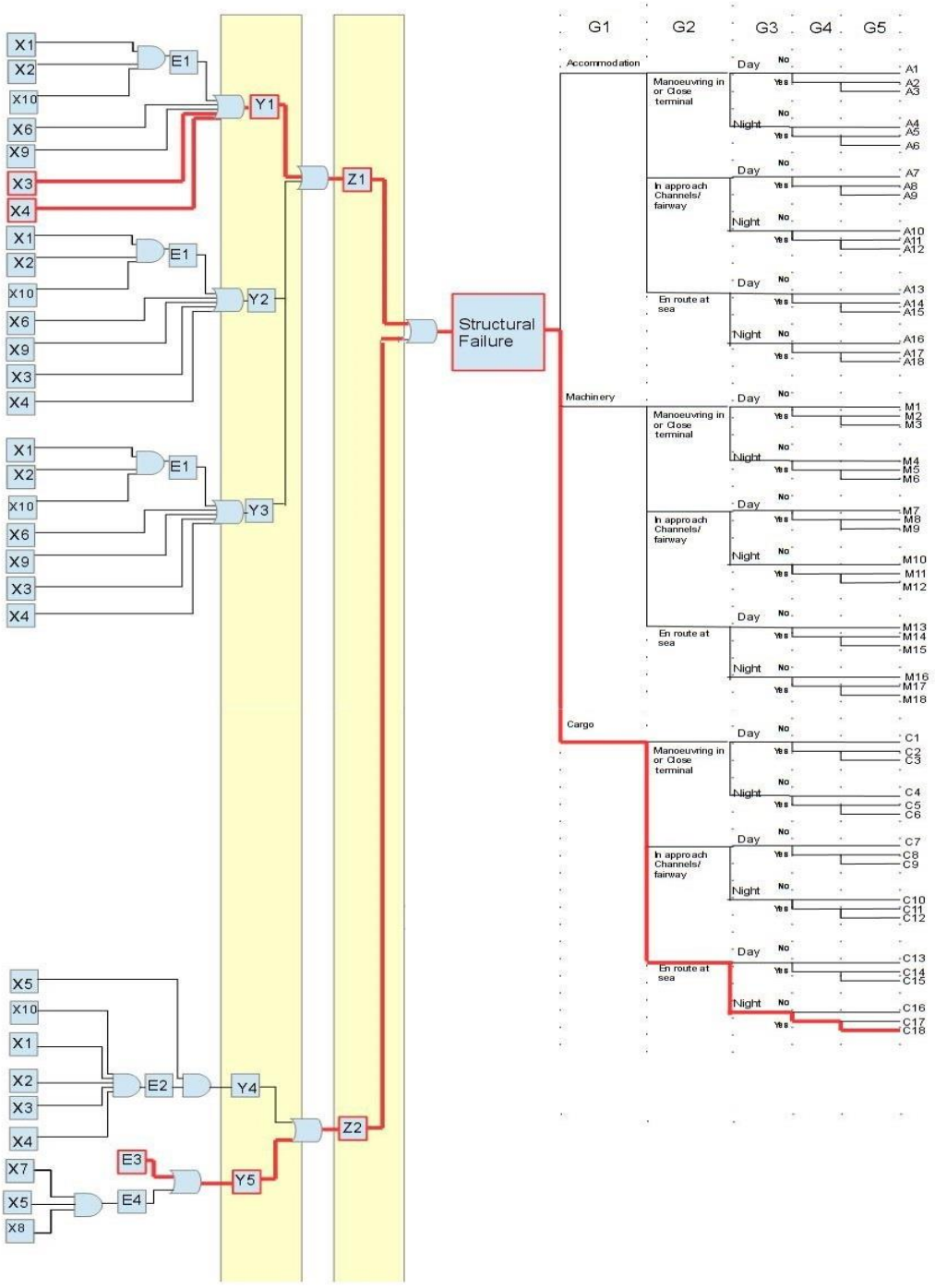

Figure 7.2 – Representation on bow tie diagram of Swanland accident

On 27 November 2011, the 34 year old Cook Islands registered general cargo ship *Swanland* experienced a structural failure when heading directly into rough seas and gale force winds while on passage from Llanddulas, Wales to Cowes, Isle of Wight with a cargo of limestone. The vessel sank about 17 minutes later. Two of the vessel's eight crew managed to swim clear and were rescued from a liferaft. The body of the chief officer was

recovered from the sea during an extensive air and sea search but the remaining crew were not found. There was no significant pollution.

Swanland's longitudinal strength had probably weakened significantly over the previous 2½ years through corrosion and wastage. The maintenance and repair of the vessel had lacked focus and oversight; no structural repairs had been undertaken since 2009.

Other contributing factors included: non-compliance with the International Maritime Solid Bulk Cargo Code, insufficient loading information, a lack of effective safety management, poor quality of survey and audit, lack of oversight of the classification society by the Flag State and the financial pressures of operating this type of vessel in the current economic downturn. The investigation also identified several safety issues concerning the immersion suits and lifejackets available on board the vessel.[53]

Table 7.2 – Components in bow tie diagram of Swanland accident

X3	Poor maintenance of vessel
X4	Poor inspection of vessel
E4	Violation of Maritime Solid Bulk Cargo Code
Y1	Corrosion
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational errors
Top event	Structural Failure
G1	Midship section (cargo)
G2	En route
G3	Night
G4	Foundering
C18	The vessel sank/ Loss of six crew

7.4 Engine room fire on board the Bahamas registered general cargo ship Baltimar Boreas on 9 February 2007

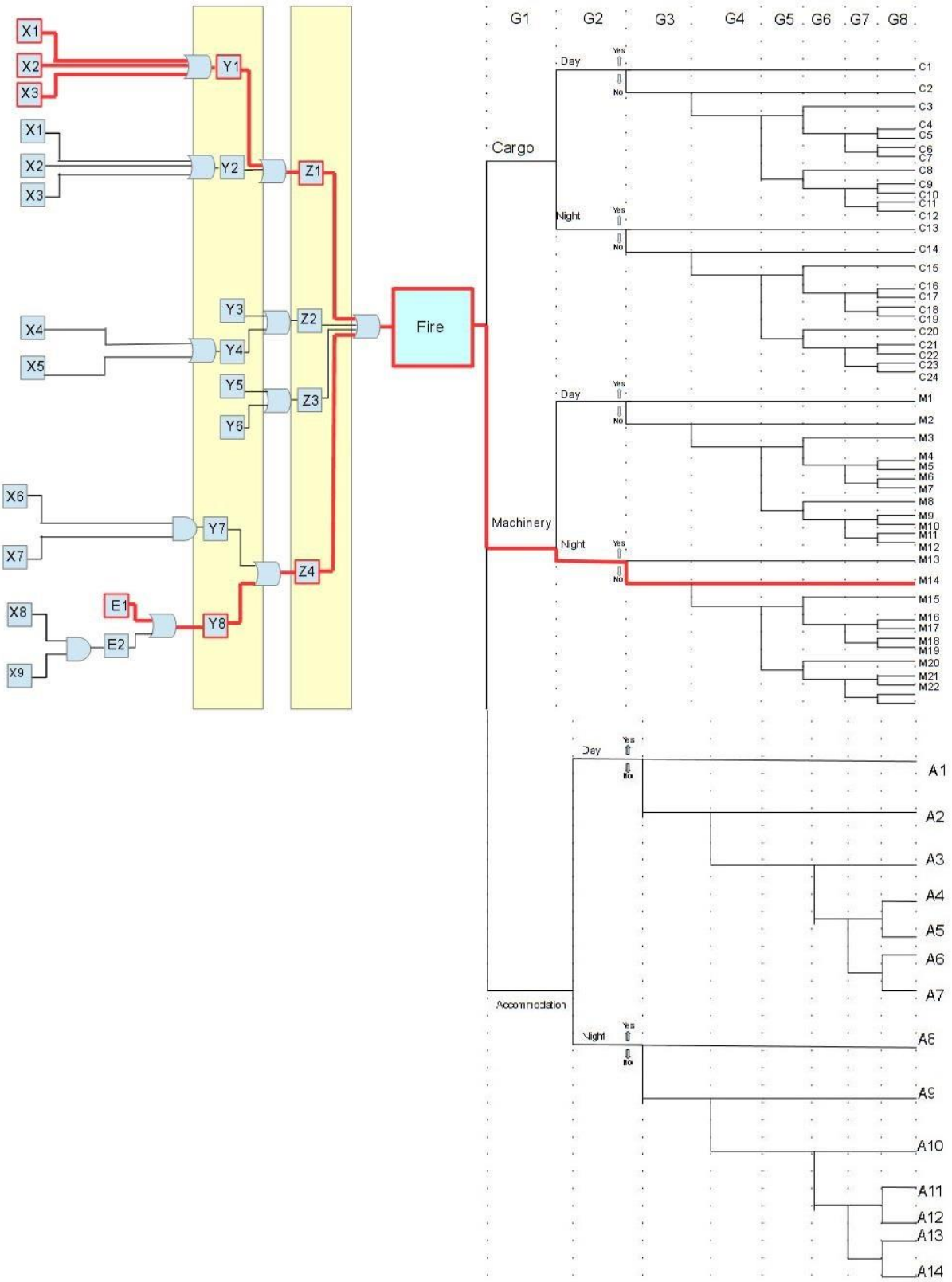

Figure 7.3 – Representation on bow tie diagram of Baltimar Boreas accident

On 9 February, the ship's fire detection system indicated a fire in the engine room. The second engineer investigated and found that the number three diesel generator was on fire. He raised the alarm and discharged a portable extinguisher towards the large fire before retreating. He stopped the engine room ventilation fans on his way out of the engine room.

The investigation identified a number of safety issues. Maintenance of the generator flexible fuel hoses was inadequate, inappropriate temporary repairs had been made and hoses longer than those specified by the generator manufacturer had been used. The poor condition of a number of fuel hoses due to long term wear had not been noted during surveys, audits and inspections in the past. Neither the generator manufacturer's instruction book nor the ship's safety management system provided guidance for the maintenance or replacement of the hoses.

Furthermore, the designed arrangement of the generator flexible fuel hoses was not in accordance with International Maritime Organization guidelines. A number of hoses were not as short as practicable and their use was not limited to only those positions or locations where it was necessary to accommodate relative movement between engine components.[54]

Table 7.3 – Components in bow tie diagram of Baltimar Boreas accident

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
E1	Violation of International Maritime Organization guidelines
Y1	Corrosion of fuel hoses
Y8	Inappropriate actions
Z1	Leakage
Z4	Operational errors
Top event	Fire
G1	Engine room
G2	Night
G3	Automatic firefighting failure
G4	Manual firefighting
M14	Electrical system badly damaged/ No injuries

7.5 Accident of CMS HANJIN LONDON on 10 July 2006

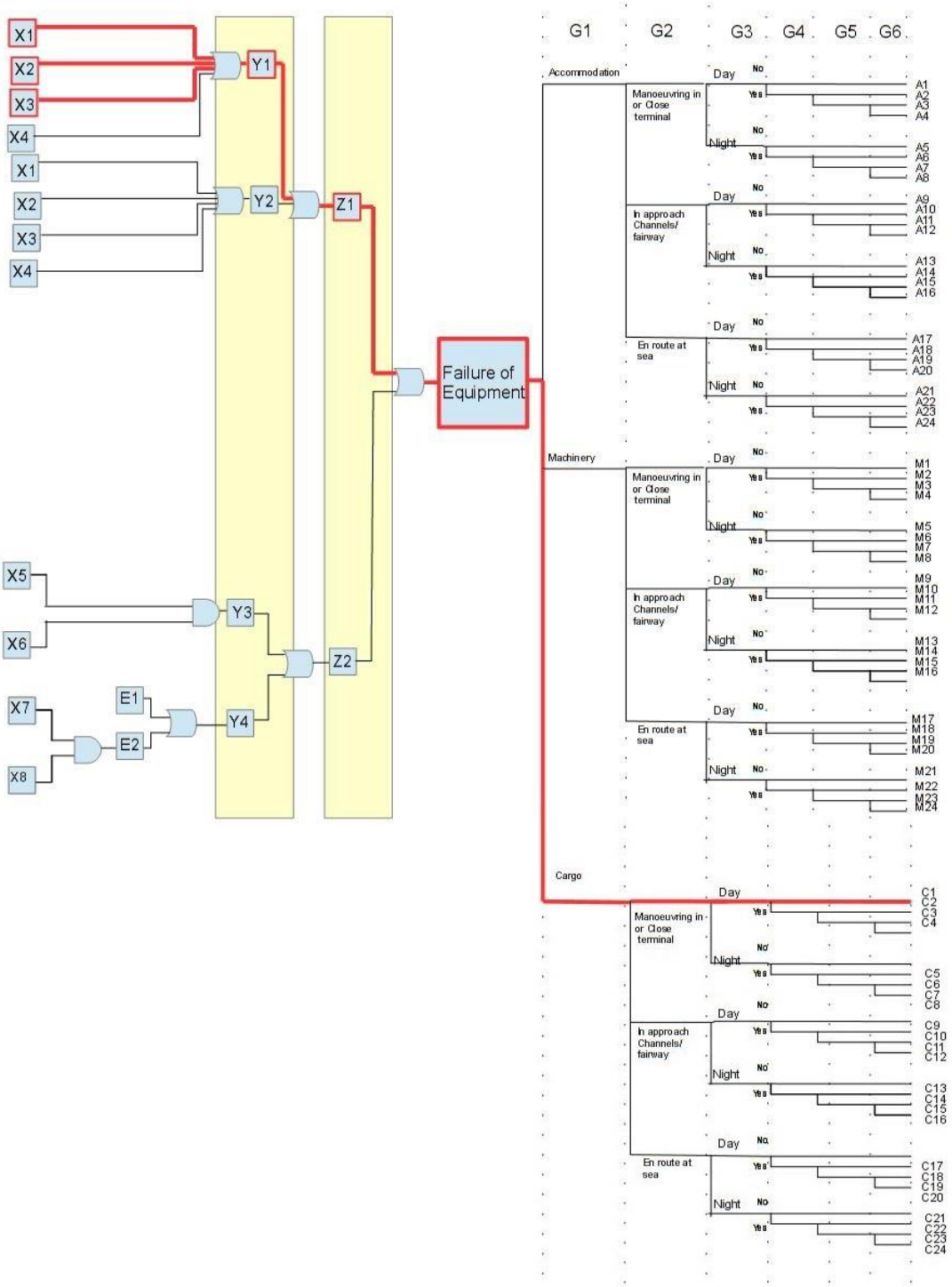

Figure 7.4 – Representation on bow tie diagram of CMS HANJIN LONDON accident

On 10 July 2006, at Predohikai 1 berth in the port of Hamburg on board the container vessel HANJIN LONDON a spillage of 40 to 100 kg harmful substances occurred from a tank container. These substances were titanium dioxide and hydrochloric acid. [55]

Table 7.4 – Components in bow tie diagram of CMS HANJIN LONDON accident

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion of tank
Z1	Broken off equipment
Top event	Failure of tank
G1	Cargo
G2	In terminal
G3	Day
C1	8 injured persons

7.6 Structural failure of MSC Napoli on 18 January 2007

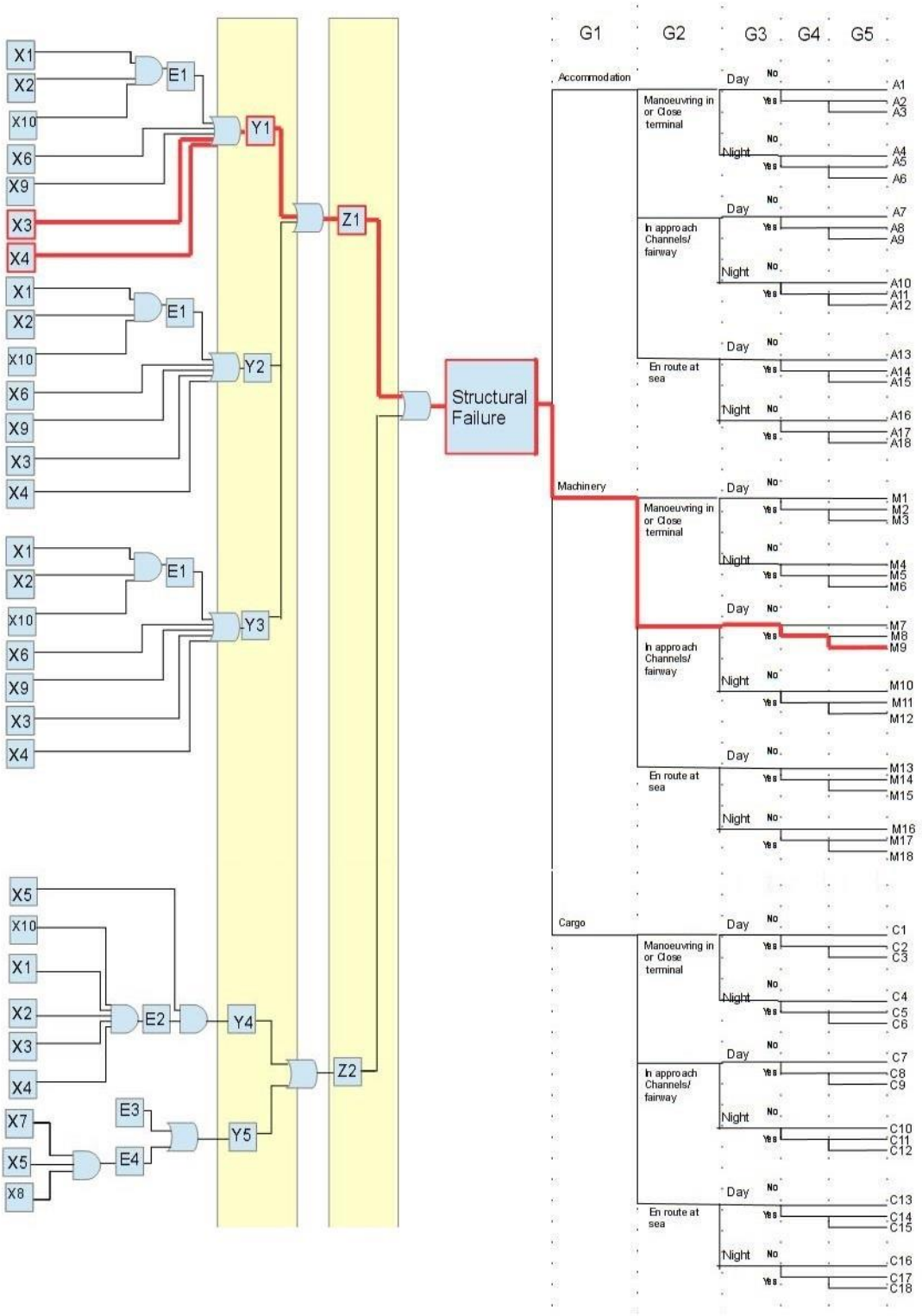

Figure 7.5 – Representation on bow tie diagram of MSC Napoli accident

When on passage in the English Channel, the 4419 TEU container ship *MSC Napoli* encountered heavy seas, causing the ship to pitch heavily. The ship was making good at speed of 11 knots and the height of the waves was up to 9m. At about 1105, the vessel suffered a catastrophic failure of her hull in way of her engine room. The master quickly assessed the seriousness of the situation and decided to abandon ship. Following the broadcast of a distress call at 1125, the 26 crew abandoned the vessel in an enclosed lifeboat.

The requirement to report structural damage, including fatigue cracking and weld repairs on main structural members, to classification societies was either not fully understood or was occasionally overlooked. [56]

Table 7.5 – Components in bow tie diagram of MSC Napoli accident

X3	Poor maintenance of engine room
X4	Poor inspection of engine room
I2	Inattention of the condition of engine room
Y2	Corrosion
Z1	Poor condition of engine room
Top event	Structural Failure
G1	Engine room
G2	On passage in a channel
G3	Day
G4	Flooding/ Catastrophic failure
G5	Loss of water tightness
M9	Loss of vessel/ No fatalities

7.7Accident on MV DRESDEN EXPRESS on 26 October 2003

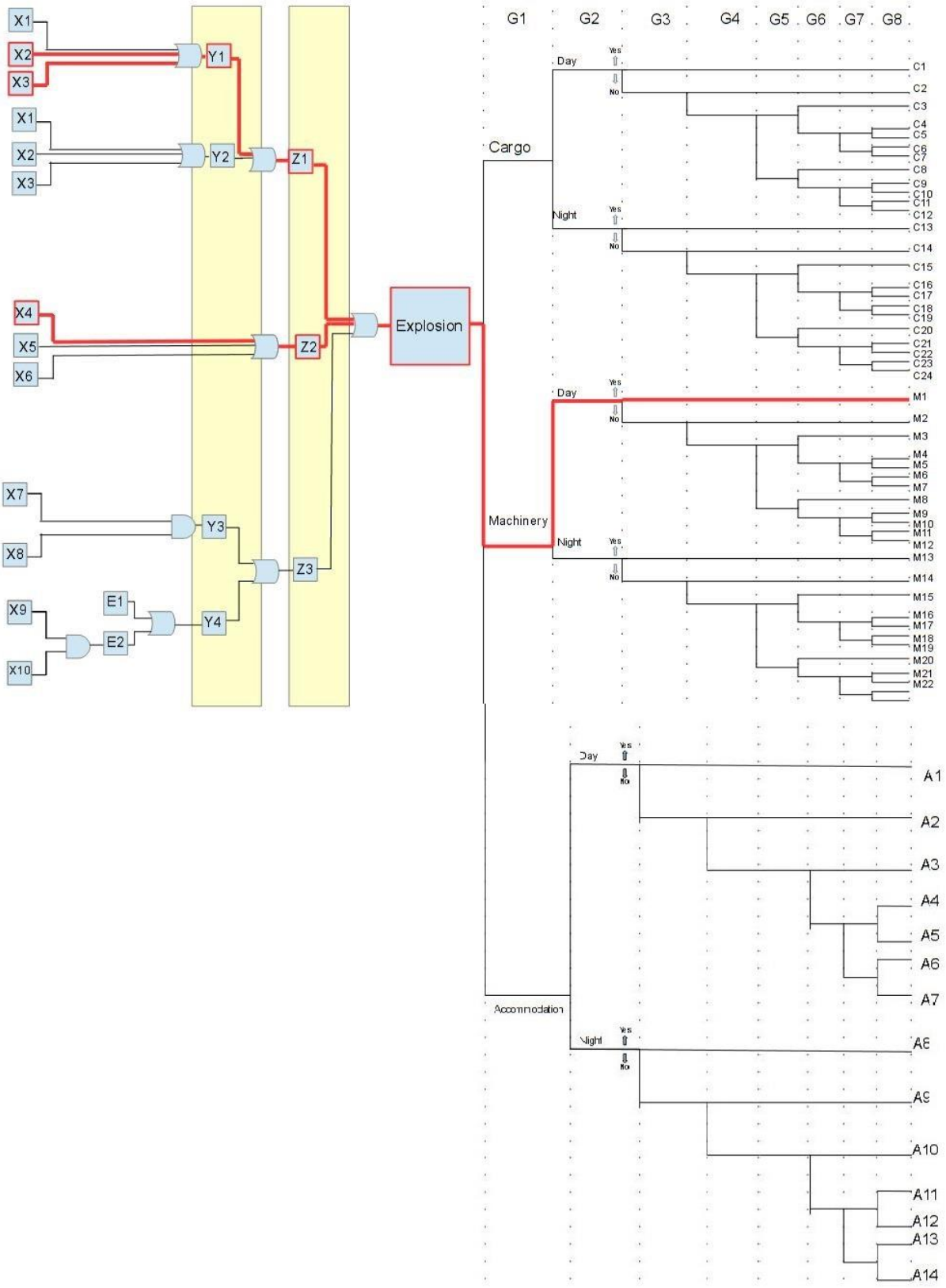

Figure 7.6 – Representation on bow tie diagram of MV DRESDEN EXPRESS accident

On 26 October 2003 MV DRESDEN EXPRESS was on sea passage from Oakland to Yokohama. There was an explosion in the area of the welding workplace in the vessel's engine room workshop. A Philippine engine fitter who was carrying out welding work died afterwards.[57]

Table 7.6 – Components in bow tie diagram of MV DRESDEN EXPRESS accident

X2	Poor maintenance
X3	Poor inspection
X4	Incautious practice of metalworking
Y1	Corrosion
Z1	Leakage of explosive materials
Z2	Sparks
Top event	Explosion
G1	Engine room
G2	Day
M1	No fire/ no extended damage to engine room/ One fatality

7.8 Accident of Ben-My-Chree during loading operations at Heysham on 26 March 2010

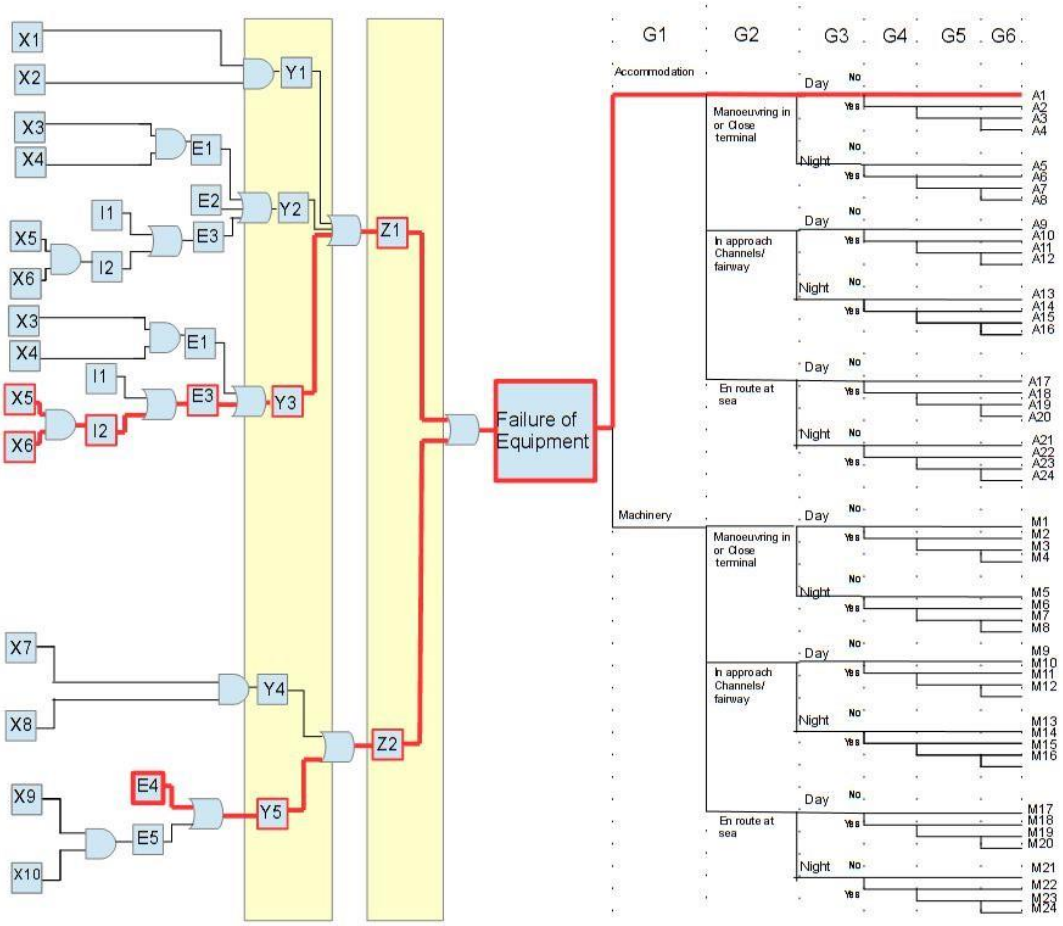

Figure 7.7 – Representation on bow tie diagram of Ben-My-Chree accident

On 26 March 2010, while embarking passengers and loading vehicles at Heysham, England, the ro-ro passenger *Ben-My-Chree* moved approximately 8m along the uayside, causing serious damage to the passenger access structure. The foot-passenger walkway detached at both ends and collapsed onto the quayside, and the gangway detached from the vessel's side shell door and was left hanging on a single rope. Fortunately, there were no injuries. Eight passengers were trapped in the gangway compartment of the shorestructure and were later rescued by the local fire service.

A number of weaknesses were evident in the passenger access structure, including:

10. The quay on which the structure was built had suffered considerable settlement over the years;
11. The walkway was secured to the rest of the structure with only two small bolts at either end, and;
12. There were no records of inspections or maintenance work carried out on the structure.

Also, the SMS made references to pitch recording paper rolls which did not exist on board.[58]

Table 7.7 – Components in bow tie diagram of Ben-My-Chree accident

X5	Poor maintenance
X6	Poor inspection
I2	Inattentions
E3	Poor condition of the equipment
E4	Violation of regulations(SMS)
Y1	Cracks
Y5	Inappropriate actions
Z1	Broken off equipment
Z2	Operational errors
Top event	Failure of passenger access structure
G1	Accommodation
G2	In terminal
G3	Day
A1	Ship's shell door frame buckled and shore side passenger access structure collapsed

7.9 Fire onboard the ro-ro passenger ferry Sea Wind on 2 December 2008

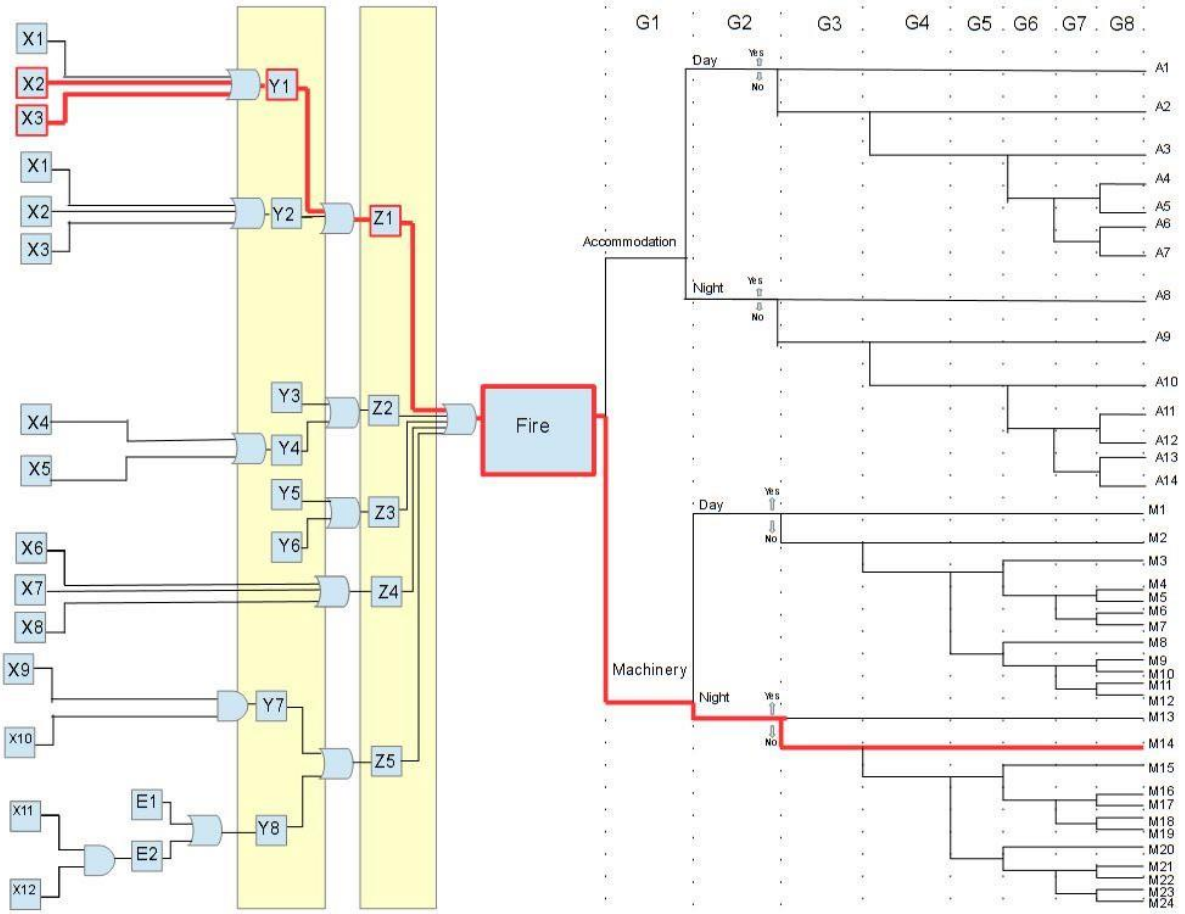

Figure 7.8 – Representation on bow tie diagram of Sea Wind accident

Ro-ro passenger ferry Sea Wind departed from Åbo for Stockholm at 20.00 on 1 December 2008 in accordance with its regular timetable. The journey progressed normally and in calm weather. There were 28 crew members and 11 passengers on board. The bridge was manned by a duty officer and a watchkeeper, and the engine department was manned by a duty 2nd engineer and a motorman. All four main engines (ME) were in use for the ships propulsion and the electrical power came from the main switch board which was supplied by the port shaft generator.

The time was 01.29 in the morning and *Sea Wind* had just left the archipelago of Åland and was heading in the open sea. The 2nd engineer on duty was in the engine control room when a violent fire broke out in the area between ME1 and ME2 in the adjacent engine room. At the same time the fire alarm for the engine department went off on the bridge.

The investigation showed that the fire onboard *Sea Wind* was caused by oil from the fuel oil system either spurting out or spraying from a broken pipe onto hot surfaces of the main engine No. 1

Contributing to the outbreak of the fire was that the crew had not noticed and repaired the loose gauge. The classification society and national maritime administration had also approved the vessel without ensuring that the low pressure section of the fuel oil system was screened off, which was a SOLAS-requirement. It is also possible that the thermal

insulation on and around the main engine No. 1 was inadequately checked. [59]

Table 7.8 – Components in bow tie diagram of Sea Wind accident

X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Leakage of fuel oil
Top event	Fire
G1	Engine room
G2	Night
G3	Automatic firefighting failure
G4	Manual firefighting
M14	Extensive damage to the engine room

7.10 Rapture of the port economiser on board Island Princess on 7 December 1997

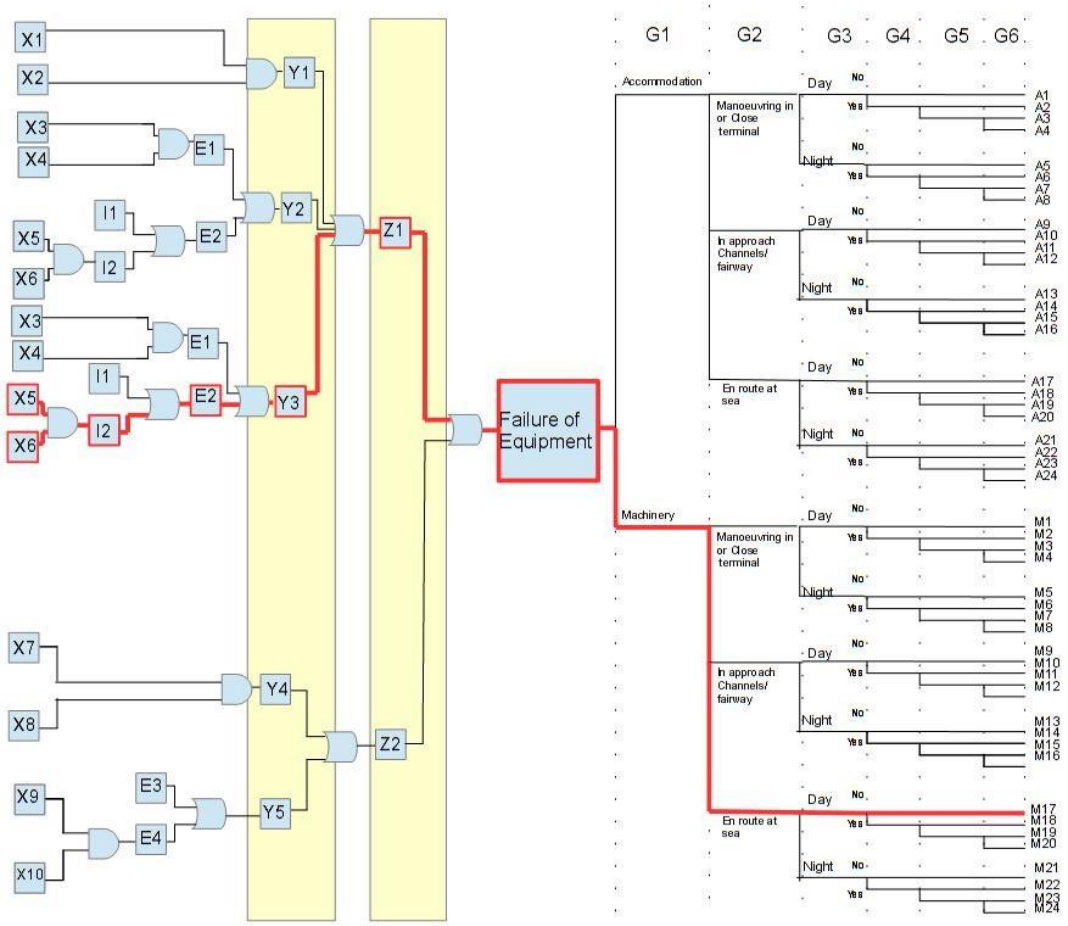

Figure 7.9 – Representation on bow tie diagram of Island Princess accident

The port gas boiler of the UK registered Princess Cruises liner Island Princess ruptured killing two people and injuring three others during sea trials in the Bay of Naples on 7 December 1997. No passengers were on board.

The investigation found spindlers had seized in their guides/ due to corrosion products at the spindle/guide interface. Poor quality boiler water and leaking safety valves created the conditions that weakened the spindles corrosion resistance.

The investigation revealed a previous history of that kind of safety that demanded particular care and attention when inspecting and maintaining. This need was not satisfied. [60]

Table 7.9 – Components in bow tie diagram of Island Princess accident

X5	Poor maintenance
X6	Poor inspection
I2	Inattentions
E2	Poor condition of the equipment
Y3	Cracking

Z1	Broken off equipment
Top event	Failure of port gas boiler
G1	Engine room
G2	En route
G3	Day
M17	2 fatalities/ 3 injuries

7.11 Accident of RMS Queen Mary 2 on 23 September 2010

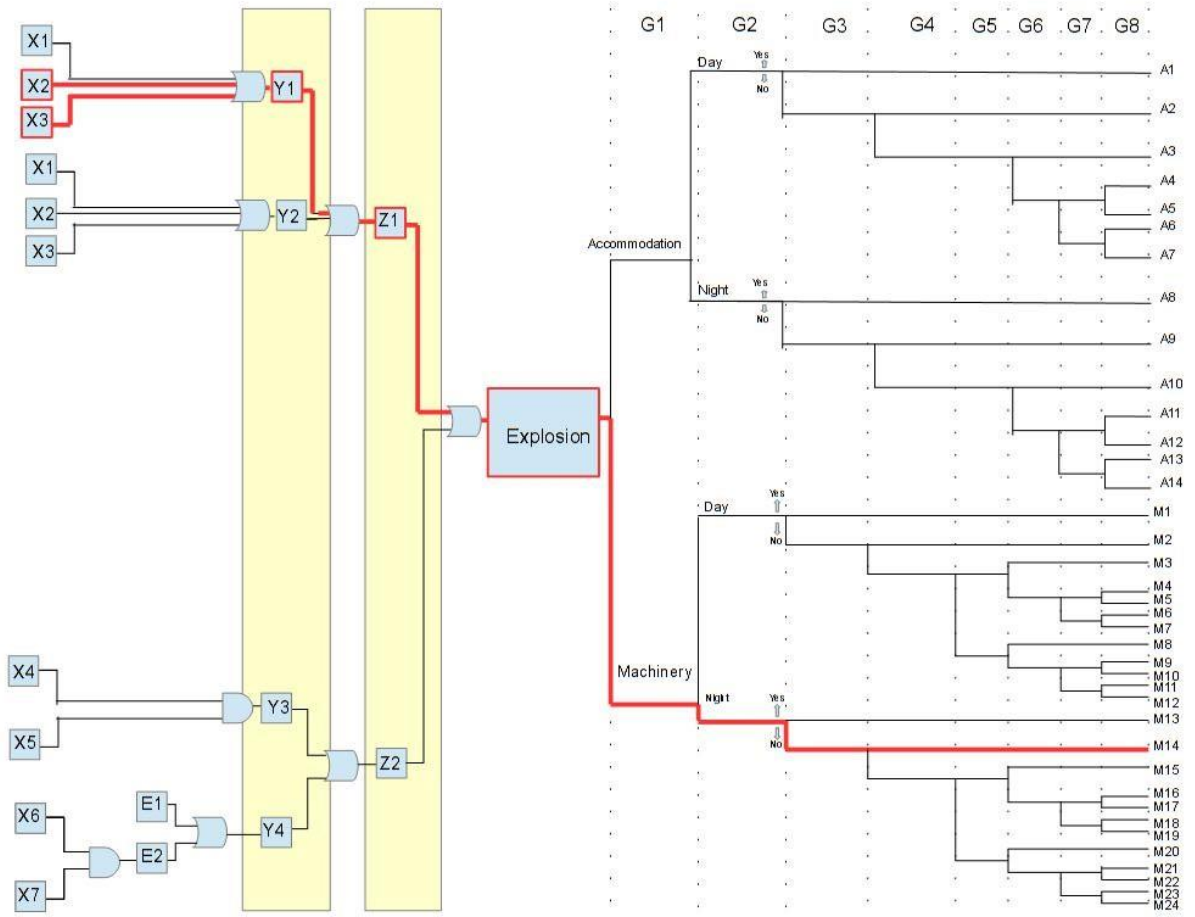

Figure 7.10 – Representation on bow tie diagram of RMS Queen Mary 2 accident

At 0425 on 23 September 2010, as *RMS Queen Mary 2* (*QM2*) was approaching Barcelona, an explosion occurred in the vessel's aft main switchboard room. Within a few seconds, all four propulsion motors shut down, and the vessel blacked out shortly afterwards. Fortunately, the vessel was clear of navigational hazards and drifted in open sea.

The explosion was triggered by deterioration in the capacitors in the aft HF. Dielectric fluid vapor sprayed out, igniting and creating the likely conditions for an arc-flash to occur between the 11000 volt bus bars that fed power to the aft HF. A current imbalance detection system, which was the only means to warn against capacitor deterioration, was

found to be inoperable, and it was evident that it had not worked for several years.[61]

Table 7.10 – Components in bow tie diagram of RMS Queen Mary 2 accident

X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Dielectric fluid vapour sprayed out
Top event	Fire
G1	Engine room
G2	Night
G3	Automatic firefighting failure
G4	Manual firefighting
M14	Two capacitors damaged, bus bars and insulators on several others damaged, bulkhead stiffeners buckled, enclosure panel doors blown out, steel doors damaged.

8. Accident scenarios

In the following section, some accidents scenarios will be presented using bow tie diagrams. The purpose of this presentation is to show how easily any accident scenario can be studied using bow ties and how random scenarios can be displayed in order to help risk management.
This can be a very useful tool if for those who want to generate scenarios and measure different probabilities and frequencies of different hazards, and their consequences.

8.1 Failure of equipment scenario of general cargo ship

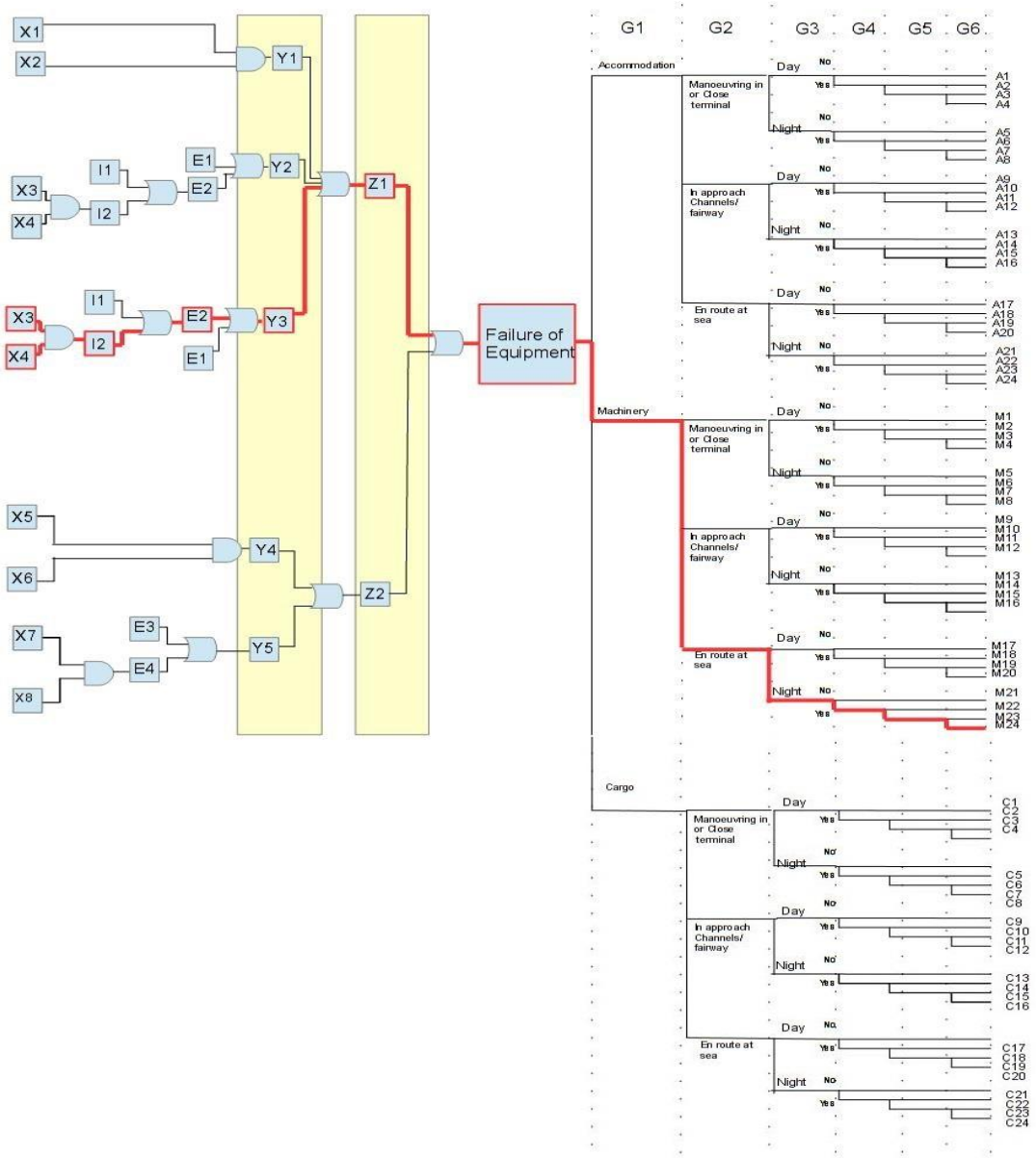

Figure 8.1 - Failure of equipment scenario of general cargo ship

This scenario represents a failure of equipment accident of general cargo vessel that happened in machinery space when vessel was en route operational state at nighttime. The initiating events was poor inspection and poor maintenance that leaded to cracks of the considered equipment.

Table 8.1 *– Failure of equipment scenario of general cargo ship*

X3	Poor maintenance
X4	Poor inspection
I2	Inattentions
E2	Poor condition of equipment
Y2	Corrosion
Z1	Broken off equipment
Top event	Failure of equipment
G1	Machinery space
G2	En route
G3	Night
G4	Consequent accident
G5	Damage to structure
G6	Loss of water tightness
M18	Worst case scenario

8.2 Failure of equipment scenario of container ship

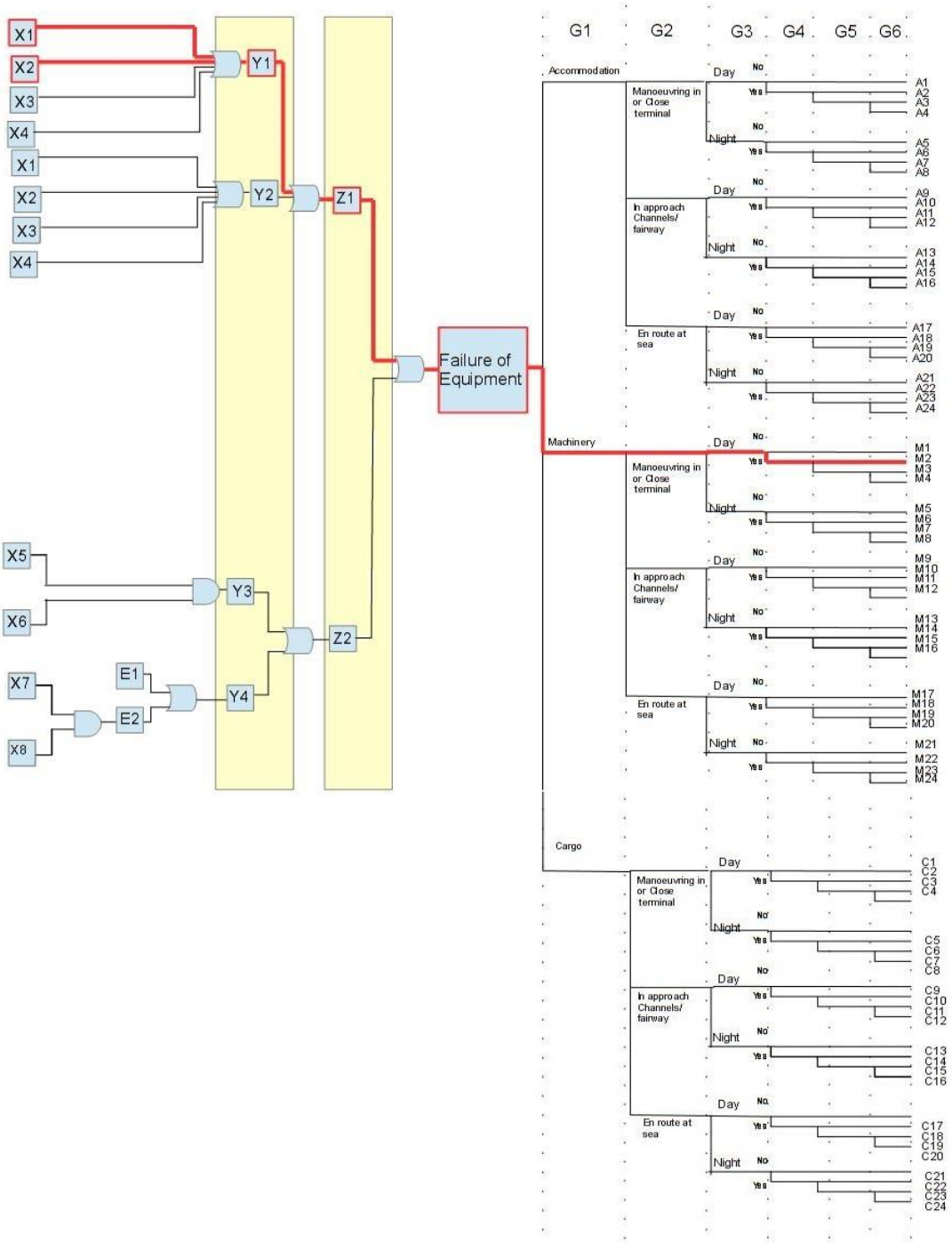

Figure 8.2- Failure of equipment scenario of container ship

This scenario represents a failure of equipment accident of container vessel that happened in machinery space when vessel was close to a terminal at daytime. The initiating events was poor inspection and poor maintenance that leaded to corrosion of the considered equipment.

Table 8.2 *– Failure of equipment scenario of container ship*

X1	Poor maintenance
Y1	Corrosion
Z1	Broken off equipment
Top event	Failure of equipment
G1	Machinery space
G2	Close to a terminal
G3	Day
G4	Consequent accident
M2	Extended damage to machinery/ Possible injuries

8.3 Failure of equipment scenario of passenger ship

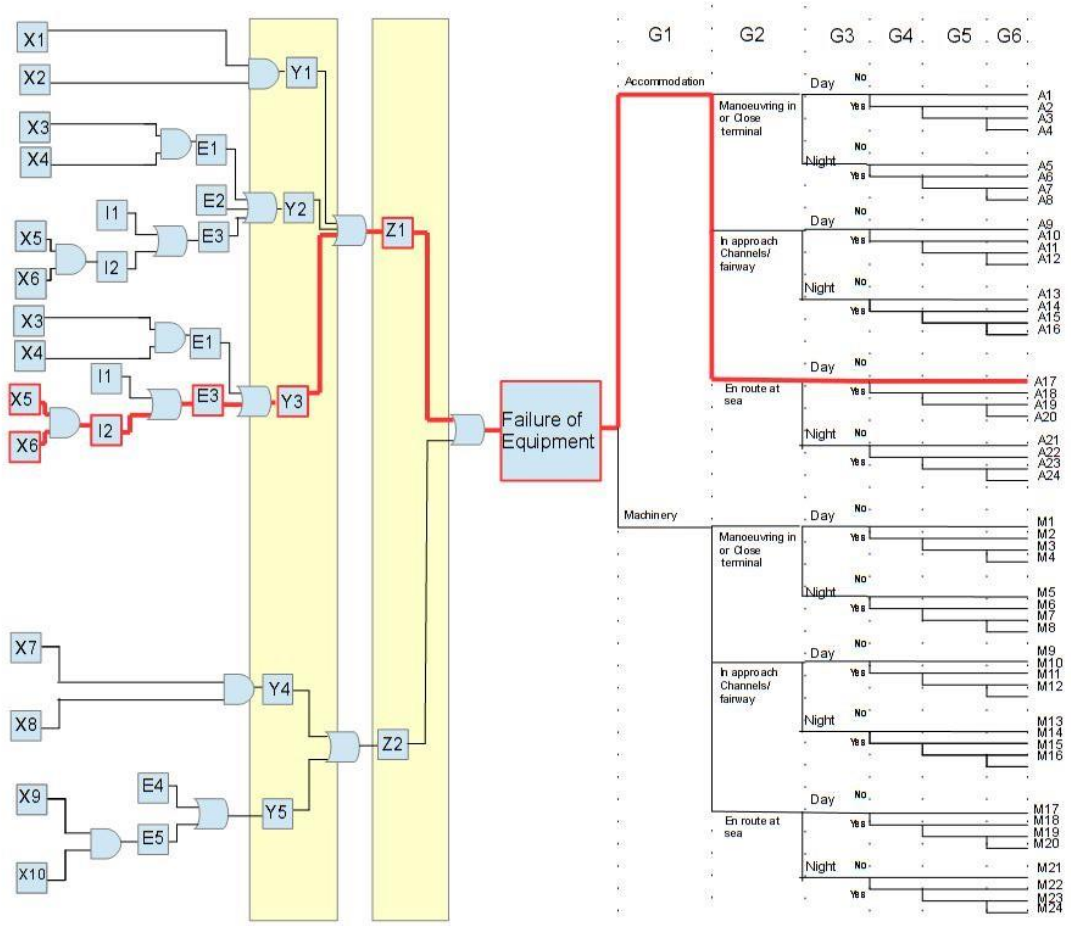

Figure 8.3- Failure of equipment scenario of passenger ship

This scenario represents a failure of equipment accident of passenger vessel that happened in accommodation space when vessel was en route operational state at

daytime. The initiating events was poor inspection and poor maintenance that leaded to cracks of the considered equipment.

Table 8.3 *– Failure of equipment scenario of passenger ship*

X5	Poor maintenance
X6	Poor inspection
I2	Inattentions
E2	Poor condition of equipment
Y3	Cracking
Z1	Broken off equipment
Top event	Failure of equipment
G1	Accommodation space
G2	En route
G3	Day
G4	No consequent accident
A17	Minor repairable damage to accommodation/ Possible injuries

8.4 Failure of equipment scenario of cruise ship

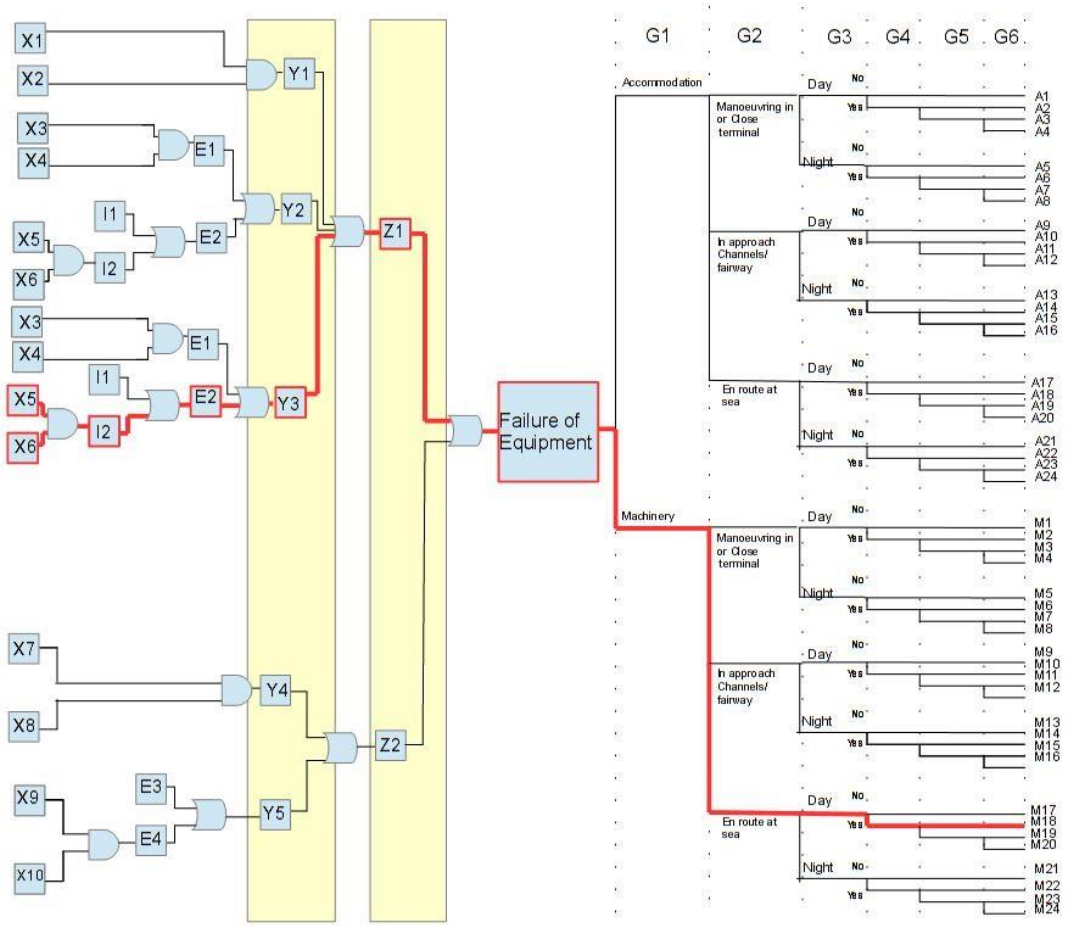

Figure 8.4 - Failure of equipment scenario of cruise ship

This scenario represents a failure of equipment accident of cruise vessel that happened in machinery space when vessel was en route operational state at daytime. The initiating events was poor inspection and poor maintenance that leaded to cracks of the considered equipment.

Table 8.4 *– Failure of equipment scenario of cruise ship*

X5	Poor maintenance
X6	Poor inspection
I2	Inattentions
E2	Poor condition of equipment
Y3	Cracking
Z1	Broken off equipment
Top event	Failure of equipment
G1	Machinery space
G2	En route
G3	Day

G4	Consequent accident
M18	Extended damage to machinery/ Possible injuries

8.5 Fire scenario of passenger ship

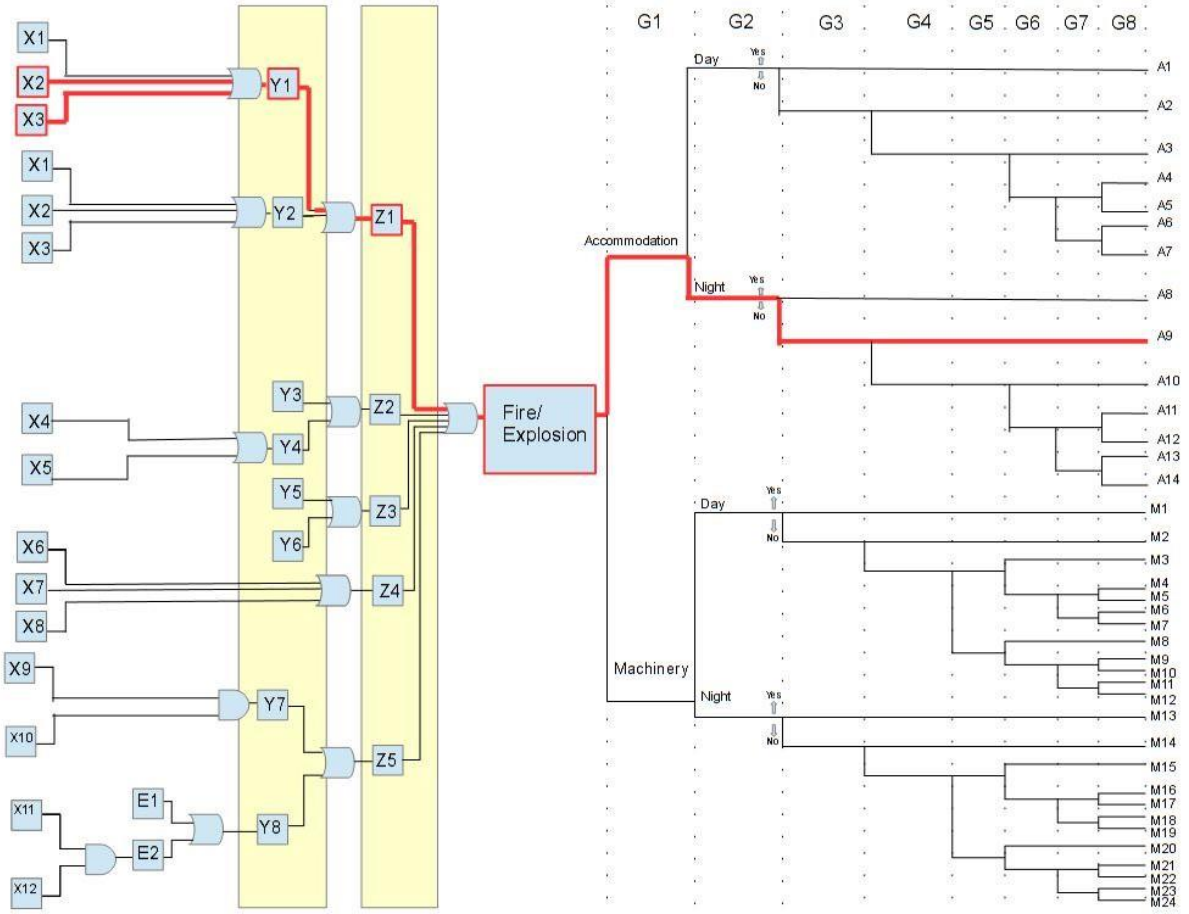

Figure 8.5- Fire scenario of passenger ship

This scenario represents a fire accident of passenger vessel that happened in accommodation space at nighttime. The initiating events was poor inspection and poor maintenance that leaded to leakage due to corrosion.

Table 8.5 *– Fire scenario of passenger ship*

X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Leakage
Top event	Fire
G1	Accommodation space

G2	Night
G3	Automatic firefighting
G4	Manual firefighting
A9	Injuries/fatalities and damage to vessel

8.6 Fire scenario of general cargo ship

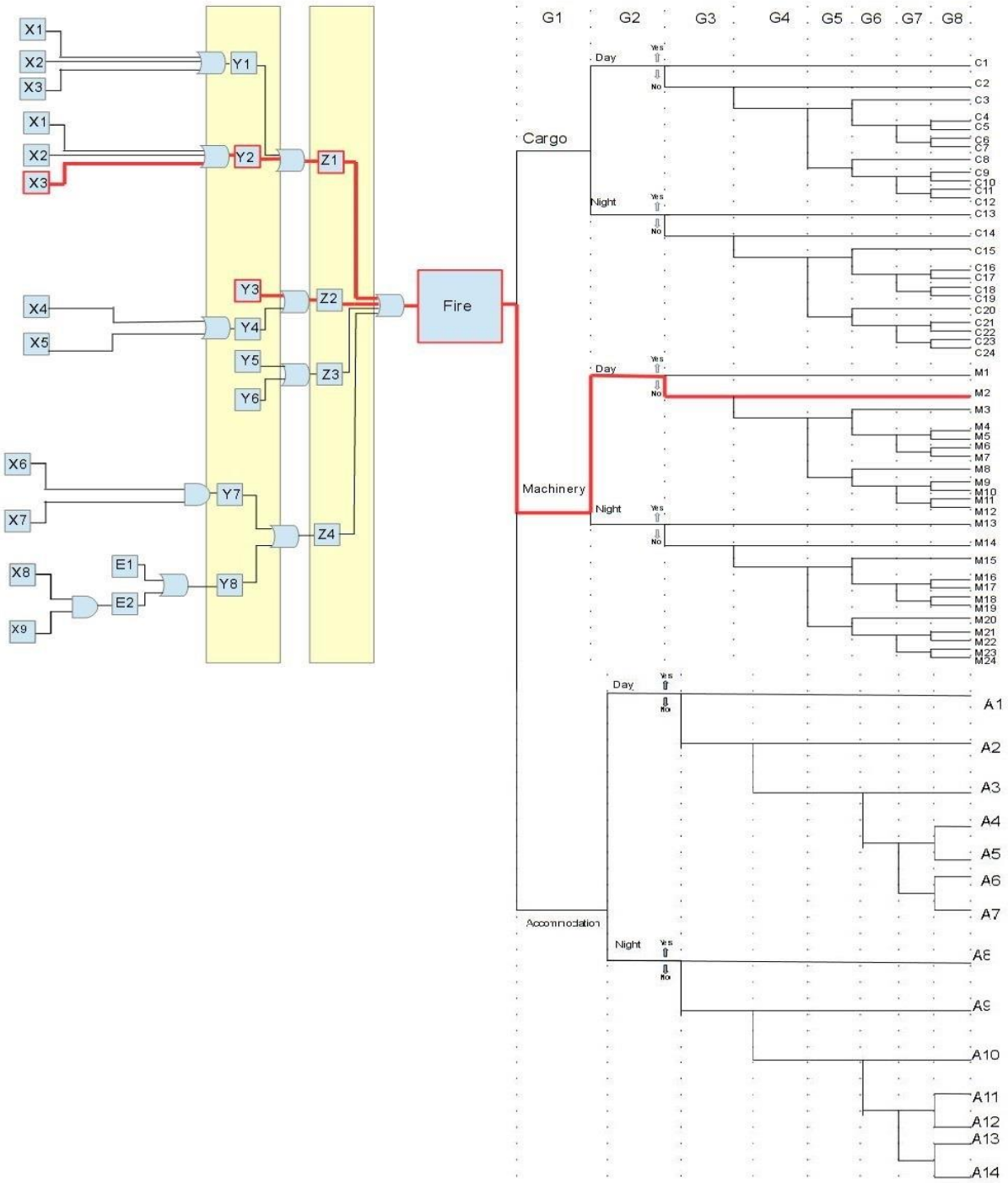

Figure 8.6 - Fire scenario of general cargo ship

This scenario represents a fire accident of general cargo vessel that happened in machinery space at day time. The initiating events was poor inspection and poor maintenance as well as overheated machine that leaded to leakage, due to corrosion, and inappropriate high temperatures.

Table 8.6 *– Fire scenario of general cargo ship*

X3	Poor inspection
Y2	Cracking
Y3	Overheating machine
Z1	Leakage
Z2	Inappropriate temperatures
Top event	Fire
G1	Machinery space
G2	Day
G3	Automatic firefighting
G4	Manual firefighting
M2	Extended damage to machinery/ Possible damage to vessel

8.7 Explosion scenario of container ship

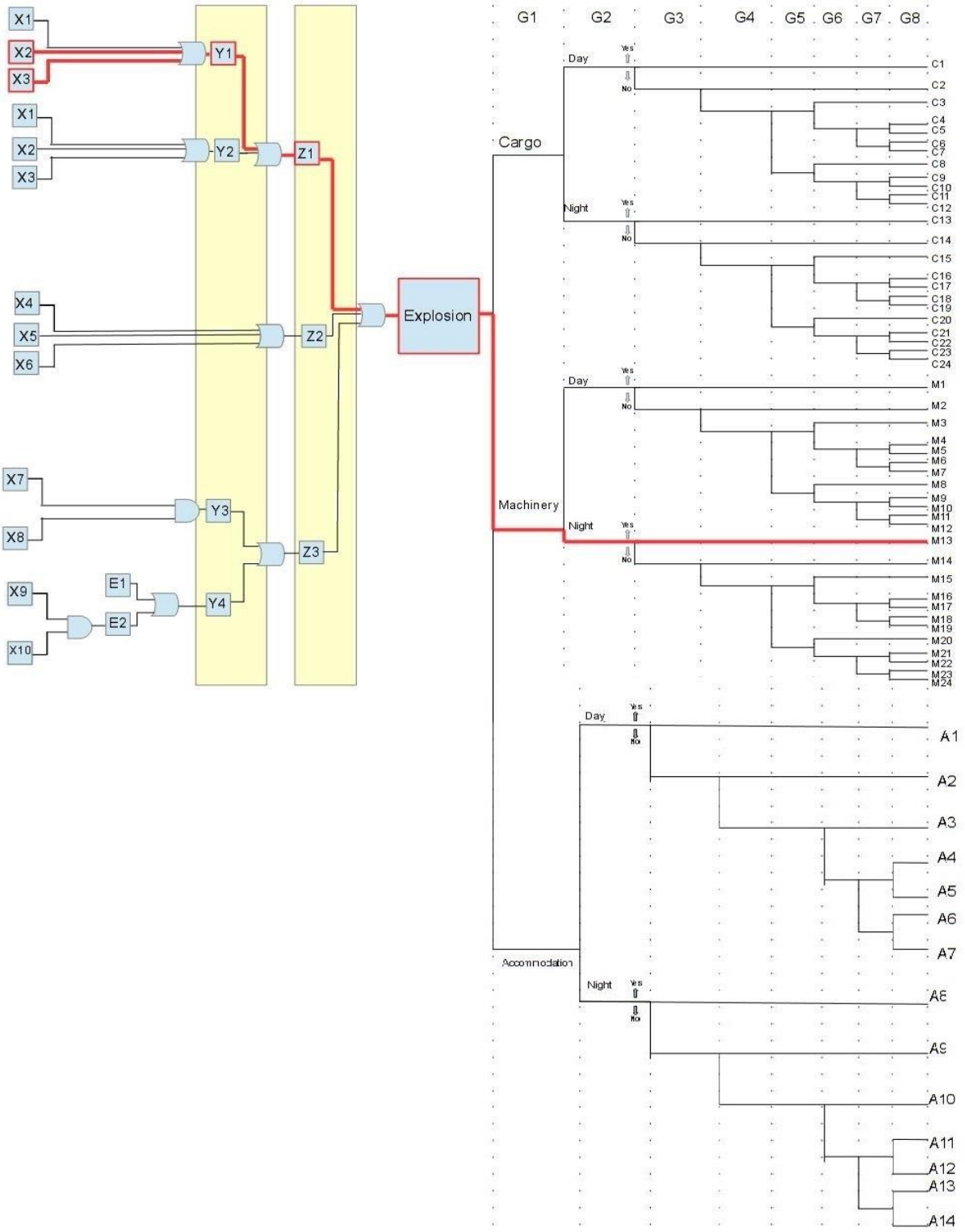

Figure 8.7- Explosion scenario of container ship

This scenario represents an explosion accident of container vessel that happened in machinery space at nighttime. The initiating events was poor inspection and poor maintenance that leaded to leakage due to cracking.

Table 8.7 *– Explosion scenario of container ship*

X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Leakage
Top event	Explosion
G1	Machinery space
G2	Night
G3	Automatic firefighting
M13	Minor damage to machinery

8.8 Explosion scenario of cruise ship

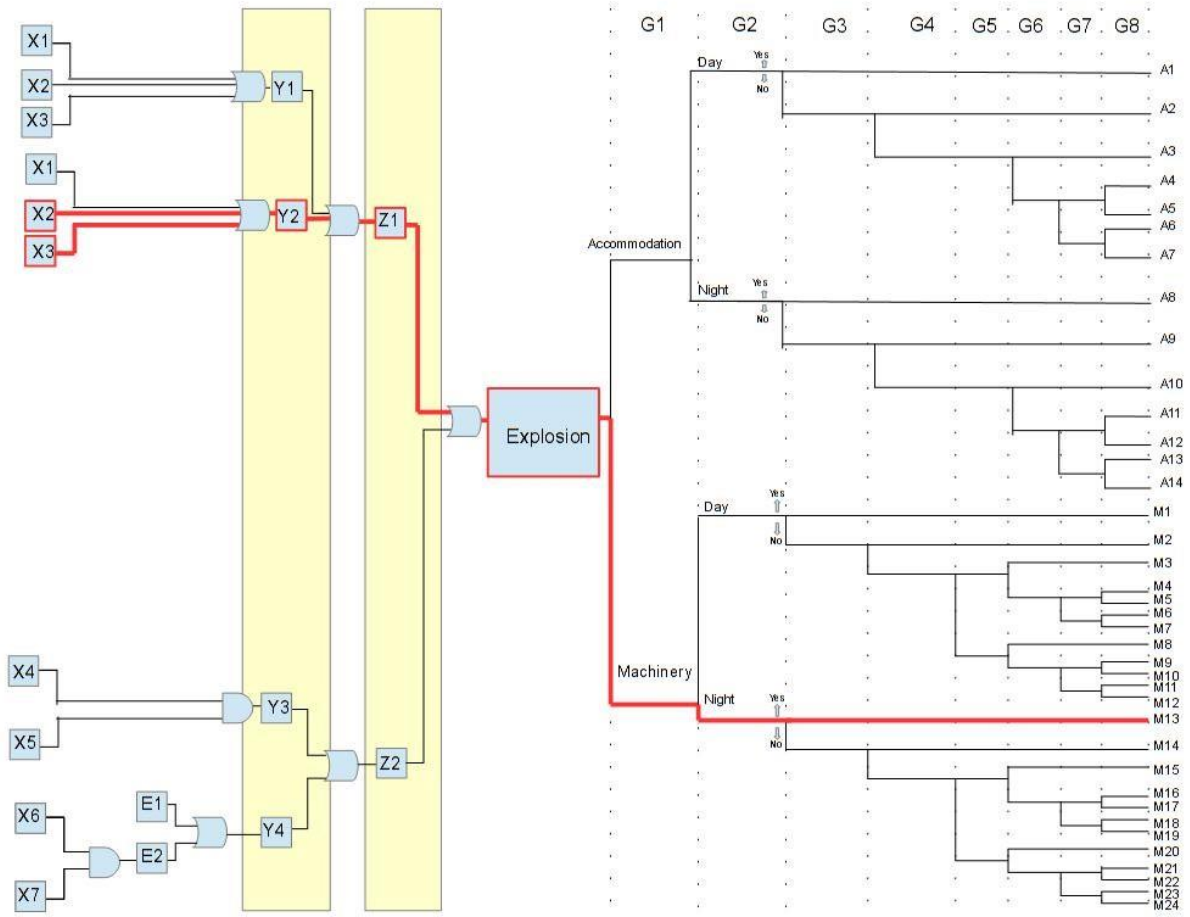

Figure 8.8 - Explosion scenario of cruise ship

This scenario represents an explosion accident of cruise vessel that happened in machinery space at nighttime. The initiating events was poor inspection and poor maintenance that leaded to leakage due to corrosion.

Table 8.8 *– Explosion scenario of cruise ship*

X2	Poor maintenance
X3	Poor inspection
Y2	Cracking
Z1	Leakage
Top event	Explosion
G1	Machinery space
G2	Night
G3	Automatic firefighting
M13	Minor damage to machinery

8.9 Structural failure scenario of container ship

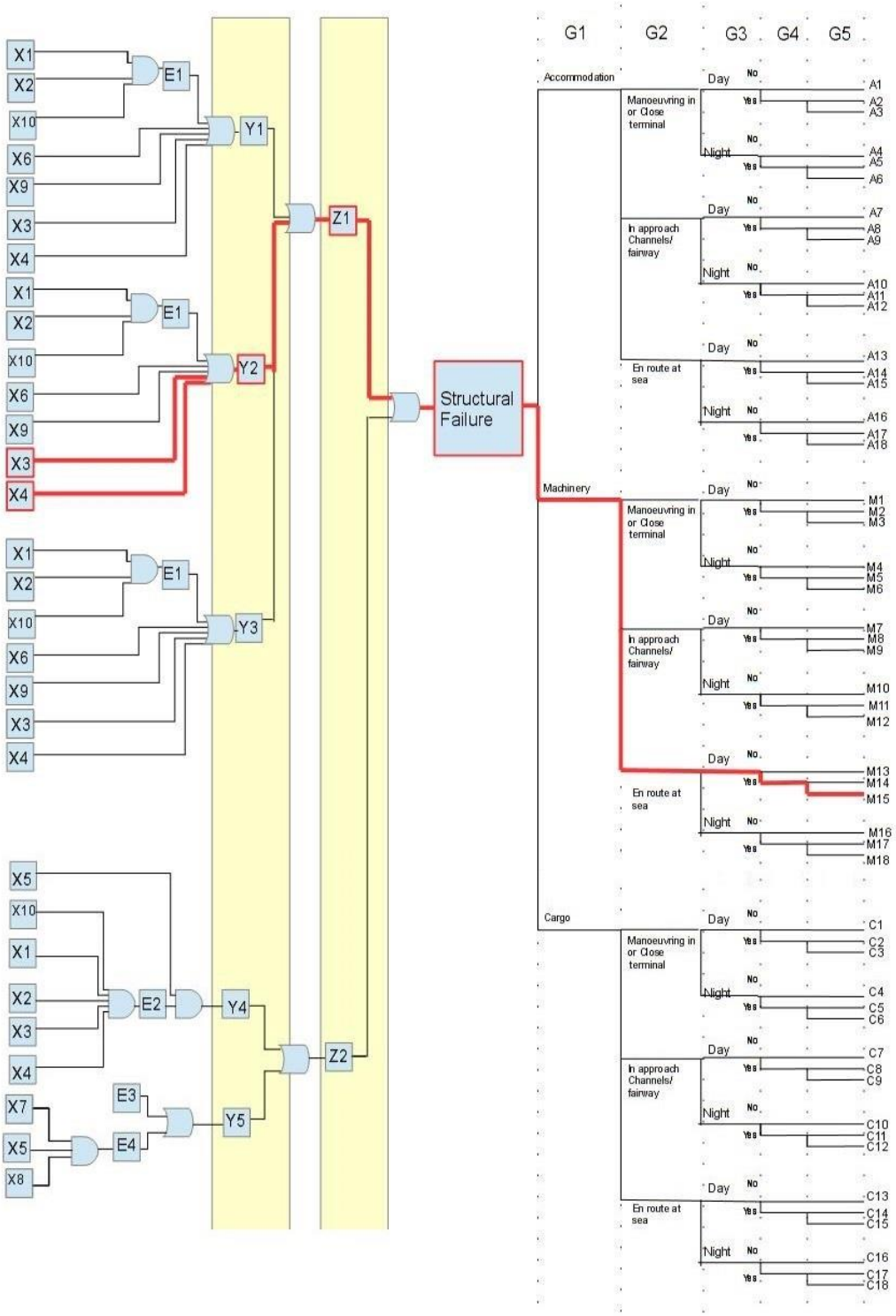

Figure 8.9 - Structural failure scenario of container ship

This scenario represents a structural failure accident of container vessel that happened in machinery space when vessel was en route operational state at daytime. The initiating events was poor inspection and poor maintenance that leaded to deformation of the structure.

Table 8.9 *– Structural failure scenario of container ship*

X3	Poor maintenance
X4	Poor inspection
Y2	Cracking
Z1	Poor condition of structure
Top event	Structural failure
G1	Machinery space
G2	En rout at sea
G3	Day
G4	Consequent accident
G5	Loss of water tightness
M15	Worst case

8.10 Structural failure scenario of general cargo ship

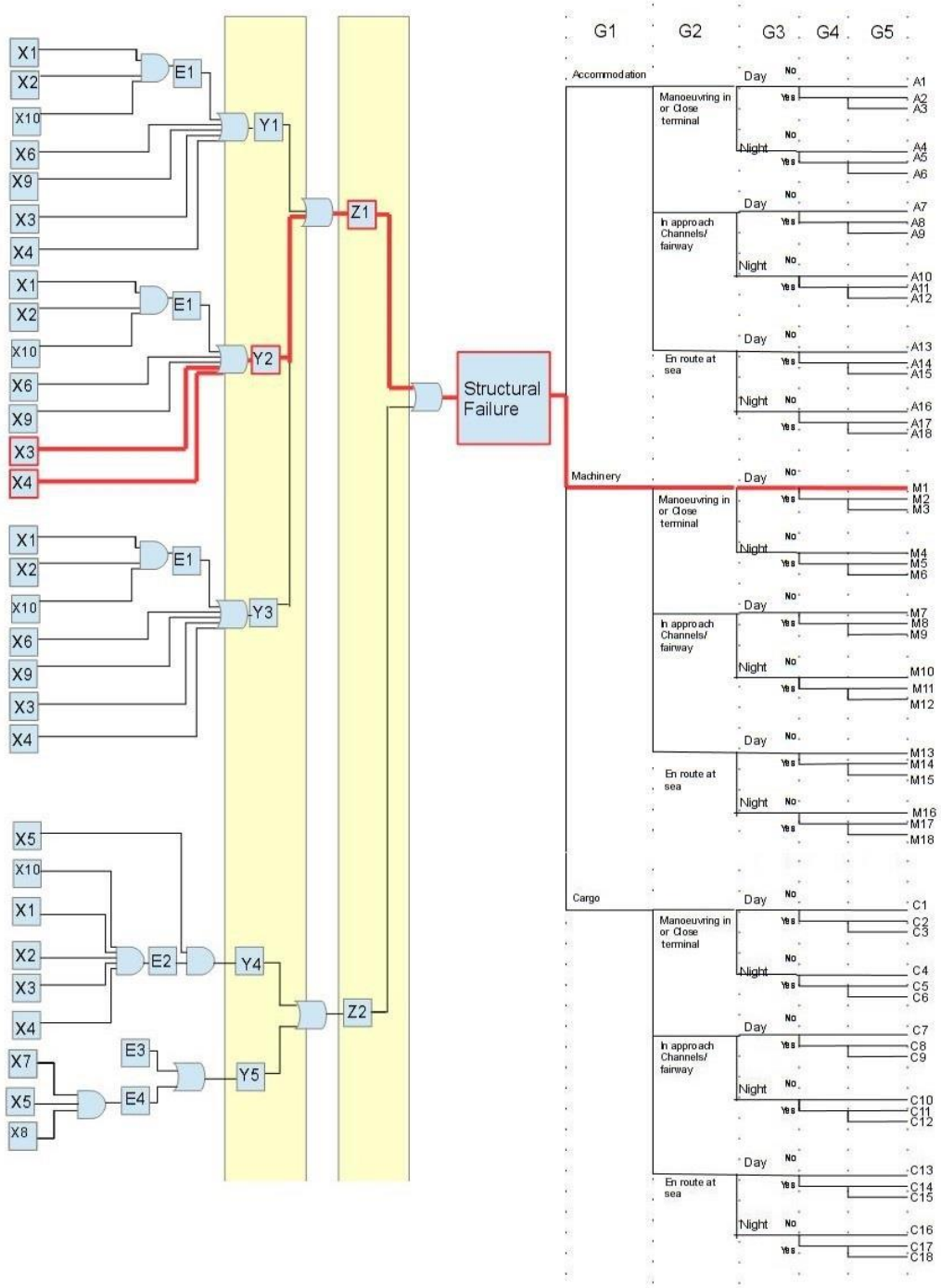

Figure 8.10 - Structural failure scenario of general cargo ship

This scenario represents a structural failure accident of general cargo vessel that happened in machinery space when vessel was close to a terminal at daytime. The initiating events was poor inspection and poor maintenance that leaded to deformation of the structure.

Table 8.10 *– Structural failure scenario of general cargo ship*

X3	Poor maintenance
X4	Poor inspection
Y2	Cracking
Z1	Poor condition of structure
Top event	Structural failure
G1	Machinery space
G2	Close to terminal
G3	Day
G4	No consequent accident
M1	Minor repairable damage to machinery

8.11 Structural failure scenario of LNG ship

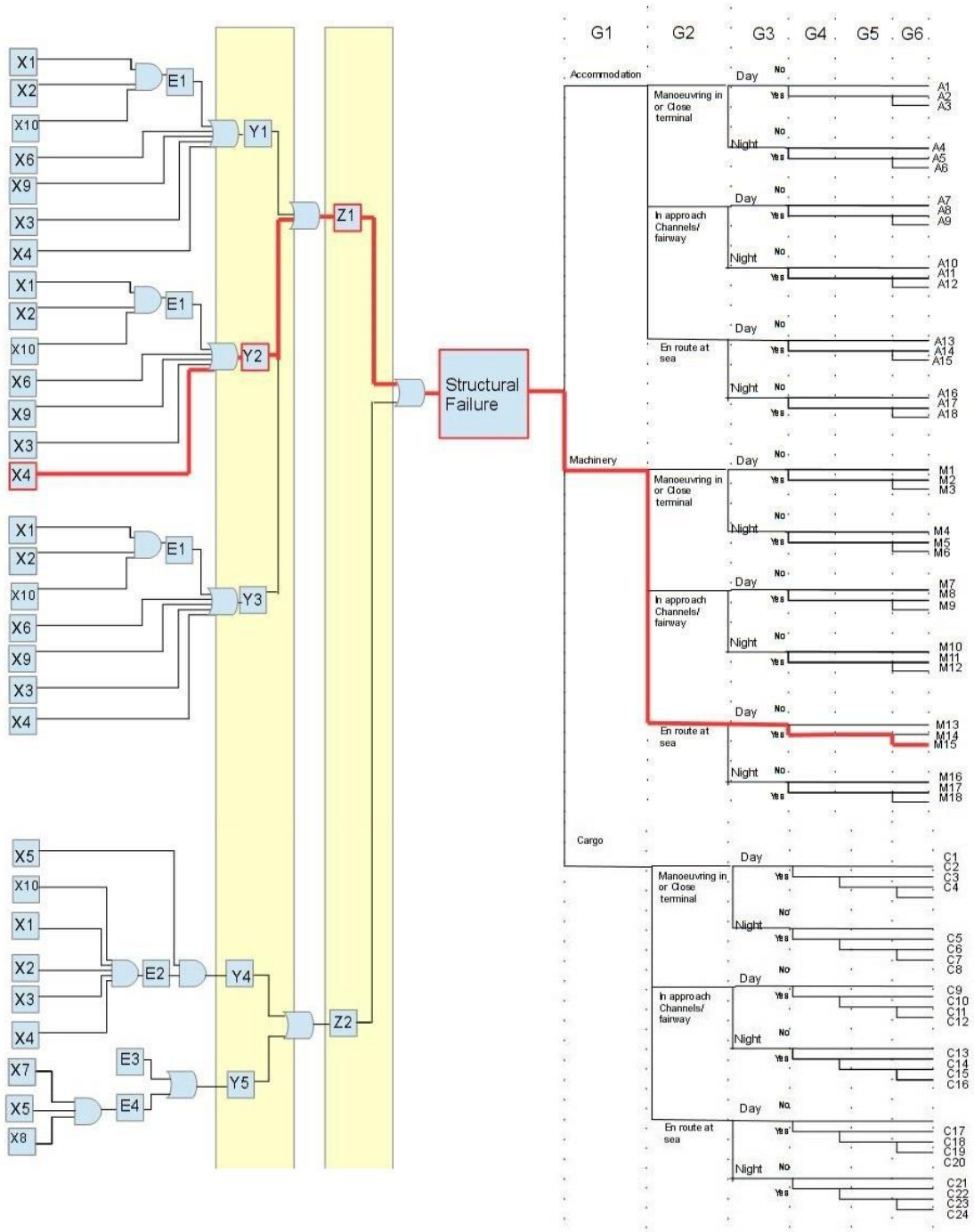

Figure 8.11 - Structural failure scenario of LNG ship

This scenario represents a structural failure accident of LNG vessel that happened in machinery space when vessel was en route operational state at daytime. The initiating events was poor inspection that leaded to deformation of the structure.

Table 8.11 – *Structural failure scenario of LNG ship*

X4	Poor inspection
Y2	Cracking
Z1	Poor condition of structure
Top event	Structural failure
G1	Machinery space
G2	En route at sea
G3	Day
G4	Consequent accident
G6	Loss of water tightness
M15	Worst case

8.12 Fire scenario of LNG ship

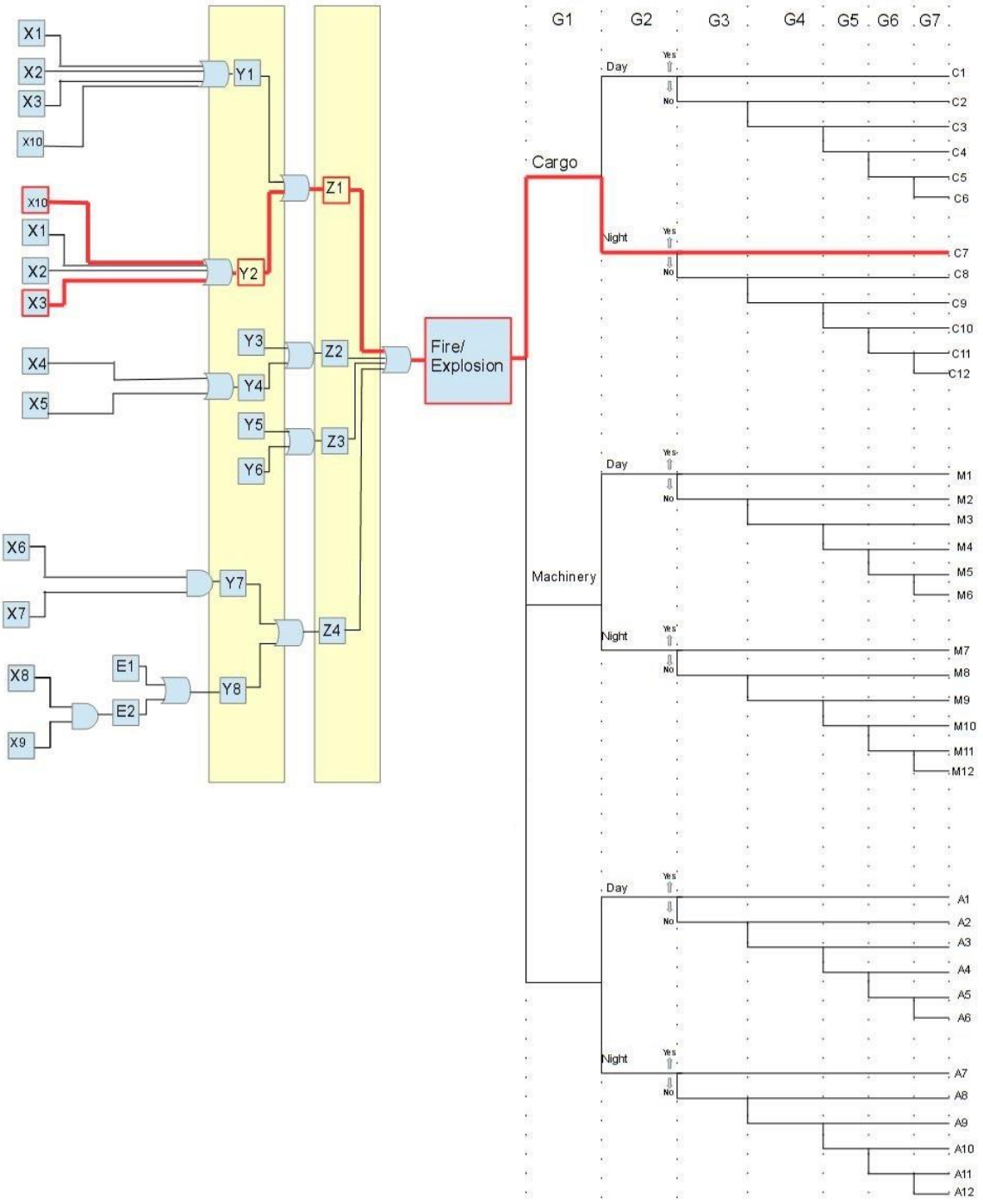

Figure 8.12 - Fire scenario of LNG ship

This scenario represents a fire accident of LNG vessel that happened in cargo area when at nighttime. The initiating events was poor inspection and sloshing of partially filled tanks that leaded to leakage due to corrosion.

Table 8.12 – *Fire scenario of LNG ship*

X3	Poor inspection
X10	Sloshing of partially filled tank
Y2	Cracking
Z1	Leakage
Top event	Fire
G1	Cargo space
G2	Night
G3	Automatic firefighting
C7	Damage to cargo area/Possible injuries

9. Conclusion

The aim of this thesis has been to contribute to the discussion about inspection mistakes accidents and their statistical as well as risk analysis. Each chapter has presented a facet of this analysis and has tried to show different variants that may involve in the occurrence of undesirble events within maritime operations.

In chapter 5, the statistical analysis of these accidents was presented as thourogly as possible. It has been obvious in this chapter that the most important categories of accidents were Failure of Equipment, Structural failure and Fire with vessels involved were mainly general cargo ,passenger vessels and container vessels. Furthermore, the highest levels of severity,according to IMO's index, are in structural failure accidents something that is clearly understandable due to the catastrophic nature of this type of failure in a vessel. Also, the time of the occurrence of the accidents has been underlined for its important role from the findings of the analysis. Many types of accidents are common in nighttime.

Chapter 6 presented results from risk analysis using bow tie diagrams. These diagrams provided a visual representation of risk, including both applicable elements and the relationships between them. The role of inspection and maintenance in accidents has been clearly defined, something that is crucial for targeting the dangerous areas for further treatment of top events. As a result, bow ties are a useful tool for risk analysis that include elements from domains treated separately, on a single representation and shows the linking of hazards in a linear way.

For the sake of better understanding of the importance of bow ties, a number of ten accidents have presented using generalized bow tie diagrams. This presentation has shown the specific paths of the occurrences that may lead to top event. It is a user friendly tool that can help further research in this field.

To summarize, the role of inspection is crucial when researching marine accidents. All of the results pointed out the connection between accidents and mistake in inspection fields. For that reason, a well presented risk analysis is indispensable for a better understanding of the different incidents and the recommendation of this deliverable is the use of bow tie diagrams.

In line with the identified areas, efforts need to be made to incorporate the findings for a future research in the fields of marine accidents. Furthermore in the future studies in order to measure the analyzed risk factors, bow ties could be filled with actual numbers about failure probabilities.

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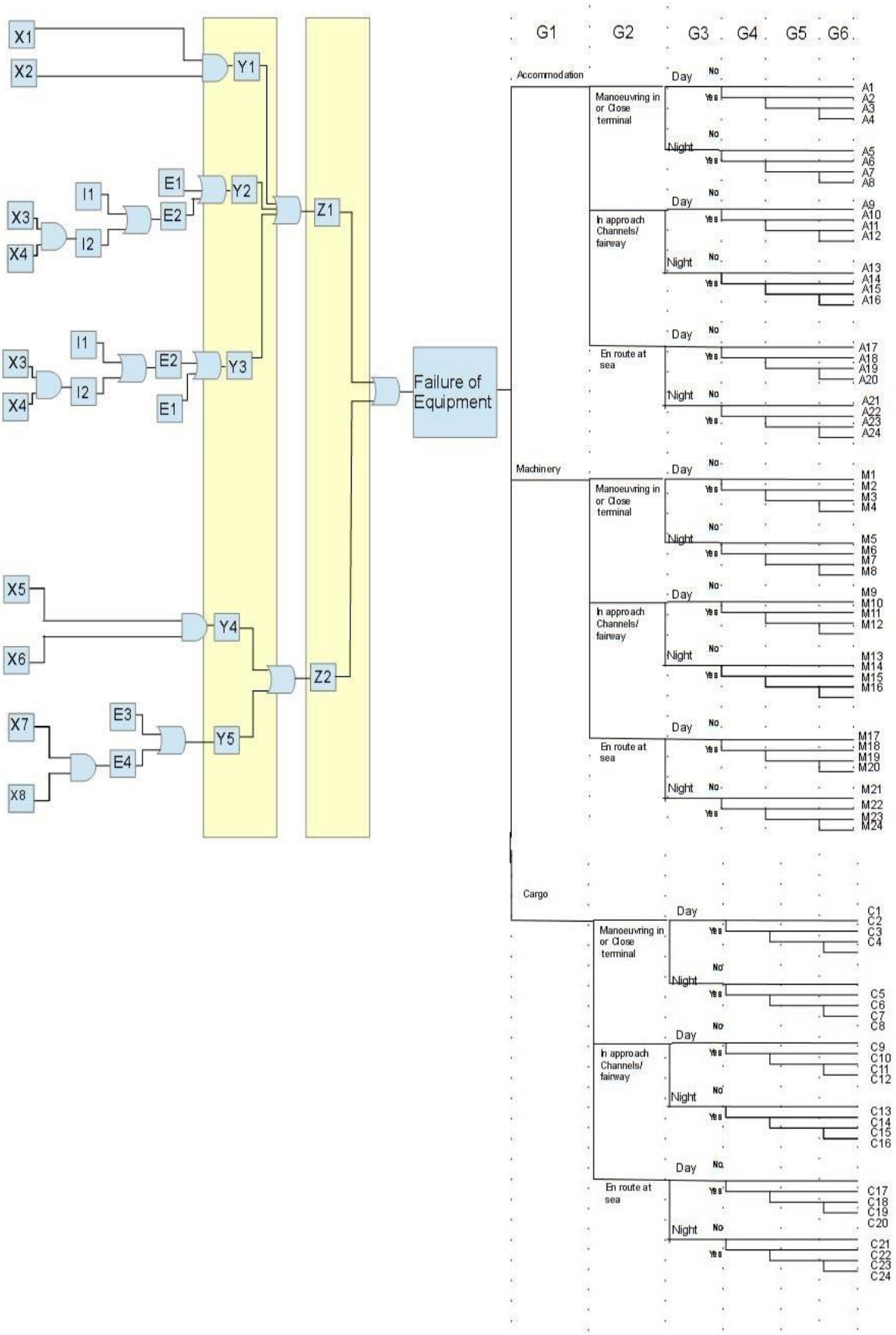
Annex 1

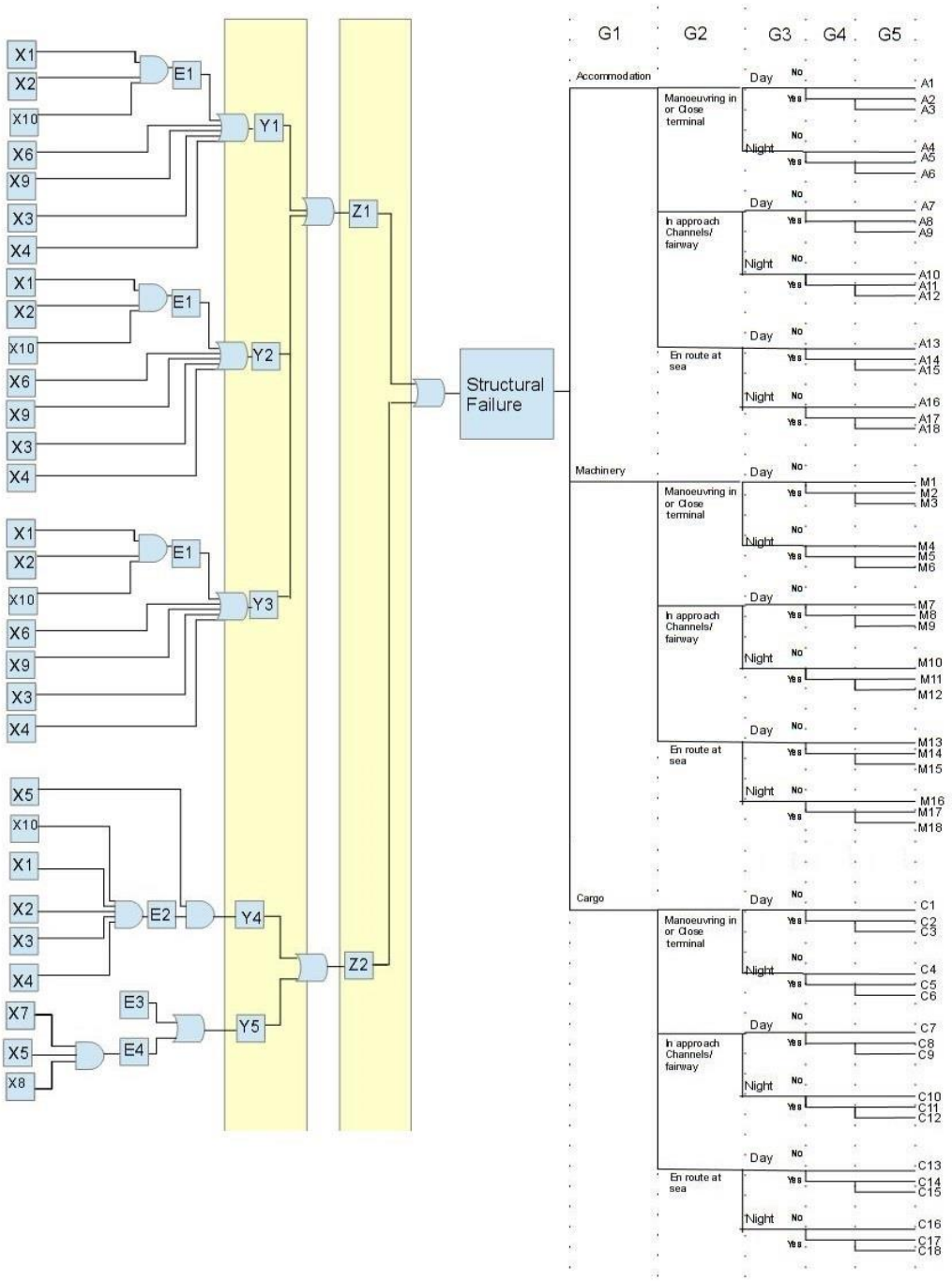
General cargo ships



X1	Poor instalation
X2	Poor supervision from the crew
X3	Poor maintenance
X4	Poor inspection
X5	Inexperienced personnel
X6	Untrained personnel
X7	Crew did not pay attention
X8	Deficiencies of manuals
I1	Insufficient attention to repairs
I2	Inattentions
E1	Weather conditions
E2	Poor condition of equipment
E3	Violation of regulations
E4	Process not followed
Y1	Deficient equipment
Y2	Corrosion
Y3	Cracking
Y4	Insufficient quality of personnel
Y5	Inappropriate actions
Z1	Broken off or loose equipment
Z2	Operational error

G1	Location
G2	Operational state
G3	Time of day
G4	Consequenct accident
G5	Damage to structure
G6	Loss of water tightness
A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A8	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Minor repairable damage to accommodation/ Possible injuries
A10	Extended damage to accommodation/ Injuries and possible fatalities
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Injuries
A14	Extended damage to accommodation/ Injuries and possible fatalities
A15	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A16	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A17	Minor repairable damage to accommodation/ Possible injuries
A18	Extended damage to accommodation/ Injuries and possible fatalities
A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all crew

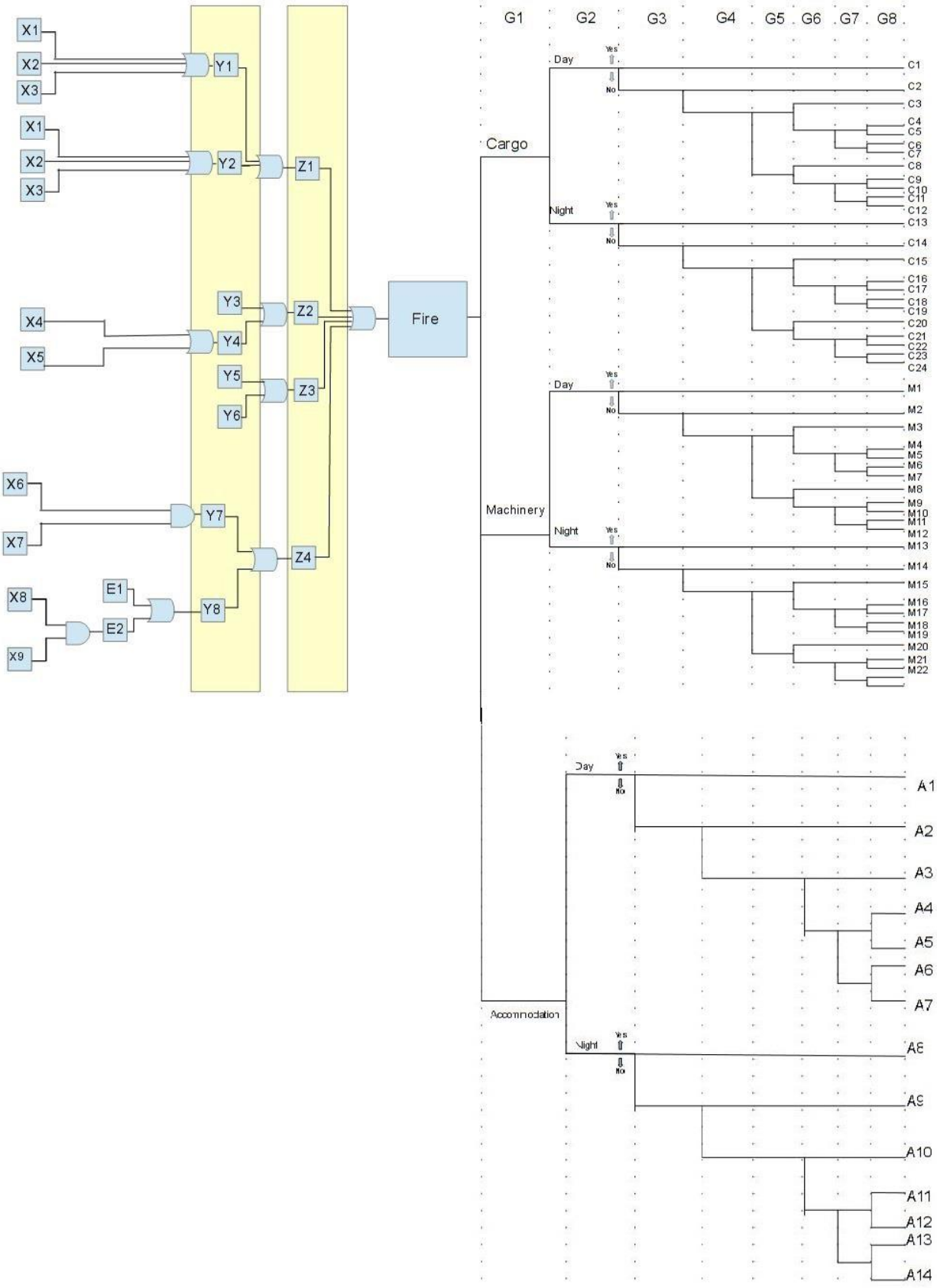
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
M6	Extended damage to machinery/ Possible injuries
M7	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M8	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Minor repairable damage to machinery
M10	Extended damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery/ Possible injuries
M14	Extended damage to machinery/ Possible injuries
M15	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M16	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M17	Minor repairable damage to machinery
M18	Extended damage to machinery/ Possible injuries
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all crew
M21	Minor repairable damage to machinery/ Possible injuries
M22	Extended damage to machinery/ Possible injuries
M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to cargo
C2	Extended damage to cargo/ Possible injuries
C3	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C4	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C5	Minor repairable damage to cargo/ Possible injuries
C6	Extended damage to cargo/ Possible injuries
C7	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C8	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C9	Minor repairable damage to cargo
C10	Extended damage to cargo/ Possible injuries
C11	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to cargo/ Possible injuries
C14	Extended damage to cargo/ Possible injuries
C15	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C16	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C17	Minor repairable damage to cargo
C18	Extended damage to cargo/ Possible injuries
C19	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C20	Worst case: Loss of vessel/Loss of all crew
C21	Minor repairable damage to cargo/ Possible injuries
C22	Extended damage to cargo/ Possible injuries
C23	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C24	Worst case: Loss of vessel/Loss of all crew


X1
X2
X10
X6
X9
X3
X4
E1
Y1
X1
X2
X10
X6
X9
X3
X4
E1
Y2
X1
X2
X10
X6
X9
X3
X4
E1
Y3
X5
X10
X1
X2
X3
X4
E2
Y4
X7
X5
X8
E3
E4
Y5
Z1
Z2
Structural Failure
G1
G2
G3
G4
G5
Accommodation
Manoeuvring in or Close terminal
In approach Channels/ fairway
En route at sea
Day
Night
No
Yes
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
A16
A17
A18
Machinery
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
Cargo
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18

X1	Poor design calculations
X2	Poor endurance tests
X3	Poor maintenance
X4	Poor inspection
X5	Inadequate personnel
X6	Insufficient attention to repairs
X7	Crew did not pay attention
X8	Deficiencies of manuals
X9	Adverse weather conditions
X10	Poor construction/ purchase of equipment
E1	Inferior quality of structure
E2	Poor condition of equipment
E3	Violation of regulations
E4	Misuse of equipment
Y1	Corrosion
Y2	Cracking
Y3	Deformation
Y4	Navigational failure
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational error

G1	Location
G2	Operational state
G3	Time of day
G4	Consequenct accident
G5	Loss of water tightness
A1	Minor repairable damage to accommodation/ Possible injuries
A2	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A3	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Minor repairable damage to accommodation/ Injuries
A5	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A6	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A7	Minor repairable damage to accommodation/ Possible injuries
A8	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A10	Minor repairable damage to accommodation/ Injuries
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Possible injuries
A14	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A15	Worst case: Loss of vessel/Loss of all crew
A16	Minor repairable damage to accommodation/ Injuries
A17	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A18	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M3	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Minor repairable damage to machinery/ Possible injuries
M5	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M6	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M7	Minor repairable damage to machinery
M8	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities

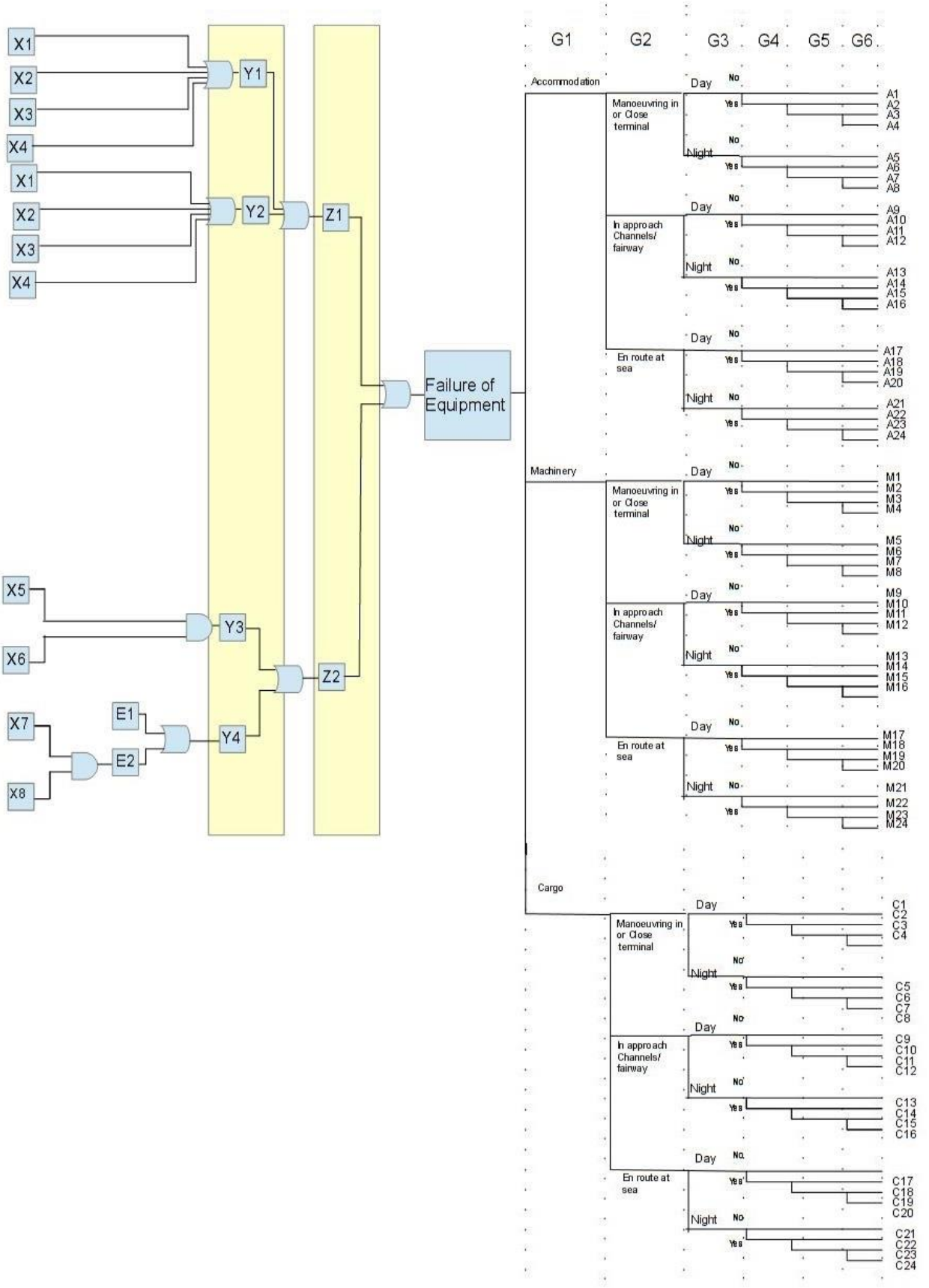
M9	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M10	Minor repairable damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery
M14	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M15	Worst case: Loss of vessel/Loss of all crew
M16	Minor repairable damage to machinery/ Possible injuries
M17	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M18	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to cargo
C2	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C3	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C4	Minor repairable damage to cargo/ Possible injuries
C5	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C6	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C7	Minor repairable damage to cargo
C8	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C9	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C10	Minor repairable damage to cargo/ Possible injuries
C11	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to cargo
C14	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C15	Worst case: Loss of vessel/Loss of all crew
C16	Minor repairable damage to cargo/ Possible injuries
C17	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C18	Worst case: Loss of vessel/Loss of all crew


X1
X2
X3
Y1
X1
X2
X3
Y2
Z1
Y3
Z2
X4
Y4
X5
Fire
Y5
Z3
Y6
X6
Y7
X7
Z4
E1
X8
Y8
E2
X9
G1
G2
G3
G4
G5
G6
G7
G8
Cargo
Day
Night
Machinery
Day
Night
Accommodation
Day
Night
Yes
No
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
M19
M20
M21
M22
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Poor design
X5	Poor supervision from the crew
X6	Inexperienced personnel
X7	Untrained personnel
X8	Crew did not pay attention
X9	Deficiencies of manuals
E1	Violation of regulations
E2	Process not followed
Y1	Corrosion
Y2	Cracking
Y3	Overheating machine
Y4	Hot surfaces
Y5	Incorrect tightening
Y6	Use of unauthorised spare part
Y7	Insufficient quality of personnel
Y8	Inappropriate actions
Z1	Leakage
Z2	Inappropriate temperature
Z3	Crankcase explosion
Z4	Operational error

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting
G5	Fire spread to accommodation
G6	Firefighting assistance from other vessel or land
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew
C1	Minor damage to cargo
C2	Extended damage to cargo/ Possible damage to vessel
C3	Serious damage to cargo/ Damage to vessel/ Crew injuries
C4	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C5	Very serious cargo damage/Loss of vessel/ Crew injuries and fatalities
C6	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C8	Serious damage to cargo/ Damage to vessel
C9	Very serious cargo damage/serious damage to vessel
C10	Very serious cargo damage/Loss vessel/ Crew injuries fatalities
C11	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C13	Minor damage to cargo
C14	Extended damage to cargo/ Possible damage to vessel
C15	Serious damage to cargo/ Damage to vessel/ Crew injuries and possible fatalities
C16	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C17	Very serious cargo damage/Loss vessel/ Crew injuries fatalities
C18	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C20	Serious damage to cargo/ Damage to vessel
C21	Very serious cargo damage/serious damage to vessel
C22	Very serious cargo damage/Loss vessel/ Crew injuries fatalities

C23	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M5	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
M9	Very serious damage to machinery/serious damage to vessel
M10	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M11	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M13	Minor damage to machinery
M14	Extended damage to machinery/ Possible damage to vessel
M15	Serious damage to machinery/ Damage to vessel/ Crew injuries and possible fatalities
M16	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M17	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M18	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M20	Serious damage to machinery/ Damage to vessel
M21	Very serious damage to machinery/serious damage to vessel
M22	Very serious damage to machinery/Loss of vessel/ Crew injuries and fatalities
M23	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A1	Minor repairable damage to accommodation
A2	Extended damage to accommodation/ Possible damage to vessel
A3	Serious damage to accommodation/ Damage to vessel/ Possible crew injuries
A4	Very serious damage to accommodation/serious damage to vessel/ Injuries and possible fatalities/
A5	Crew casualties/ Very serious damage to accommodation / Loss of vessel
A6	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A8	Minor repairable damage to accommodation
A9	Extended damage to accommodation/ Possible damage to vessel/ Injuries
A10	Serious damage to accommodation/ Damage to vessel/ Crew injuries and possible fatalities
A11	Very serious damage to accommodation/serious damage to vessel/ Injuries and fatalities
A12	Crew casualties/ Very serious damage to accommodation / Loss of vessel/
A13	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A14	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew


X1
X2
X3
X4
X1
X2
X3
X4
Y1
Y2
Z1
Failure of Equipment
X5
X6
X7
X8
E1
E2
Y3
Y4
Z2
G1
G2
G3
G4
G5
G6
Accommodation
Manoeuvring in or Close terminal
In approach Channels/ fairway
En route at sea
Day
Night
No
Yes
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
A16
A17
A18
A19
A20
A21
A22
A23
A24
Machinery
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
M19
M20
M21
M22
M23
M24
Cargo
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
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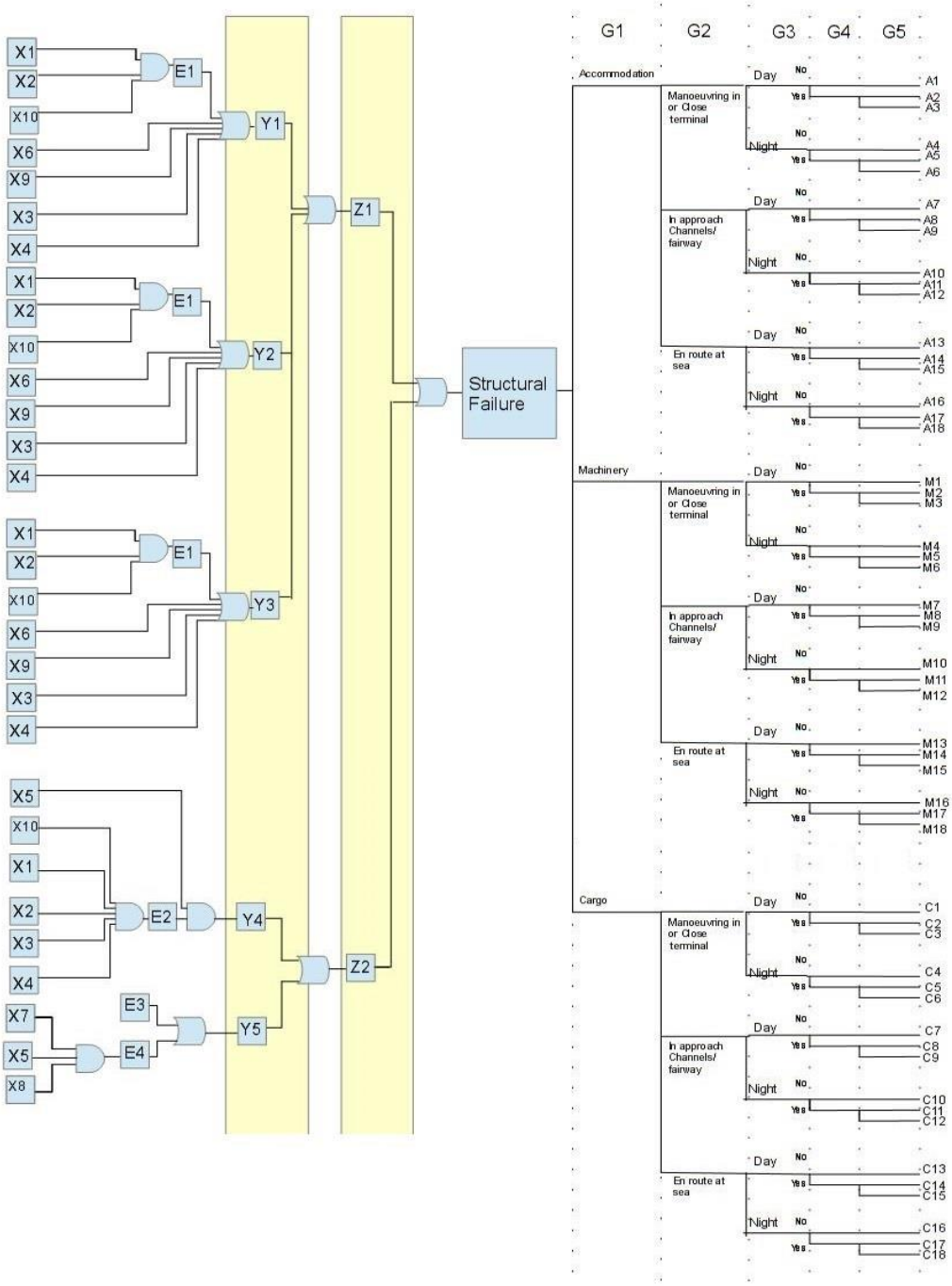
C21
C22
C23
C24

X1	Poor maintenance
X2	Poor inspection
X3	Poor repairs
X4	Poor design
X5	Inexperienced personnel
X6	Untrained personnel
X7	Crew did not pay attention
X8	Deficiencies of manuals
Y1	Corrosion
Y2	Cracking
Y3	Insufficient quality of personnel
Y4	Inappropriate actions
E1	Violation of regulations
E2	Process not followed
Z1	Broken off or loose equipment
Z2	Operational error

G1	Location
G2	Operational state
G3	Time of day
G4	Consequenct accident
G5	Damage to structure
G6	Loss of water tightness
A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A8	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Minor repairable damage to accommodation/ Possible injuries
A10	Extended damage to accommodation/ Injuries and possible fatalities
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Injuries
A14	Extended damage to accommodation/ Injuries and possible fatalities
A15	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A16	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A17	Minor repairable damage to accommodation/ Possible injuries
A18	Extended damage to accommodation/ Injuries and possible fatalities
A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
M6	Extended damage to machinery/ Possible injuries

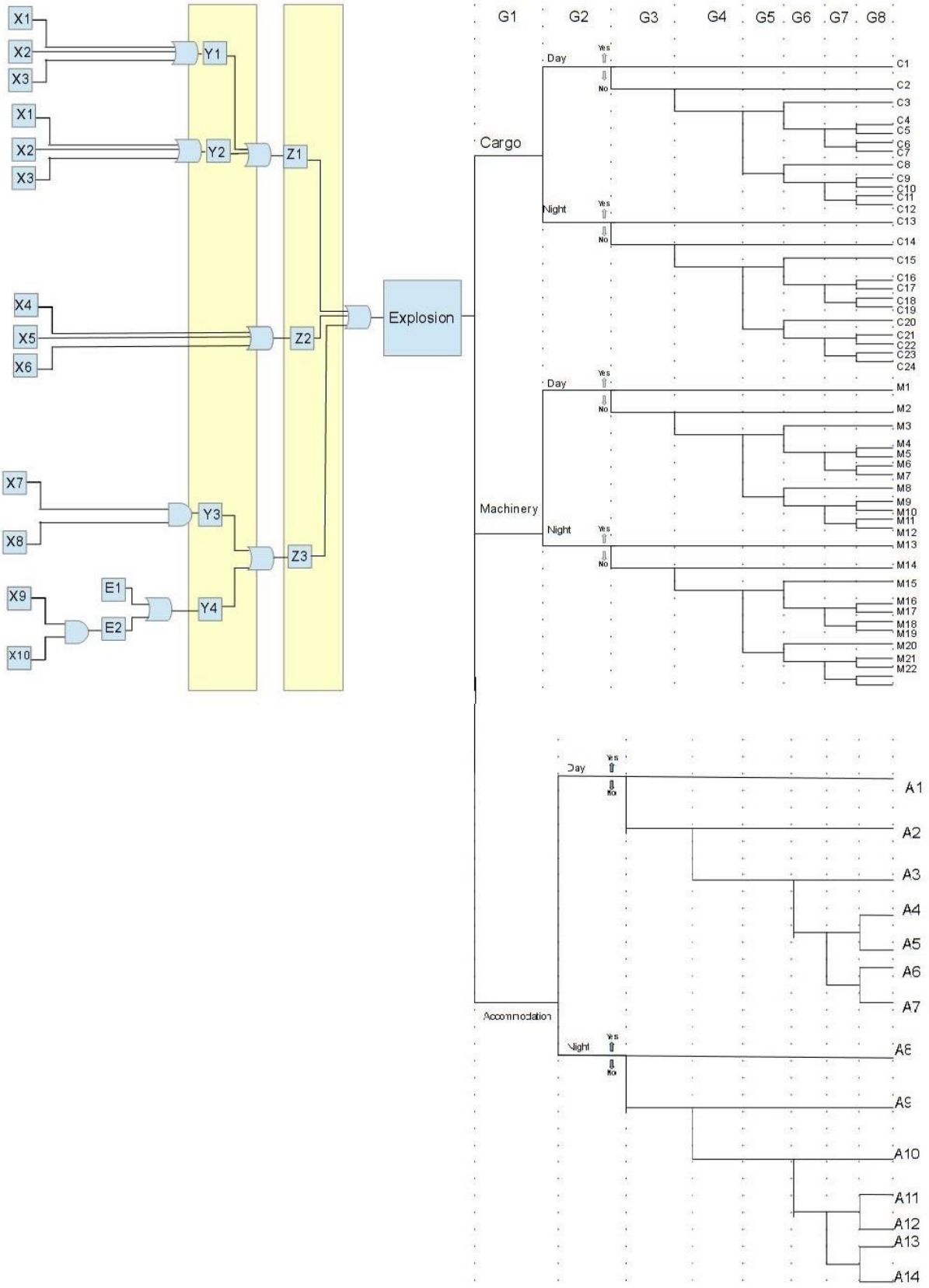
M7	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M8	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Minor repairable damage to machinery
M10	Extended damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery/ Possible injuries
M14	Extended damage to machinery/ Possible injuries
M15	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M16	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M17	Minor repairable damage to machinery
M18	Extended damage to machinery/ Possible injuries
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all crew
M21	Minor repairable damage to machinery/ Possible injuries
M22	Extended damage to machinery/ Possible injuries
M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to containers
C2	Extended damage to containers/ Possible injuries
C3	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C4	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C5	Minor repairable damage to containers/ Possible injuries
C6	Extended damage to containers/ Possible injuries
C7	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C8	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C9	Minor repairable damage to containers
C10	Extended damage to containers/ Possible injuries
C11	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to containers/ Possible injuries
C14	Extended damage to containers/ Possible injuries
C15	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C16	Very serious damage to containers/ Damage to vessel/ Injuries and fatalities
C17	Minor repairable damage to containers
C18	Extended damage to containers/ Possible injuries
C19	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C20	Worst case: Loss of vessel/Loss of all crew
C21	Minor repairable damage to containers/ Possible injuries
C22	Extended damage to containers/ Possible injuries
C23	Serious damage to containers/ Damage to vessel/ Injuries and fatalities
C24	Worst case: Loss of vessel/Loss of all crew


X1
X2
X10
X6
X9
X3
X4
E1
Y1
Z1
Structural Failure
Y2
Y3
X5
X7
X8
E2
E3
E4
Y4
Y5
Z2
G1
G2
G3
G4
G5
Accommodation
Machinery
Cargo
Manoeuvring in or Close terminal
In approach Channels/ fairway
En route at sea
Day
Night
No
Yes
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
A16
A17
A18
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18

X1	Poor design calculations
X2	Poor endurance tests
X3	Poor maintenance
X4	Poor inspection
X5	Inadequate personnel
X6	Insufficient attention to repairs
X7	Crew did not pay attention
X8	Deficiencies of manuals
X9	Adverse weather conditions
X10	Poor construction/ purchase of equipment
E1	Inferior quality of structure
E2	Poor condition of equipment
E3	Violation of regulations
E4	Misuse of equipment
Y1	Corrosion
Y2	Cracking
Y3	Deformation
Y4	Navigational failure
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational error

G1	Location
G2	Operational state
G3	Time of day
G4	Consequenct accident
G5	Loss of water tightness
A1	Minor repairable damage to accommodation/ Possible injuries
A2	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A3	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Minor repairable damage to accommodation/ Injuries
A5	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A6	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A7	Minor repairable damage to accommodation/ Possible injuries
A8	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A10	Minor repairable damage to accommodation/ Injuries
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Possible injuries
A14	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A15	Worst case: Loss of vessel/Loss of all crew
A16	Minor repairable damage to accommodation/ Injuries
A17	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A18	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M3	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Minor repairable damage to machinery/ Possible injuries
M5	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M6	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M7	Minor repairable damage to machinery
M8	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities

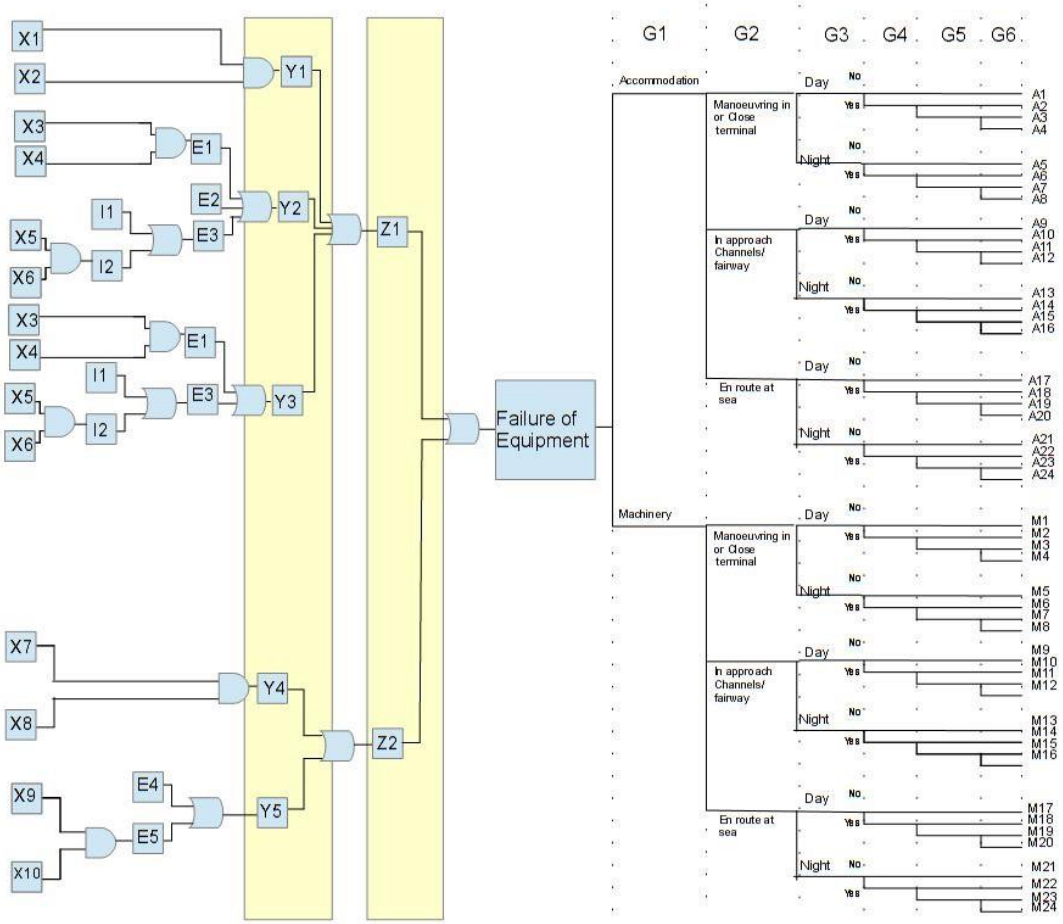
M9	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M10	Minor repairable damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery
M14	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M15	Worst case: Loss of vessel/Loss of all crew
M16	Minor repairable damage to machinery/ Possible injuries
M17	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M18	Worst case: Loss of vessel/Loss of all crew
C1	Minor repairable damage to cargo
C2	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C3	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C4	Minor repairable damage to cargo/ Possible injuries
C5	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C6	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C7	Minor repairable damage to cargo
C8	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C9	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C10	Minor repairable damage to cargo/ Possible injuries
C11	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C12	Very serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C13	Minor repairable damage to cargo
C14	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C15	Worst case: Loss of vessel/Loss of all crew
C16	Minor repairable damage to cargo/ Possible injuries
C17	Serious damage to cargo/ Damage to vessel/ Injuries and fatalities
C18	Worst case: Loss of vessel/Loss of all crew


X1
X2
X3
Y1
X1
X2
X3
Y2
Z1
X4
X5
X6
Z2
Explosion
X7
X8
Y3
Z3
X9
E1
Y4
E2
X10
G1
G2
G3
G4
G5
G6
G7
G8
Cargo
Day
Yes
No
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
Night
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
Machinery
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
M19
M20
M21
M22
Accommodation
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Incautious practice of metalworking
X5	Electrical malfunction
X6	Mechanical malfunction
X7	Untrained personnel
X8	Inexperienced personnel
X9	Crew did not pay attention
X10	Deficiencies of manuals
E1	Violation of regulations
E2	Process not followed
Y1	Corrosion
Y2	Cracking
Y3	Insufficient quality of personnel
Y4	Inappropriate actions
Z1	Leakage of explosive mixture of materials
Z2	Sparks
Z3	Operational error

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting
G5	Fire spread to accommodation
G6	Firefighting assistance from other vessel or land
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew
C1	Minor damage to cargo
C2	Extended damage to cargo/ Possible damage to vessel
C3	Serious damage to cargo/ Damage to vessel/ Crew injuries
C4	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C5	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C6	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C8	Serious damage to cargo/ Damage to vessel
C9	Very serious cargo damage/serious damage to vessel
C10	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C11	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C13	Minor damage to cargo
C14	Extended damage to cargo/ Possible damage to vessel
C15	Serious damage to cargo/ Damage to vessel/ Crew injuries and possible fatalities
C16	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C17	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C18	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
C20	Serious damage to cargo/ Damage to vessel
C21	Very serious cargo damage/serious damage to vessel
C22	Very serious cargo damage/serious damage to vessel/ Crew injuries and possible fatalities
C23	Injuries, fatalities/ Very serious cargo damage/ Very serious vessel damage
C24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M1	Minor repairable damage to machinery

M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M5	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
M9	Very serious damage to machinery/serious damage to vessel
M10	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M11	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M13	Minor damage to machinery
M14	Extended damage to machinery/ Possible damage to vessel
M15	Serious damage to machinery/ Damage to vessel/ Crew injuries and possible fatalities
M16	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M17	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M18	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M19	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M20	Serious damage to machinery/ Damage to vessel
M21	Very serious damage to machinery/serious damage to vessel
M22	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities
M23	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A1	Minor repairable damage to accommodation
A2	Extended damage to accommodation/ Possible damage to vessel
A3	Serious damage to accommodation/ Damage to vessel/ Possible crew injuries
A4	Very serious damage to accommodation/serious damage to vessel/ Injuries and possible fatalities/
A5	Crew casualties/ Very serious damage to accommodation / Serious damage to vessel/
A6	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
A8	Minor repairable damage to accommodation
A9	Extended damage to accommodation/ Possible damage to vessel/ Injuries
A10	Serious damage to accommodation/ Damage to vessel/ Crew injuries and possible fatalities
A11	Very serious damage to accommodation/serious damage to vessel/ Injuries and fatalities
A12	Crew casualties/ Very serious damage to accommodation / Serious damage to vessel/
A13	Injuries, fatalities/ Very serious damage to accommodation/ Very serious vessel damage
A14	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew

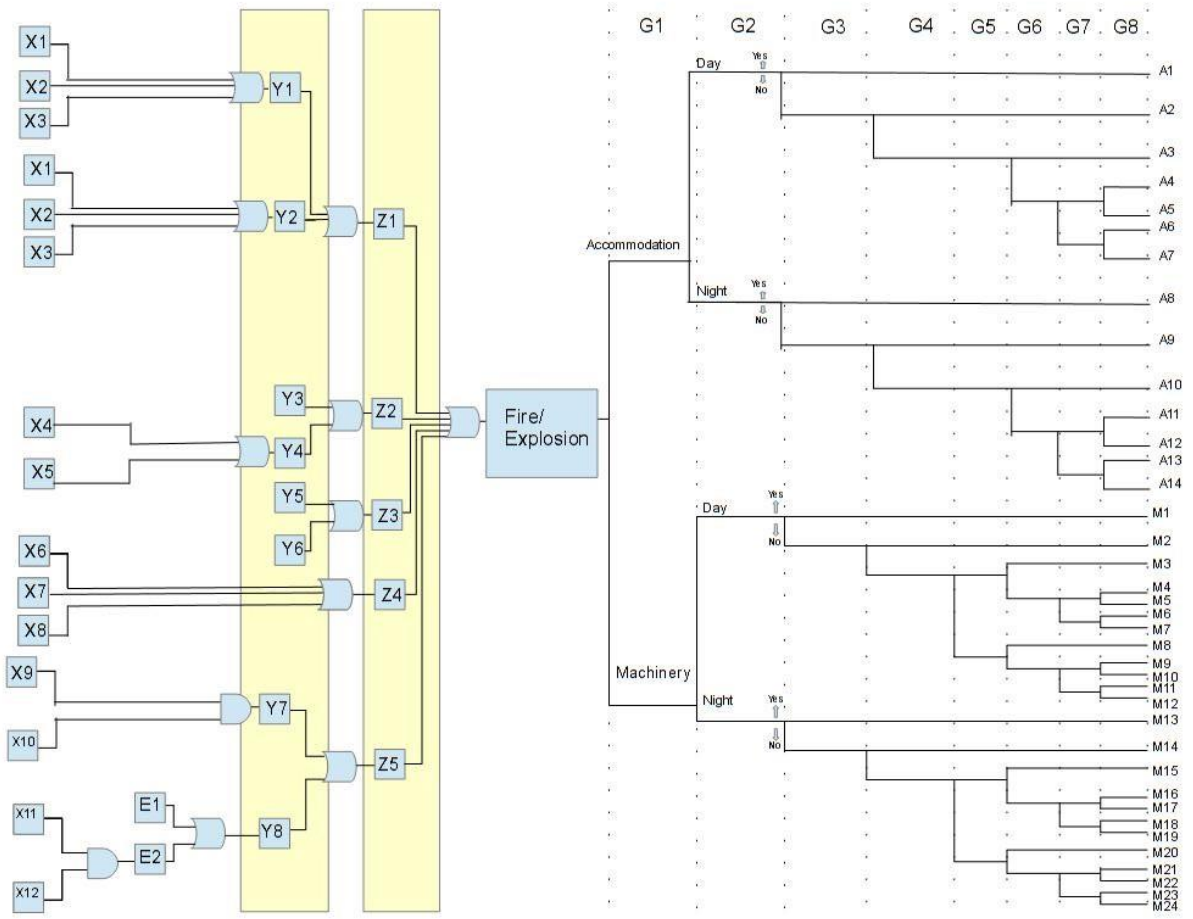


X1	Poor instalation
X2	Poor supervision from the crew
X3	Poor design calculations
X4	Poor endurance tests
X5	Poor maintenance
X6	Poor inspection
X7	Inexperienced personnel
X8	Untrained personnel
X9	Crew did not pay attention
X10	Deficiencies of manuals
I1	Insufficient attention to repairs
I2	Inattentions
E1	Inferior quality of materials
E2	Weather conditions
E3	Poor condition of equipment
E4	Violation of regulations
E5	Process not followed
Y1	Deficient equipment
Y2	Corrosion
Y3	Cracking
Y4	Insufficient quality of personnel
Y5	Inappropriate actions

Z1	Broken off or loose equipment
Z2	Operational error

G1	Location
G2	Operational state
G3	Time of day
G4	Consequenct accident
G5	Damage to structure
G6	Loss of water tightness
A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A8	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Minor repairable damage to accommodation/ Possible injuries
A10	Extended damage to accommodation/ Injuries and possible fatalities
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Injuries
A14	Extended damage to accommodation/ Injuries and possible fatalities
A15	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A16	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A17	Minor repairable damage to accommodation/ Possible injuries
A18	Extended damage to accommodation/ Injuries and possible fatalities
A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all passengers and crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all passengers and crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
M6	Extended damage to machinery/ Possible injuries
M7	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M8	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Minor repairable damage to machinery
M10	Extended damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery/ Possible injuries
M14	Extended damage to machinery/ Possible injuries
M15	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M16	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M17	Minor repairable damage to machinery
M18	Extended damage to machinery/ Possible injuries
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all passengers and crew
M21	Minor repairable damage to machinery/ Possible injuries
M22	Extended damage to machinery/ Possible injuries

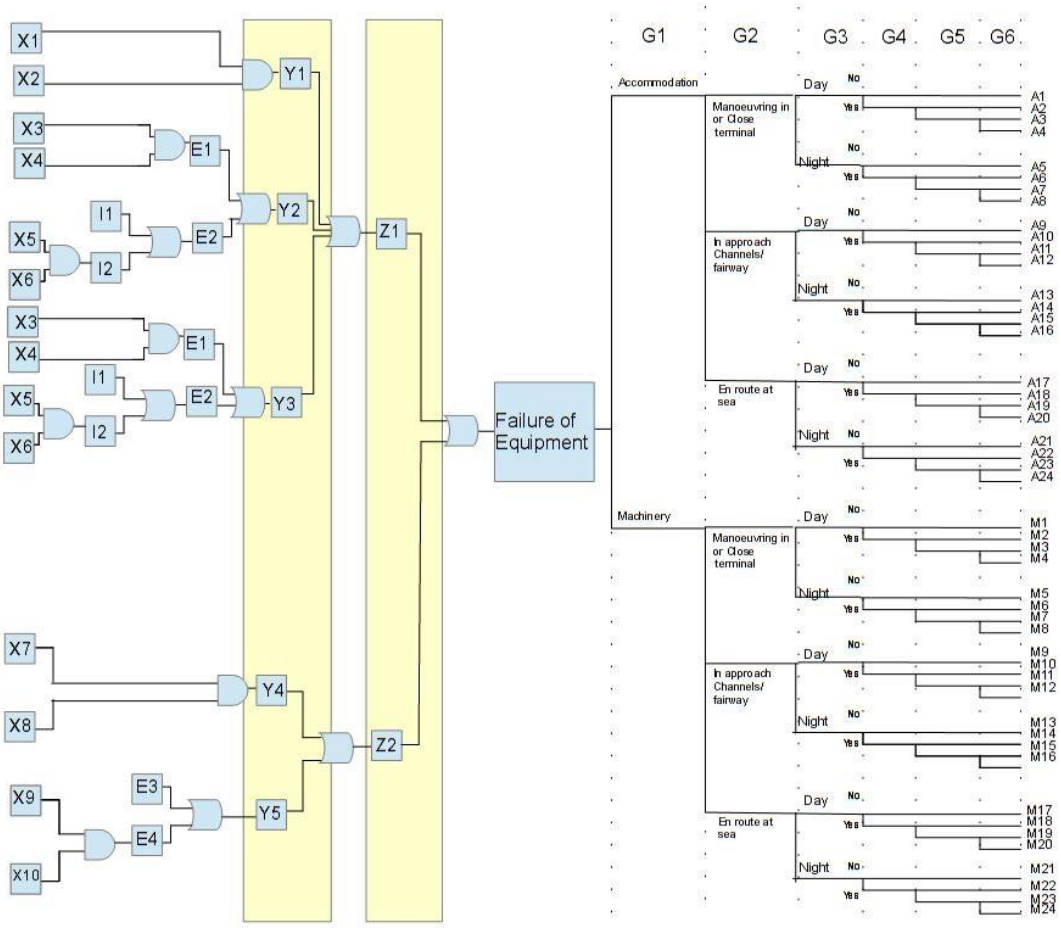
M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all passengers and crew



X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Poor design
X5	Poor supervision from the crew
X6	Incautious practice of metalworking
X7	Electrical malfunction
X8	Mechanical malfunction
X9	Inexperienced personnel
X10	Untrained personnel
X11	Crew did not pay attention
X12	Deficiencies of manuals
E1	Violation of regulations
E2	Process not followed
Y1	Corrosion
Y2	Cracking
Y3	Overheating machine
Y4	Hot surfaces
Y5	Incorrect tightening
Y6	Use of unauthorised spare part
Y7	Insufficient quality of personnel
Y8	Inappropriate actions

Z1	Leakage
Z2	Inappropriate temperature
Z3	Crankcase explosion
Z4	Sparks
Z5	Operational error

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting
G5	Fire spread to accommodation
G6	Assistance from other vessel or land/ Rescue of passengers
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew
A1	Possible Injuries
A2	Injuries and possible fatalities
A3	Injuries/fatalities and damage to vessel
A4	Injuries and fatalities/ Serious damage to vessel
A5	Many fatalities/Loss of crew and loss of vessel
A6	Many passangers and crew fatalities
A7	Worst case: Loss of vessel/ Loss of passengers and crew
A8	Injuries and possible fatalities
A9	Injuries/fatalities and damage to vessel
A10	Injuries and fatalities/ Serious damage to vessel
A11	Injuries and fatalities/ Serious damage to vessel
A12	Many fatalities/Loss of crew and loss of vessel
A13	Many passangers and crew fatalities
A14	Worst case: Loss of vessel/ Loss of passengers and crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew and passengers injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew,passengers injuries and possible fatalities
M5	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
M9	Very serious damage to machinery/serious damage to vessel
M10	Very serious damage to machinery/Loss vessel/ Crew, passengers fatalities
M11	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M12	Worst case: Loss of vessel/ Loss of passengers and crew
M13	Minor damage to machinery
M14	Extended damage to machinery/ Possible damage to vessel
M15	Serious damage to machinery/ Damage to vessel/ Crew, passengers injuries and possible fatalities
M16	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M17	Very serious damage to machinery/Loss vessel/ Crew, passengers fatalities
M18	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M19	Worst case: Loss of vessel/ Loss of passengers and crew
M20	Serious damage to machinery/ Damage to vessel
M21	Very serious damage to machinery/serious damage to vessel
M22	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M23	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of passengers and crew



X1	Poor instalation
X2	Poor supervision from the crew
X3	Poor design calculations
X4	Poor endurance tests
X5	Poor maintenance
X6	Poor inspection
X7	Inexperienced personnel
X8	Untrained personnel
X9	Crew did not pay attention
X10	Deficiencies of manuals
I1	Insufficient attention to repairs
I2	Inattentions
E1	Inferior quality of materials
E2	Poor condition of equipment
E3	Violation of regulations
E4	Process not followed
Y1	Deficient equipment
Y2	Corrosion
Y3	Cracking
Y4	Insufficient quality of personnel
Y5	Inappropriate actions

Z1	Broken off or loose equipment
Z2	Operational error

G1	Location
G2	Operational state
G3	Time of day
G4	Consequenct accident
G5	Damage to structure
G6	Loss of water tightness
A1	Minor repairable damage to accommodation/ Possible injuries
A2	Extended damage to accommodation/ Injuries and possible fatalities
A3	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A5	Minor repairable damage to accommodation/ Injuries
A6	Extended damage to accommodation/ Injuries and possible fatalities
A7	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
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A17	Minor repairable damage to accommodation/ Possible injuries
A18	Extended damage to accommodation/ Injuries and possible fatalities
A19	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A20	Worst case: Loss of vessel/Loss of all passengers and crew
A21	Minor repairable damage to accommodation/ Injuries
A22	Extended damage to accommodation/ Injuries and possible fatalities
A23	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A24	Worst case: Loss of vessel/Loss of all passengers and crew
M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible injuries
M3	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M5	Minor repairable damage to machinery/ Possible injuries
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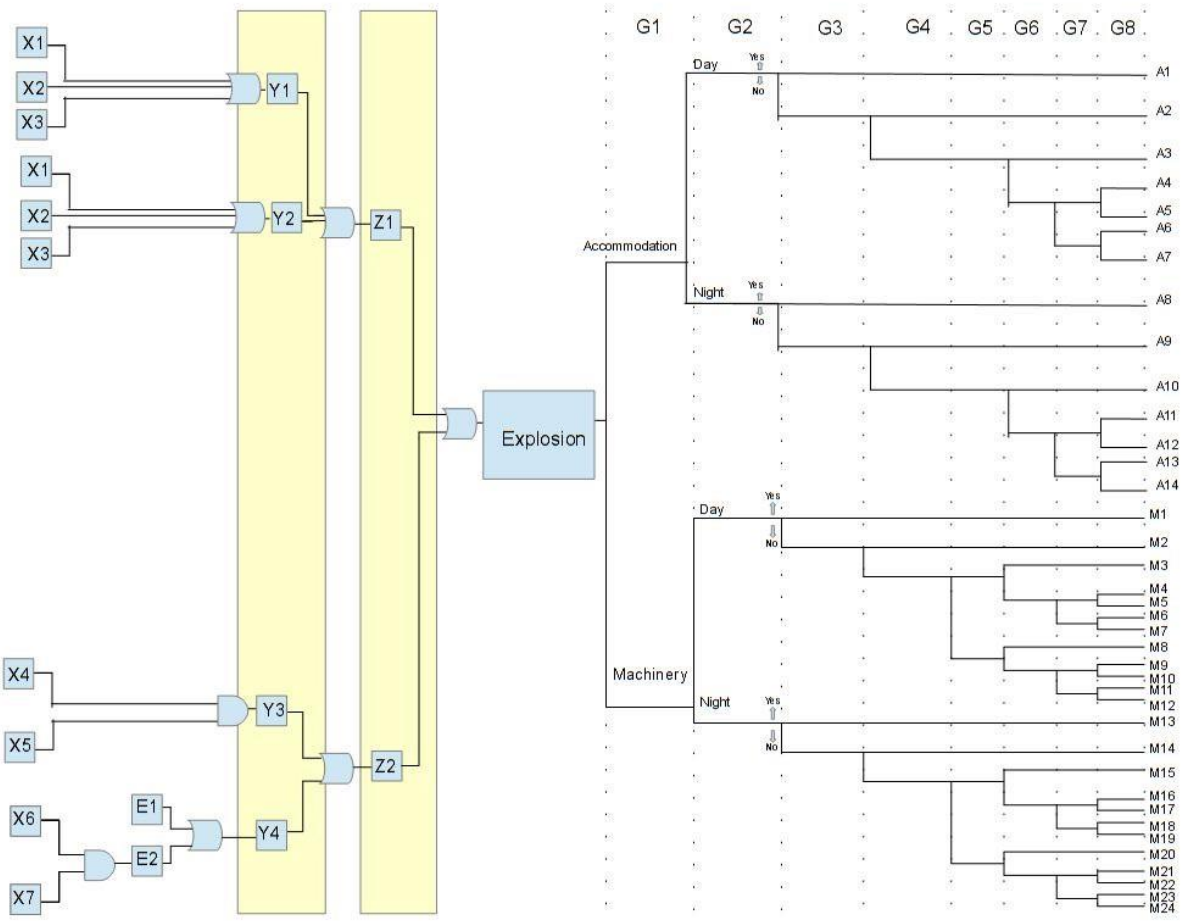
M19	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M20	Worst case: Loss of vessel/Loss of all passengers and crew
M21	Minor repairable damage to machinery/ Possible injuries
M22	Extended damage to machinery/ Possible injuries

M23	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M24	Worst case: Loss of vessel/Loss of all passengers and crew



X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
X4	Inexperienced personnel
X5	Untrained personnel
X6	Crew did not pay attention
X7	Deficiencies of manuals
E1	Violation of regulations
E2	Process not followed
Y1	Corrosion
Y2	Cracking
Y3	Insufficient quality of personnel
Y4	Inappropriate actions
Z1	Leakage
Z2	Operational error

G1	Location
G2	Time of day
G3	Automatic firefighting
G4	Manual firefighting

G5	Fire spread to accommodation
G6	Assistance from other vessel or land/ Rescue of passengers
G7	Fire extinguishing, vessel towing
G8	Ship evacuation/ Rescue of crew
A1	Possible Injuries
A2	Injuries and possible fatalities
A3	Injuries/fatalities and damage to vessel
A4	Injuries and fatalities/ Serious damage to vessel
A5	Many fatalities/Loss of crew and loss of vessel
A6	Many passangers and crew fatalities
A7	Worst case: Loss of vessel/ Loss of passengers and crew
A8	Injuries and possible fatalities
A9	Injuries/fatalities and damage to vessel
A10	Injuries and fatalities/ Serious damage to vessel
A11	Injuries and fatalities/ Serious damage to vessel
A12	Many fatalities/Loss of crew and loss of vessel
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M1	Minor repairable damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew and passengers injuries
M4	Very serious damage to machinery/serious damage to vessel/ Crew,passengers injuries and possible fatalities
M5	Very serious damage to machinery/serious damage to vessel/ Crew, passengers injuries and possible fatalities
M6	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M7	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew
M8	Serious damage to machinery/ Damage to vessel
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M10	Very serious damage to machinery/Loss vessel/ Crew, passengers fatalities
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M12	Worst case: Loss of vessel/ Loss of passengers and crew
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M21	Very serious damage to machinery/serious damage to vessel
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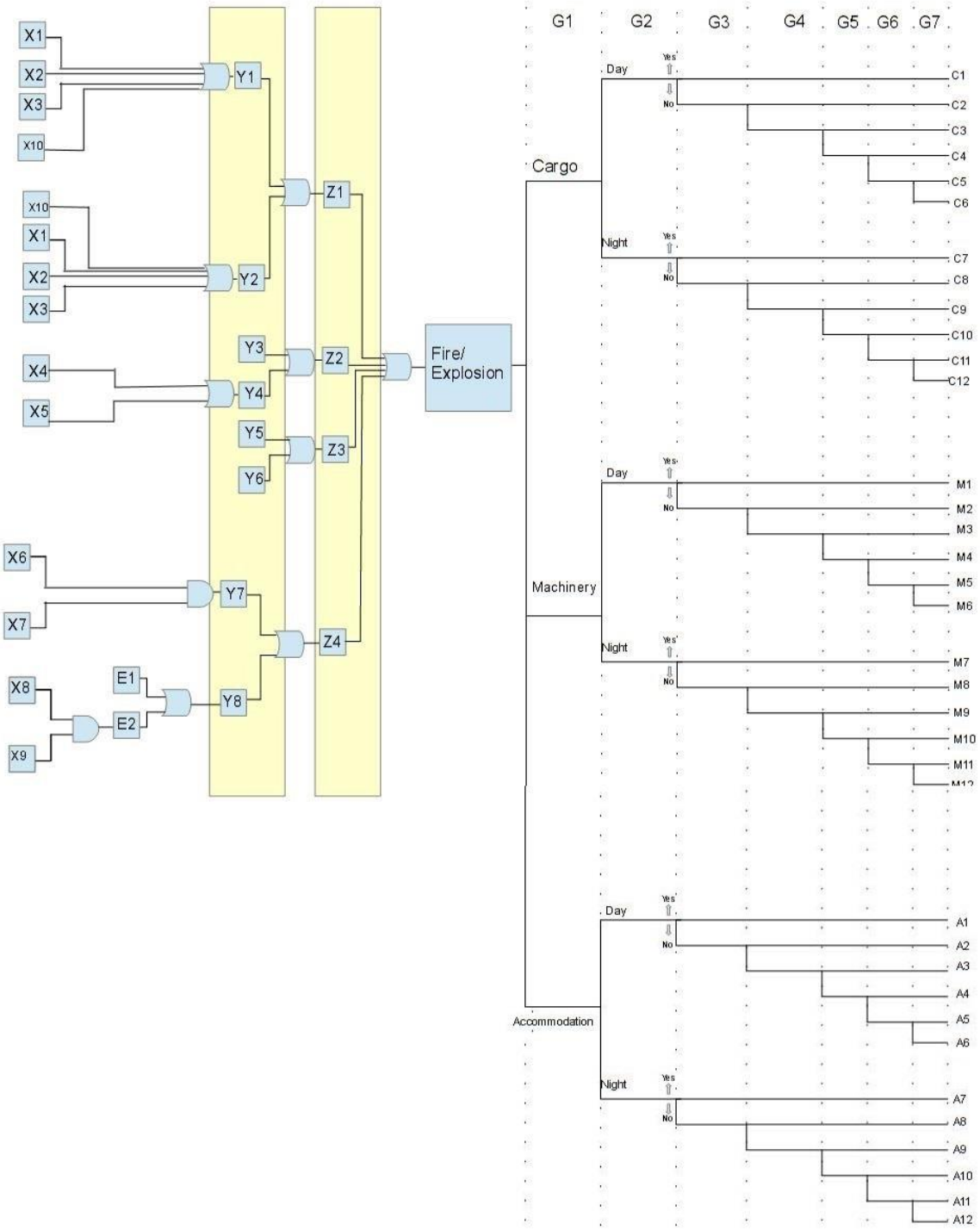
M23	Injuries, fatalities/ Very serious damage to machinery/ Very serious vessel damage
M24	Worst case: Loss of vessel/ Loss of passengers and crew

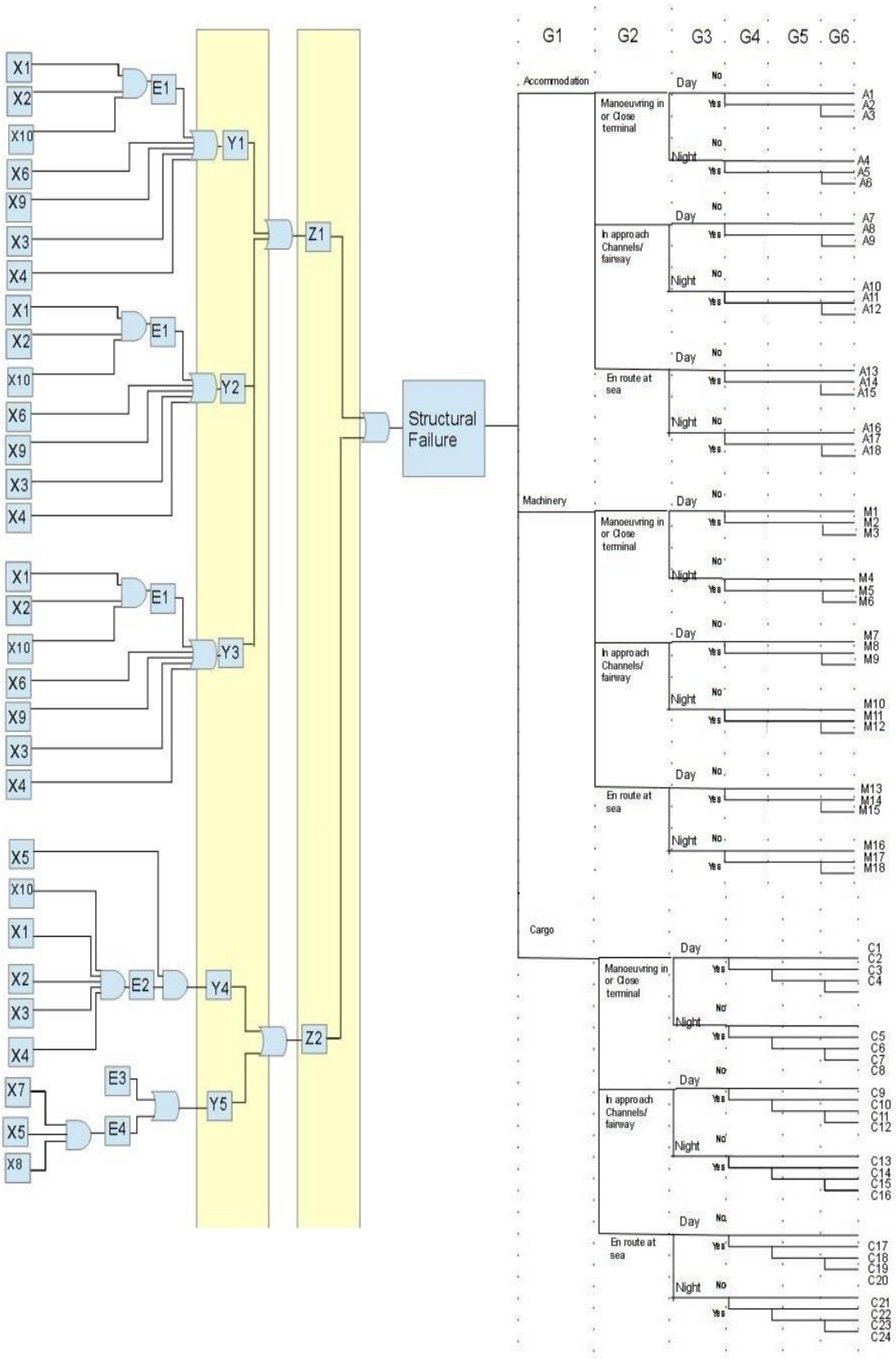


X1	Poor repairs

X2	Poor maintenance
X3	Poor inspection
X4	Poor design
X5	Poor supervision from the crew
X6	Inexperienced personnel
X7	Untrained personnel
X8	Crew did not pay attention
X9	Deficiencies of manuals
X10	Sloshing of partially filled tank
E1	Violation of regulations
E2	Process not followed
Y1	Corrosion
Y2	Cracking
Y3	Overheating machine
Y4	Hot surfaces
Y5	Incorrect tightening
Y6	Use of unauthorised spare part
Y7	Insufficient quality of personnel
Y8	Inappropriate actions
Z1	Leakage
Z2	Inappropriate temperature
Z3	Crankcase explosion
Z4	Operational error

G1	Location
G2	Time of day
G3	Successful fire fighting systems
G4	No LNG leakage
G5	No pool fire
G6	Fire extinguishing, vessel towing
G7	Ship evacuation/ Rescue of crew
C1	Minor damage to cargo area
C2	Extended damage to cargo area/ Possible damage to vessel
C3	Serious damage to cargo area/ Damage to vessel/ Crew injuries/Possible environmental pollution
C4	Very serious damage to cargo area/serious damage to vessel/ Crew injuries and possible fatalities/ Possible environmental pollution
C5	Very serious damage to cargo area /Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
C6	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
C7	Damage to cargo area/Possible injuries
C8	Extended damage to cargo area/ Possible damage to vessel/ Crew injuries
C9	Serious damage to cargo area/ Damage to vessel/ Crew injuries/Possible environmental pollution
C10	Very serious damage to cargo area/serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
C11	Very serious damage to cargo area/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
C12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
M1	Minor damage to machinery
M2	Extended damage to machinery/ Possible damage to vessel
M3	Serious damage to machinery/ Damage to vessel/ Crew injuries/Possible environmental pollution
M4	Very serious damage to machinery/serious damage to vessel/ Crew injuries and possible fatalities/ Possible environmental pollution
M5	Very serious damage to machinery/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
M6	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution

M7	Damage to machinery/Possible injuries
M8	Extended damage to machinery/ Possible damage to vessel/ Crew injuries
M9	Serious damage to machinery/ Damage to vessel/ Crew injuries/Possible environmental pollution
M10	Very serious damage to machinery/serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
M11	Very serious damage to machinery/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
M12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
A1	Minor damage to accommodation
A2	Extended damage to accommodation/ Possible damage to vessel
A3	Serious damage to accommodation/ Damage to vessel/ Crew injuries/Possible environmental pollution
A4	Very serious damage to accommodation/serious damage to vessel/ Crew injuries and possible fatalities/ Possible environmental pollution
A5	Very serious damage to accommodation/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
A6	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution
A7	Damage to accommodation/Possible injuries
A8	Extended damage to accommodation/ Possible damage to vessel/ Crew injuries
A9	Serious damage to accommodation/ Damage to vessel/ Crew injuries/Possible environmental pollution
A10	Very serious damage to accommodation/serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
A11	Very serious damage to accommodation/Serious damage to vessel/ Crew injuries and fatalities/ Possible environmental pollution
A12	Worst case: Loss of vessel/ Loss of cargo/ Loss of all crew/Environmental pollution


X1
X2
X10
X6
X9
X3
X4
E1
Y1
X1
X2
X10
X6
X9
X3
X4
E1
Y2
X1
X2
X10
X6
X9
X3
X4
E1
Y3
X5
X10
X1
X2
X3
X4
E2
Y4
E3
X7
X5
X8
E4
Y5
Z1
Z2
Structural Failure
G1
G2
G3
G4
G5
G6
Accommodation
Manoeuvring in or Close terminal
In approach Channels/ fairway
En route at sea
Day
Night
No
Yes
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
A16
A17
A18
Machinery
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
Cargo
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24

X1	Poor design calculations
X2	Poor endurance tests
X3	Poor maintenance
X4	Poor inspection
X5	Inadequate personnel
X6	Insufficient attention to repairs
X7	Crew did not pay attention
X8	Deficiencies of manuals
X9	Adverse weather conditions
X10	Poor construction/ purchase of equipment
E1	Inferior quality of structure
E2	Poor condition of equipment
E3	Violation of regulations
E4	Misuse of equipment
Y1	Corrosion
Y2	Cracking
Y3	Deformation
Y4	Navigational failure
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational error

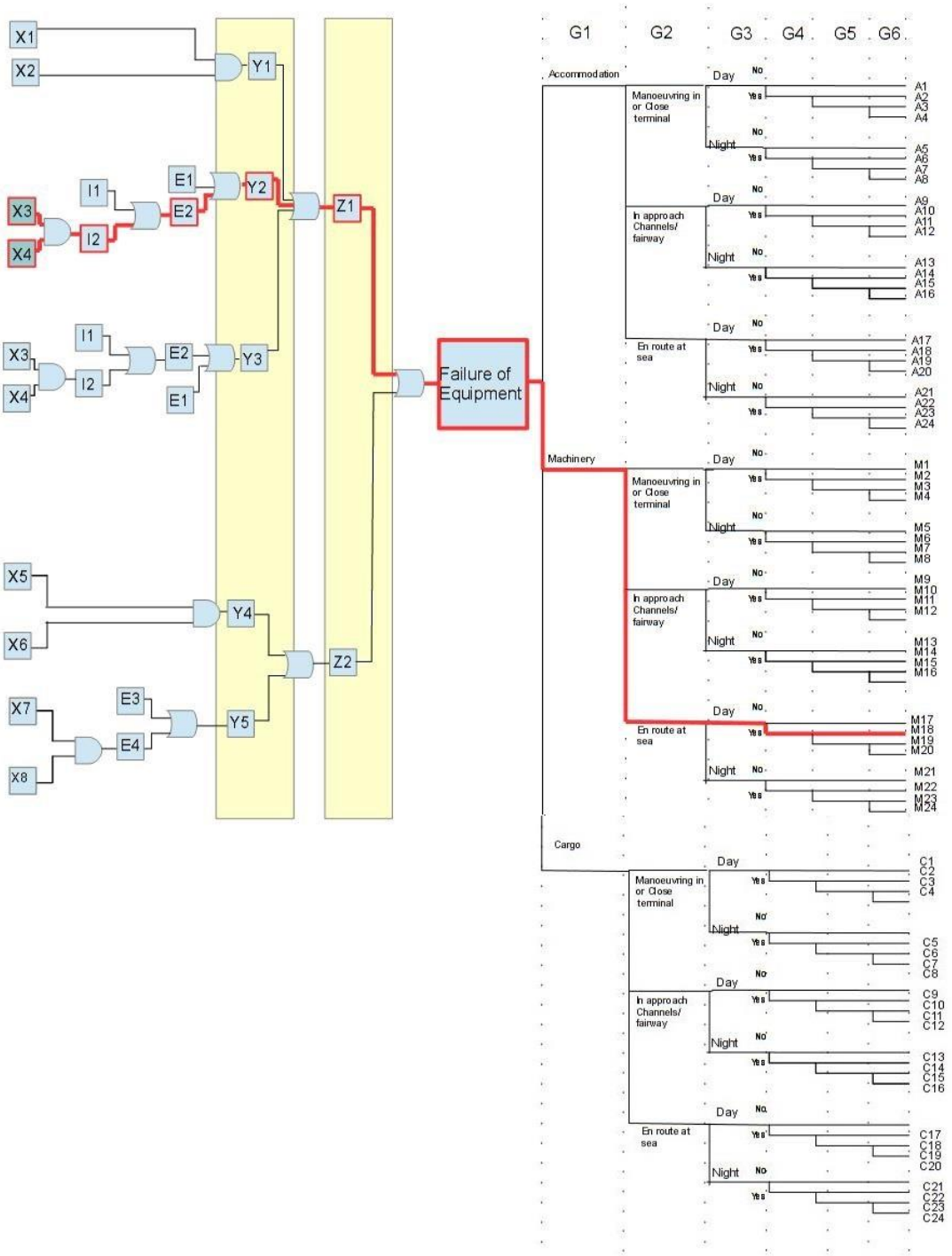
G1	Location
G2	Operational state
G3	Time of day
G4	Consequenct accident
G5	Leakage of LNG
G6	Loss of water tightness
A1	Minor repairable damage to accommodation/ Possible injuries
A2	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A3	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A4	Minor repairable damage to accommodation/ Injuries
A5	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A6	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A7	Minor repairable damage to accommodation/ Possible injuries
A8	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A9	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A10	Minor repairable damage to accommodation/ Injuries
A11	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A12	Very serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A13	Minor repairable damage to accommodation/ Possible injuries
A14	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A15	Worst case: Loss of vessel/Loss of all crew
A16	Minor repairable damage to accommodation/ Injuries
A17	Serious damage to accommodation/ Damage to vessel/ Injuries and fatalities
A18	Worst case: Loss of vessel/Loss of all crew
M1	Minor repairable damage to machinery
M2	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M3	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M4	Minor repairable damage to machinery/ Possible injuries
M5	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M6	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M7	Minor repairable damage to machinery

M8	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M9	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M10	Minor repairable damage to machinery/ Possible injuries
M11	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M12	Very serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M13	Minor repairable damage to machinery
M14	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M15	Worst case: Loss of vessel/Loss of all crew
M16	Minor repairable damage to machinery/ Possible injuries
M17	Serious damage to machinery/ Damage to vessel/ Injuries and fatalities
M18	Worst case: Loss of vessel/Loss of all crew

C1	Minor repairable damage to cargo area
C2	Extended damage to cargo area/ Possible injuries
C3	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C4	Very serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/ Possible environmental pollution
C5	Minor repairable damage to cargo area/ Possible injuries
C6	Extended damage to cargo area/ Possible injuries
C7	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C8	Very serious damage to cont cargo area / Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C9	Minor repairable damage to cargo area
C10	Extended damage to cargo area/ Possible injuries
C11	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C12	Very serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C13	Minor repairable damage to cargo area/ Possible injuries
C14	Extended damage to cargo area/ Possible injuries
C15	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C16	Very serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C17	Minor repairable damage to cargo area
C18	Extended damage to cargo area/ Possible injuries
C19	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C20	Worst case: Loss of vessel/Loss of all crew/Environmental pollution
C21	Minor repairable damage to cargo area/ Possible injuries
C22	Extended damage to cargo area/ Possible injuries
C23	Serious damage to cargo area/ Damage to vessel/ Injuries and fatalities/Possible environmental pollution
C24	Worst case: Loss of vessel/Loss of all crew/Environmental pollution

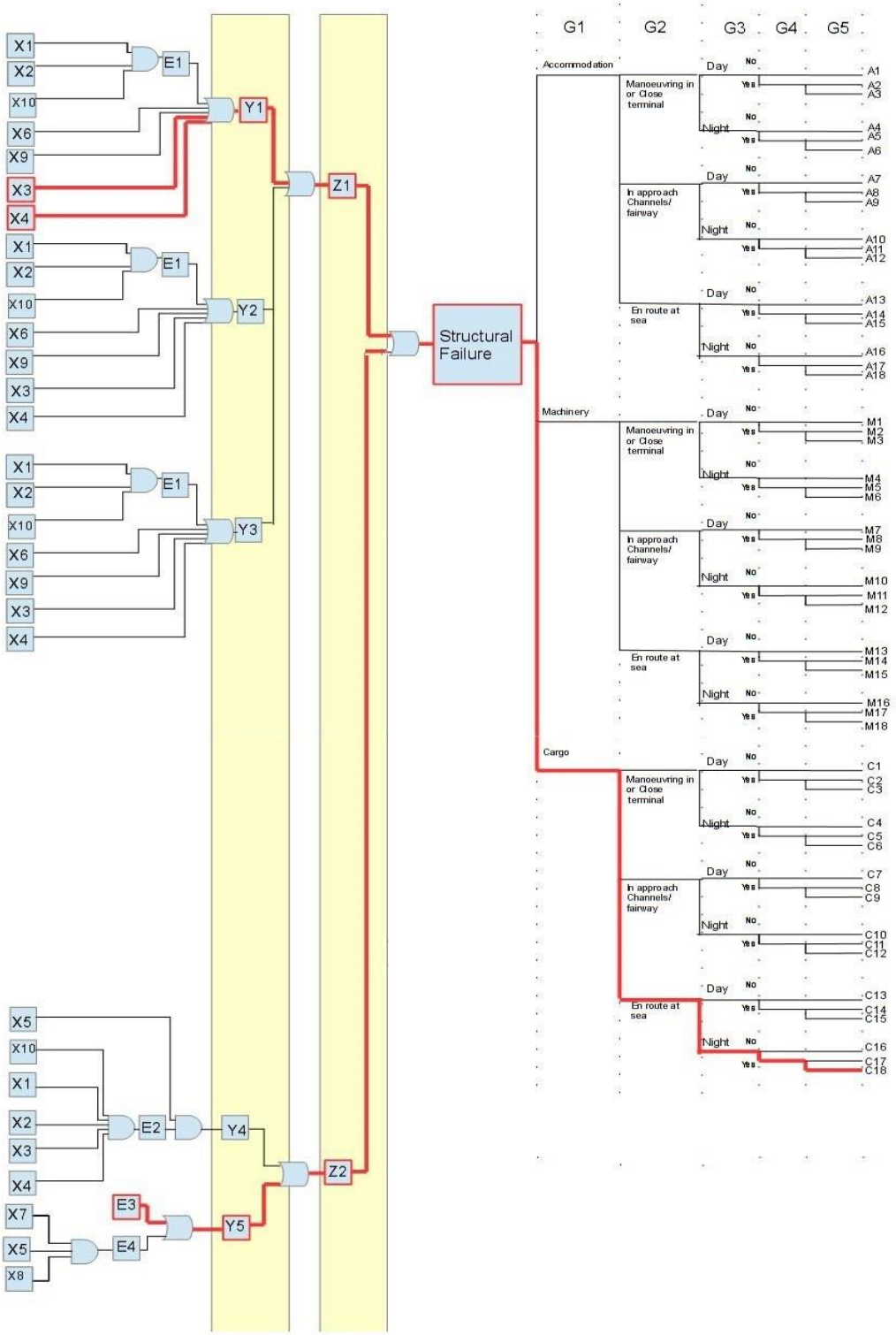
Annex 2

The ten first bowtie diagrams are related to real accidents and the rest are hypothetical scenrios as presented in previous pages.



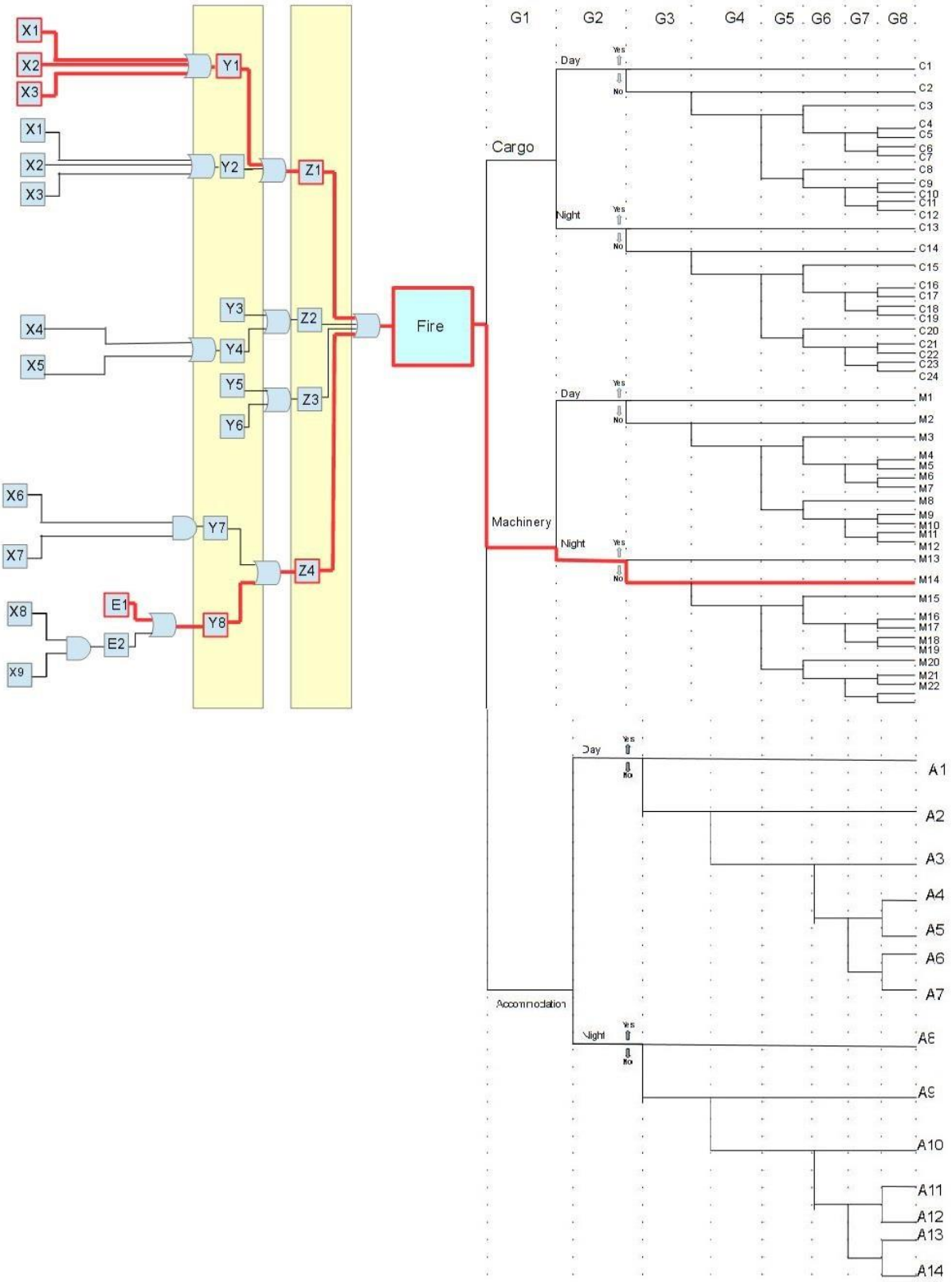
Mv Sonia accident

X3	Poor maintenance of seawater pipe
X4	Poor inspection of seawater pipe
I2	Inattention of the condition of seawater pipe
E2	Poor condition of seawater pipe
Y2	Corrosion of seawater pipe
Z1	Broken off seawater pipe
Top event	Failure of seawater pipe
G1	Engine room
G2	En route
G3	Day
G4	Flooding
M18	Ship flooded/ No injuries



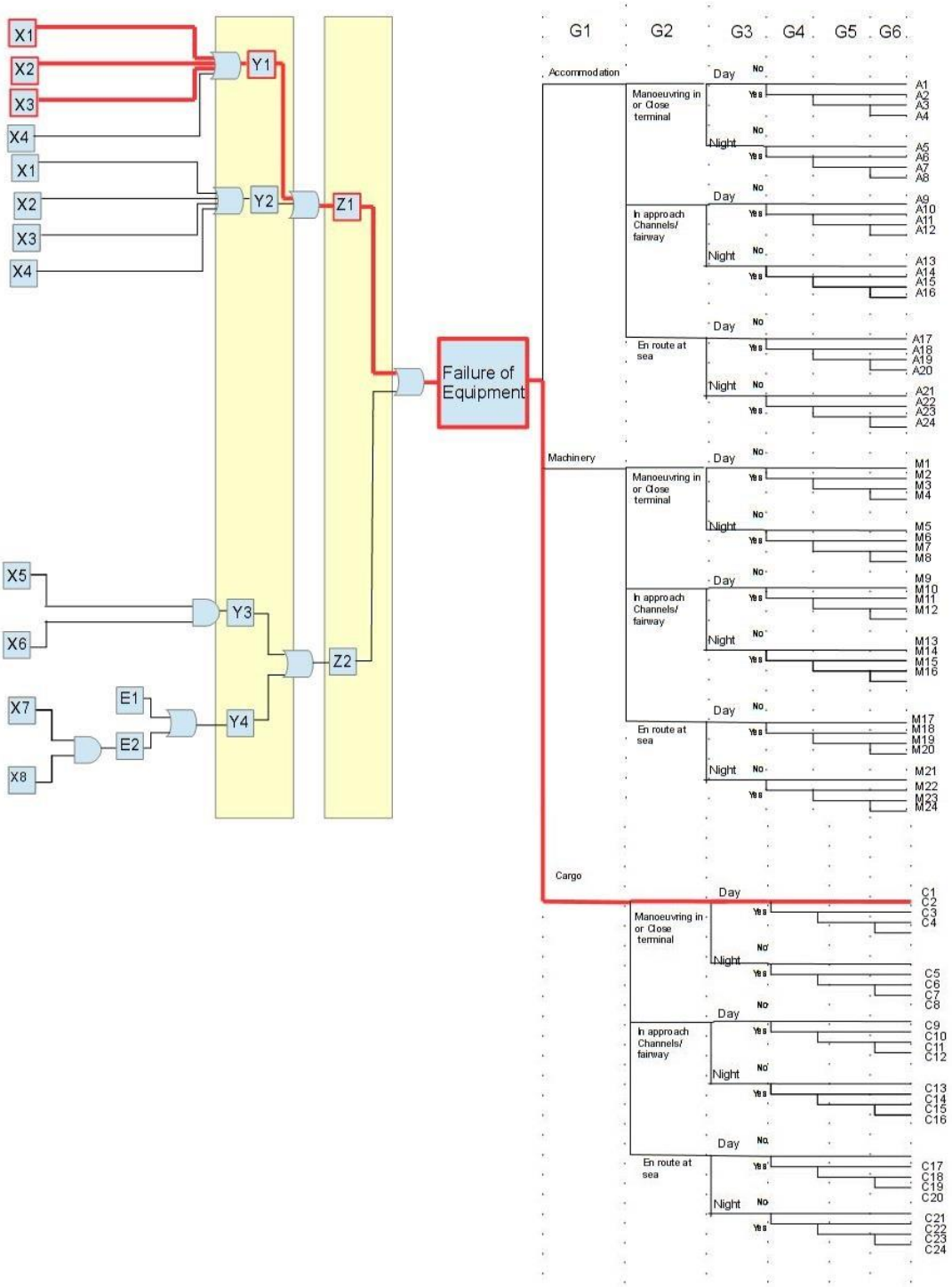
Swanland accident

X3	Poor maintenance of vessel
X4	Poor inspection of vessel
E4	Violation of Maritime Solid Bulk Cargo Code
Y1	Corrosion
Y5	Inappropriate actions
Z1	Poor condition of structure
Z2	Operational errors
Top event	Structural Failure
G1	Midship section (cargo)
G2	En route
G3	Night
G4	Foundering
C18	The vessel sank/ Loss of six crew



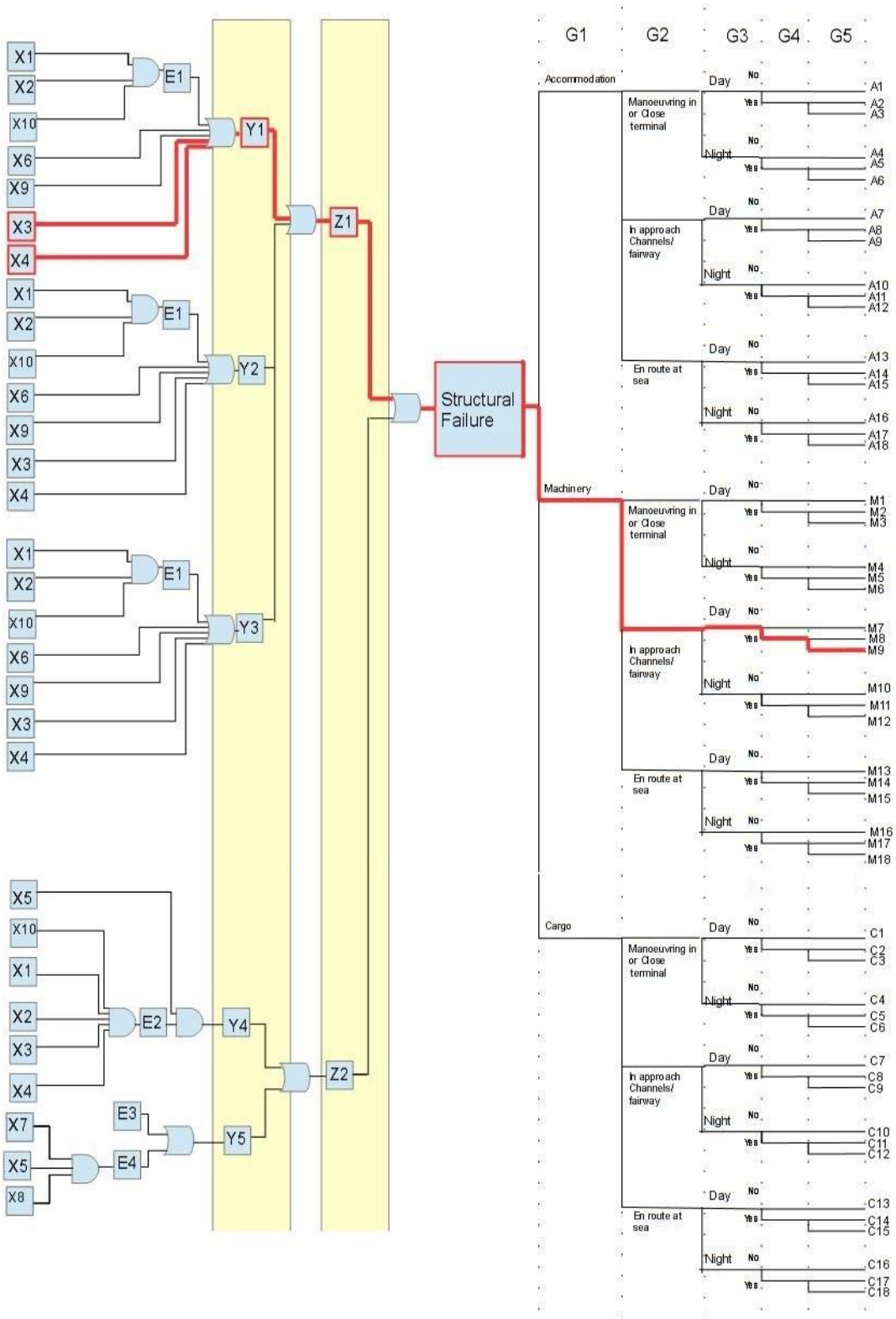
Baltimar Boreas accident

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
E1	Violation of International Maritime Organization guidelines
Y1	Corrosion of fuel hoses
Y8	Inappropriate actions
Z1	Leakage
Z4	Operational errors
Top event	Fire
G1	Engine room
G2	Night
G3	Automatic firefighting failure
G4	Manual firefighting
M14	Electrical system badly damaged/ No injuries



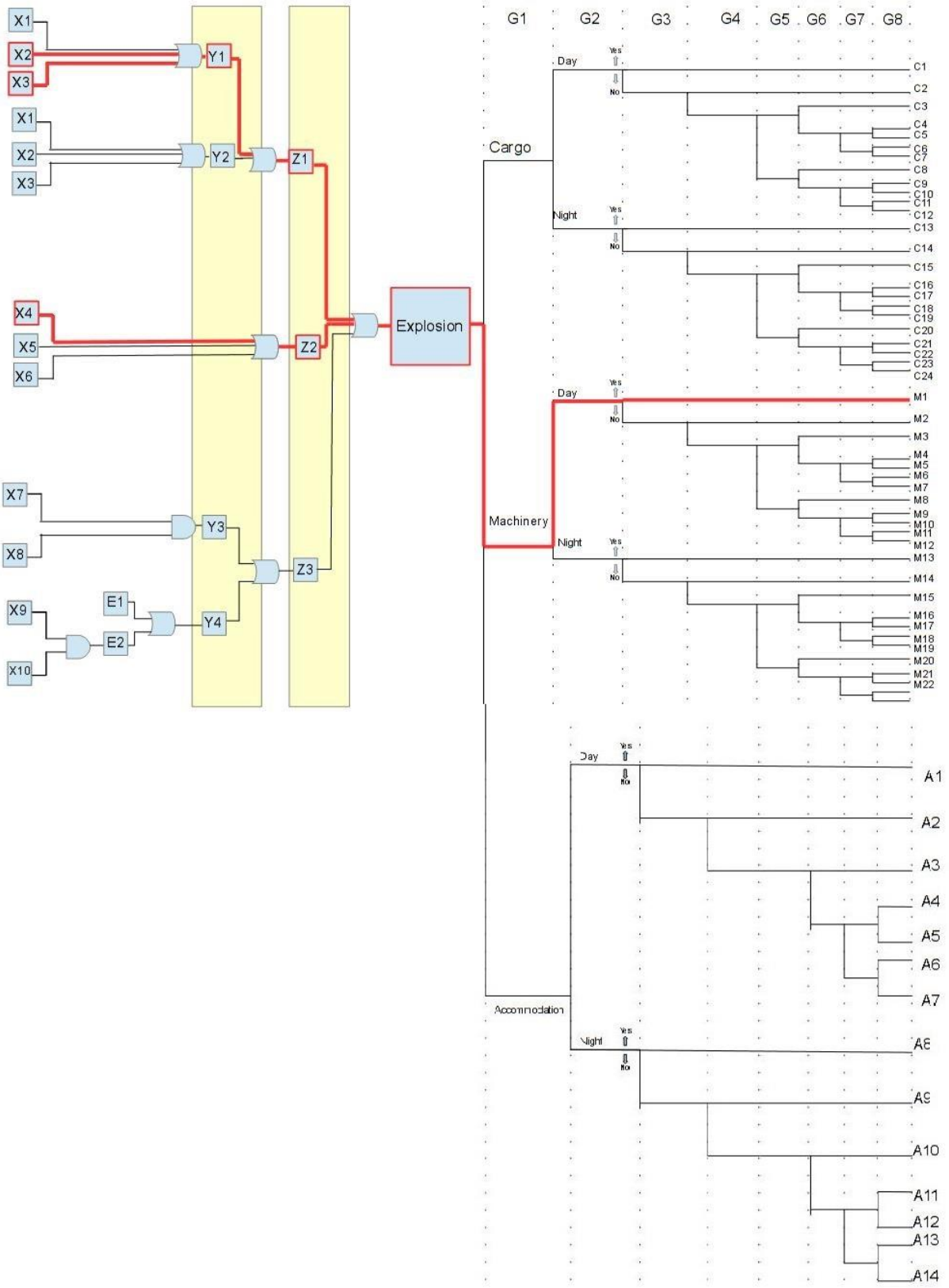
CMS HANJIN LONDON accident

X1	Poor repairs
X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion of tank
Z1	Broken off equipment
Top event	Failure of tank
G1	Cargo
G2	In terminal
G3	Day
C1	8 injured persons

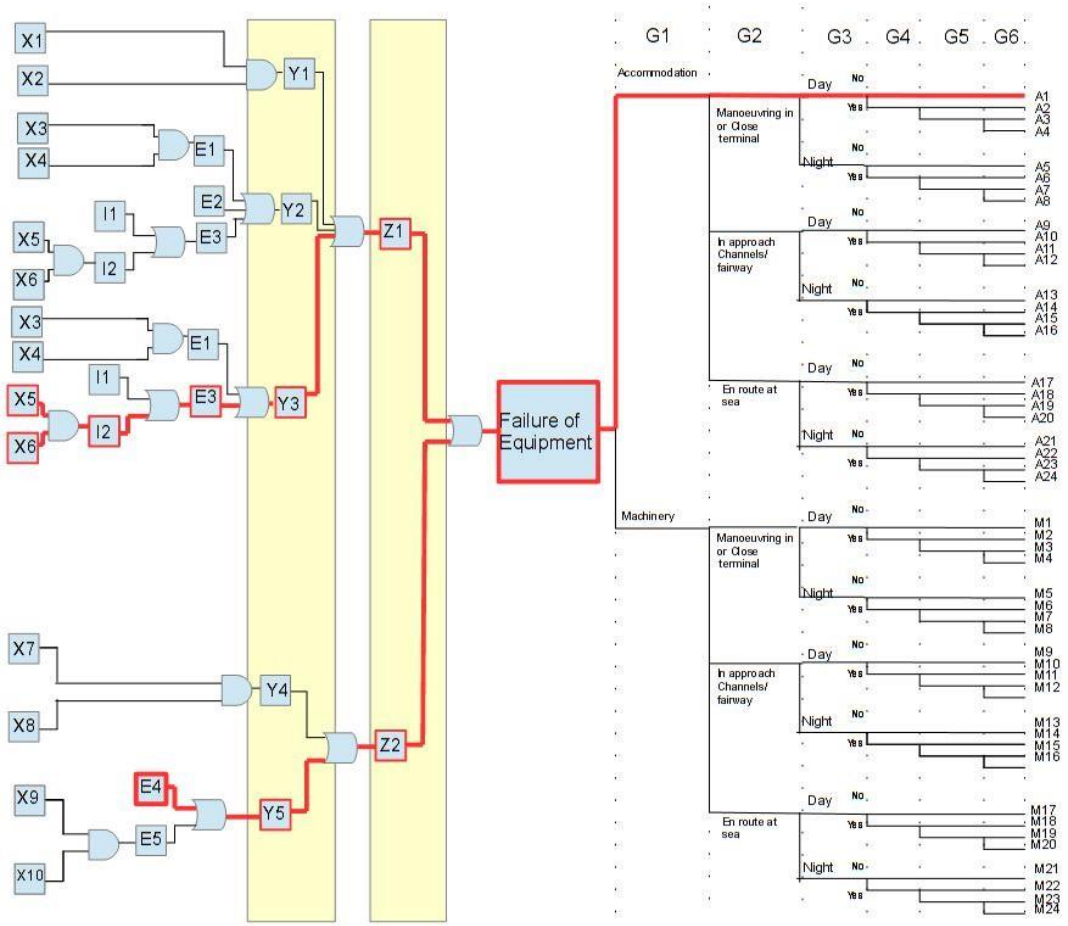


MSC Napoli accident

X3	Poor maintenance of engine room
X4	Poor inspection of engine room
I2	Inattention of the condition of engine room
Y2	Corrosion
Z1	Poor condition of engine room
Top event	Structural Failure
G1	Engine room
G2	On passage in a channel
G3	Day
G4	Flooding/ Catastrophic failure
G5	Loss of water tightness
M9	The vessel sank/ No fatalities

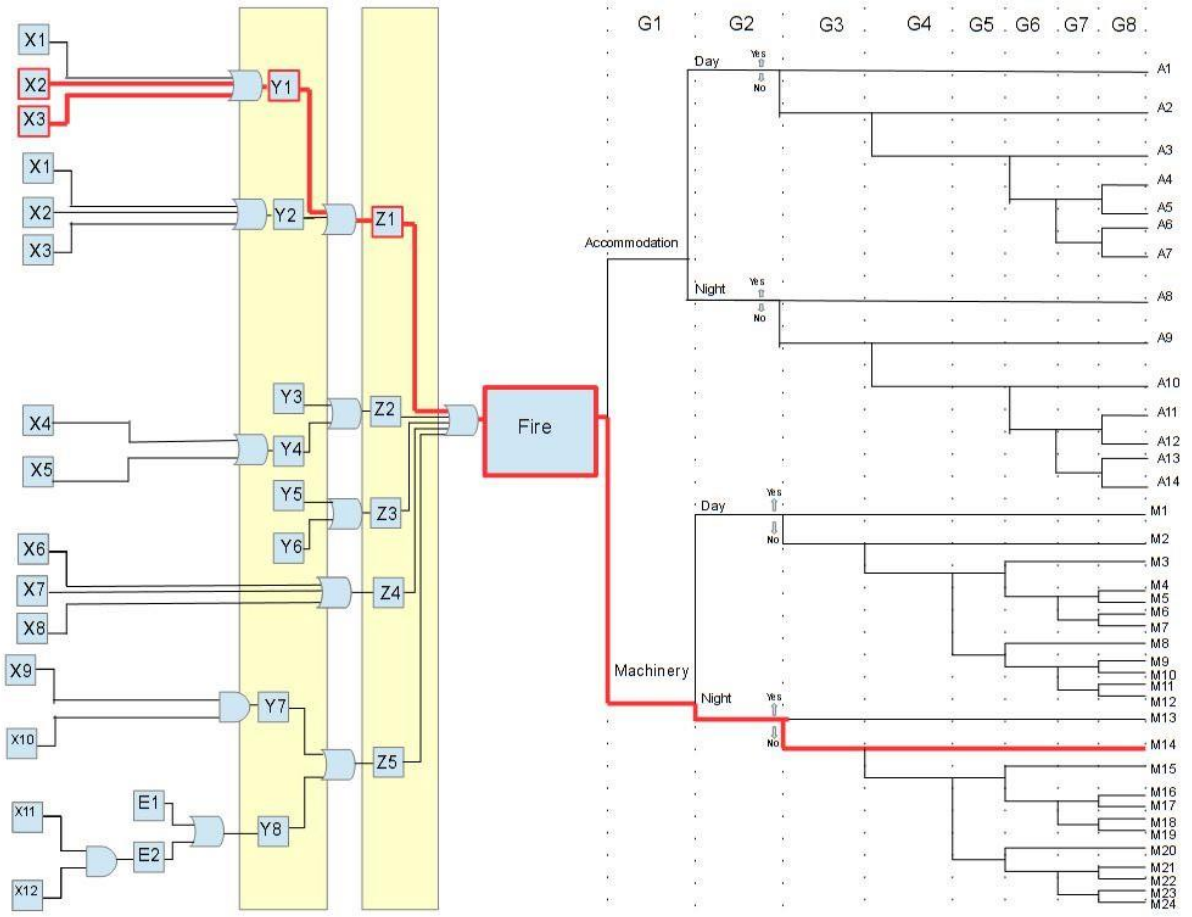

X1
X2
X3
Y1
X1
X2
X3
Y2
Z1
X4
X5
X6
Z2
Explosion
X7
X8
Y3
Z3
X9
E1
Y4
X10
E2
G1
G2
G3
G4
G5
G6
G7
G8
Cargo
Day
Night
Machinery
Day
Night
Accommodation
Day
Night
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
M19
M20
M21
M22
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14

X2	Poor maintenance
X3	Poor inspection
X4	Incautious practice of metalworking
Y1	Corrosion
Z1	Leakage of explosive materials
Z2	Sparks
Top event	Explosion
G1	Engine room
G2	Day
M1	No fire/ no extended damage to engine room/ One fatality



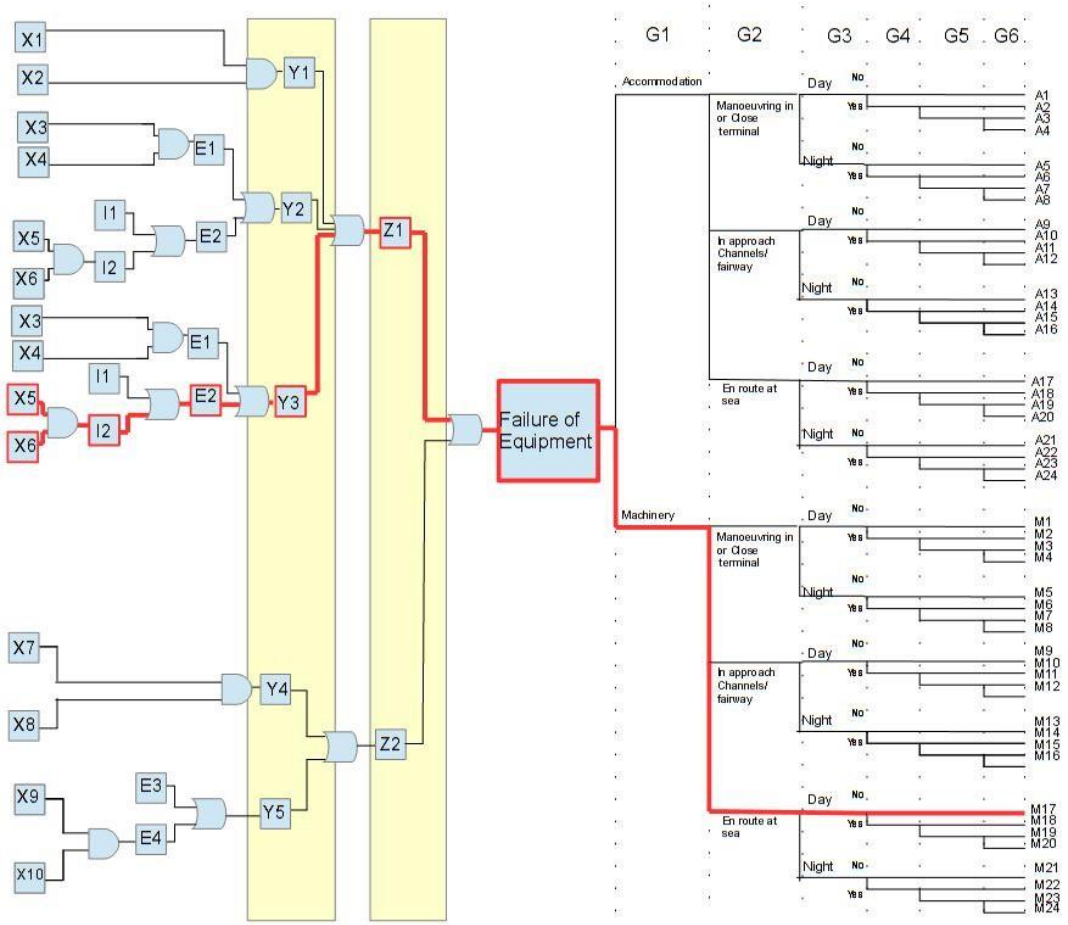
Ben-My-Chree accident

X5	Poor maintenance
X6	Poor inspection
I2	Inattentions
E3	Poor condition of the equipment
E4	Violation of regulations(SMS)
Y1	Cracks
Y5	Inappropriate actions
Z1	Broken off equipment
Z2	Operational errors
Top event	Failure of passenger access structure
G1	Accommodation
G2	In terminal
G3	Day
A1	Ship’s shell door frame buckled and shore side passenger access structure collapsed



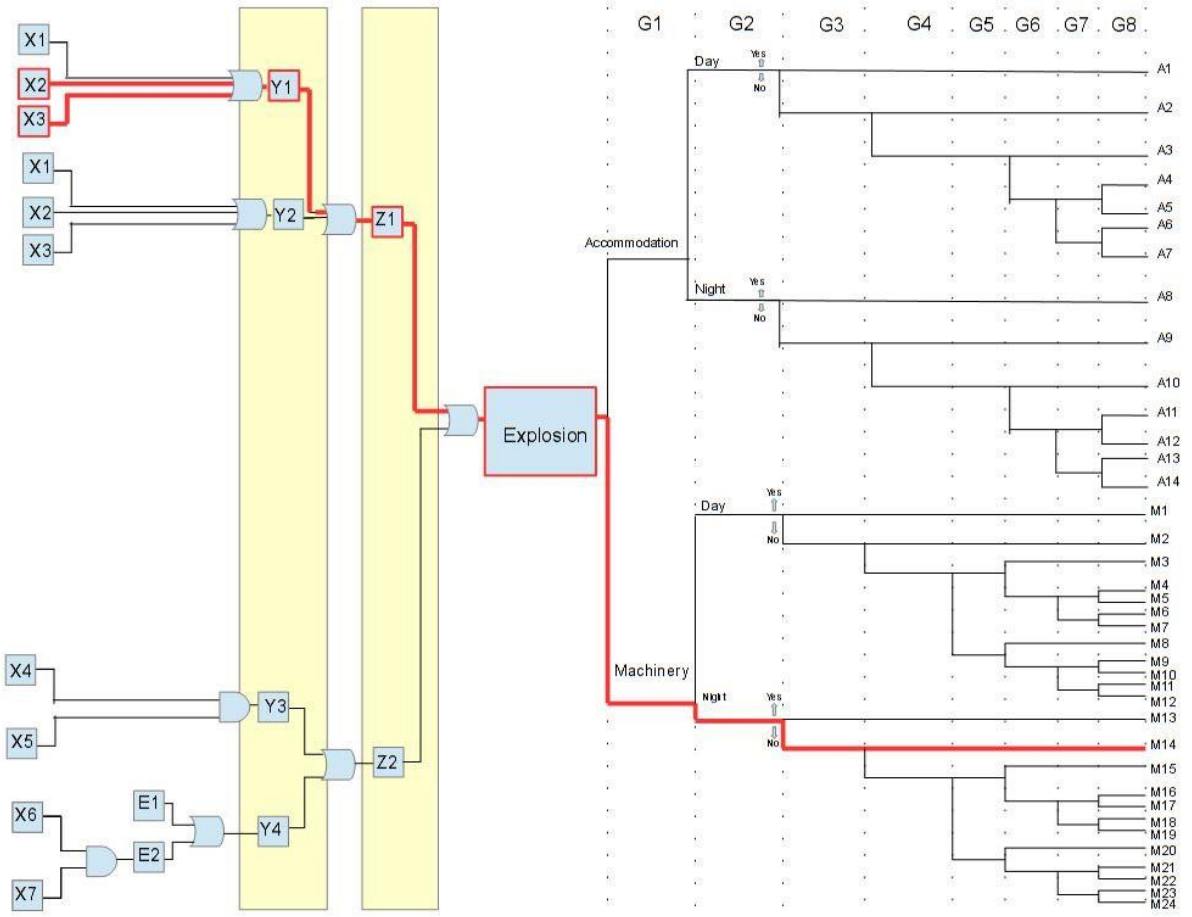
Sea Wind accident

X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Leakage of fuel oil
Top event	Fire
G1	Engine room
G2	Night
G3	Automatic firefighting failure
G4	Manual firefighting
M14	Extensive damage to the engine room



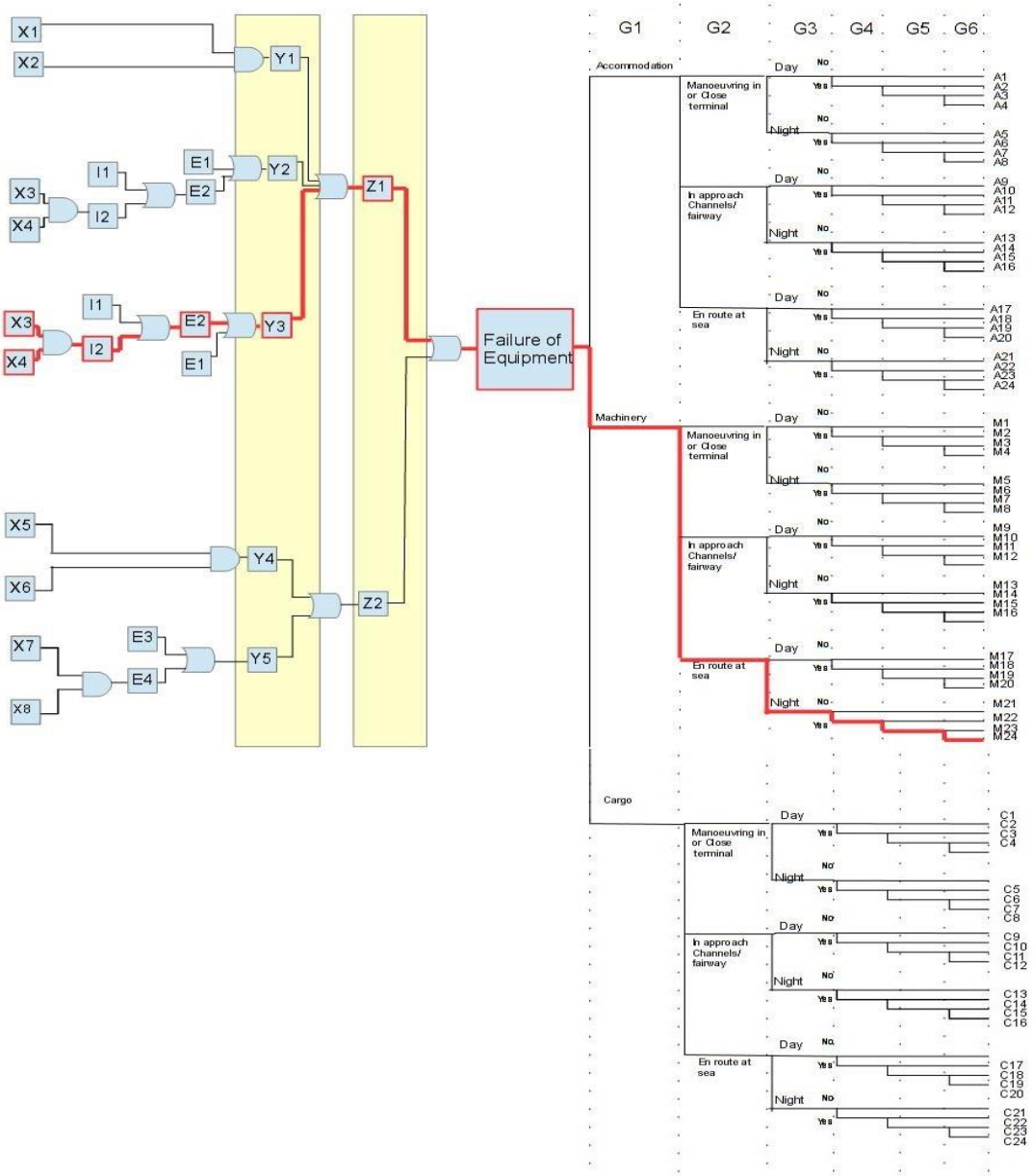
Island Princess accident

X5	Poor maintenance
X6	Poor inspection
I2	Inattentions
E2	Poor condition of the equipment
Y3	Cracking
Z1	Broken off equipment
Top event	Failure of port gas boiler
G1	Engine room
G2	En route
G3	Day
M17	2 fatalities/ 3 injuries



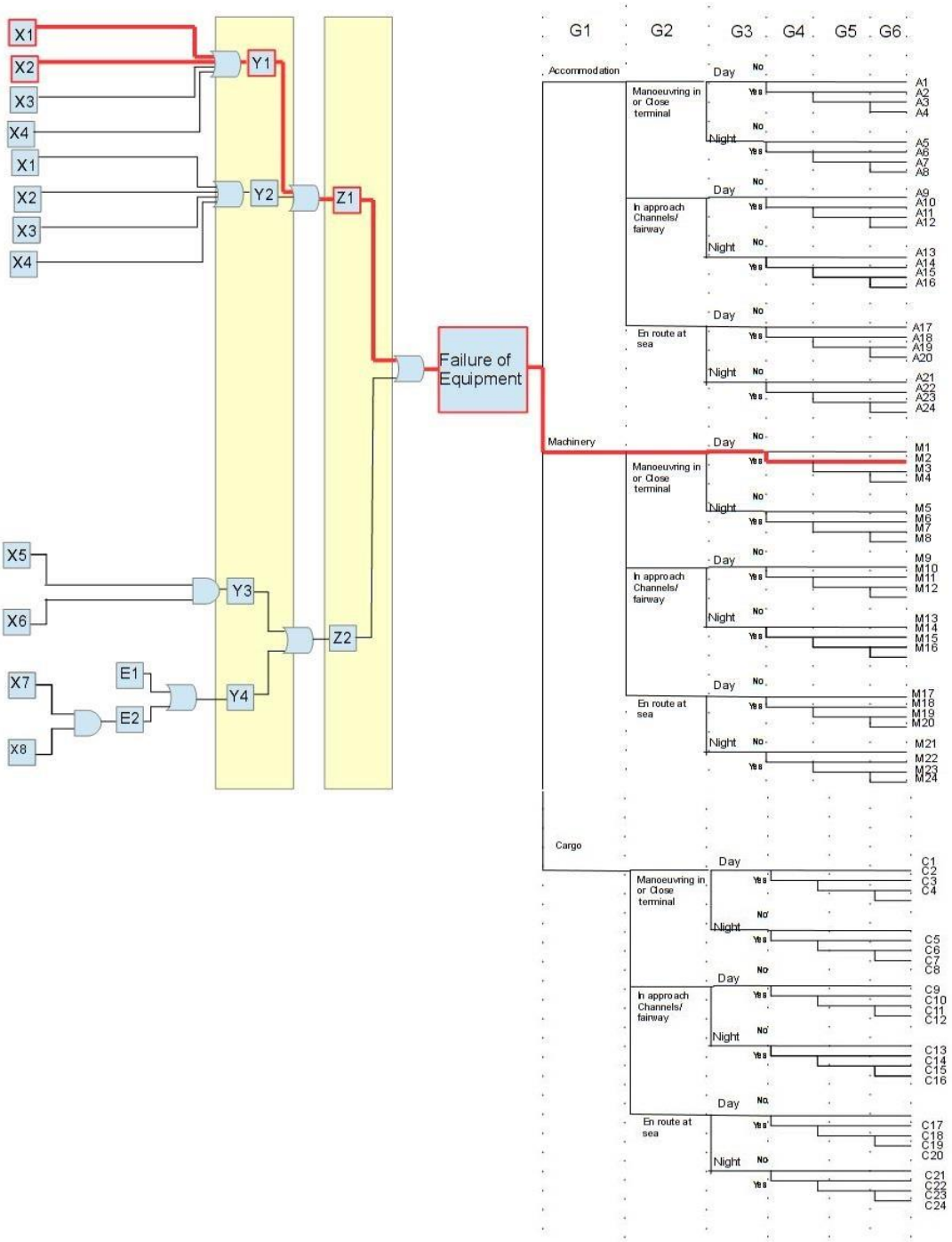
RMS Queen Mary 2 accident

X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Dielectric fluid vapour sprayed out
Top event	Fire
G1	Engine room
G2	Night
G3	Automatic firefighting failure
G4	Manual firefighting
M14	Two capacitors damaged, bus bars and insulators on several others damaged, bulkhead stiffeners buckled, enclosure panel doors blown out, steel doors damaged.



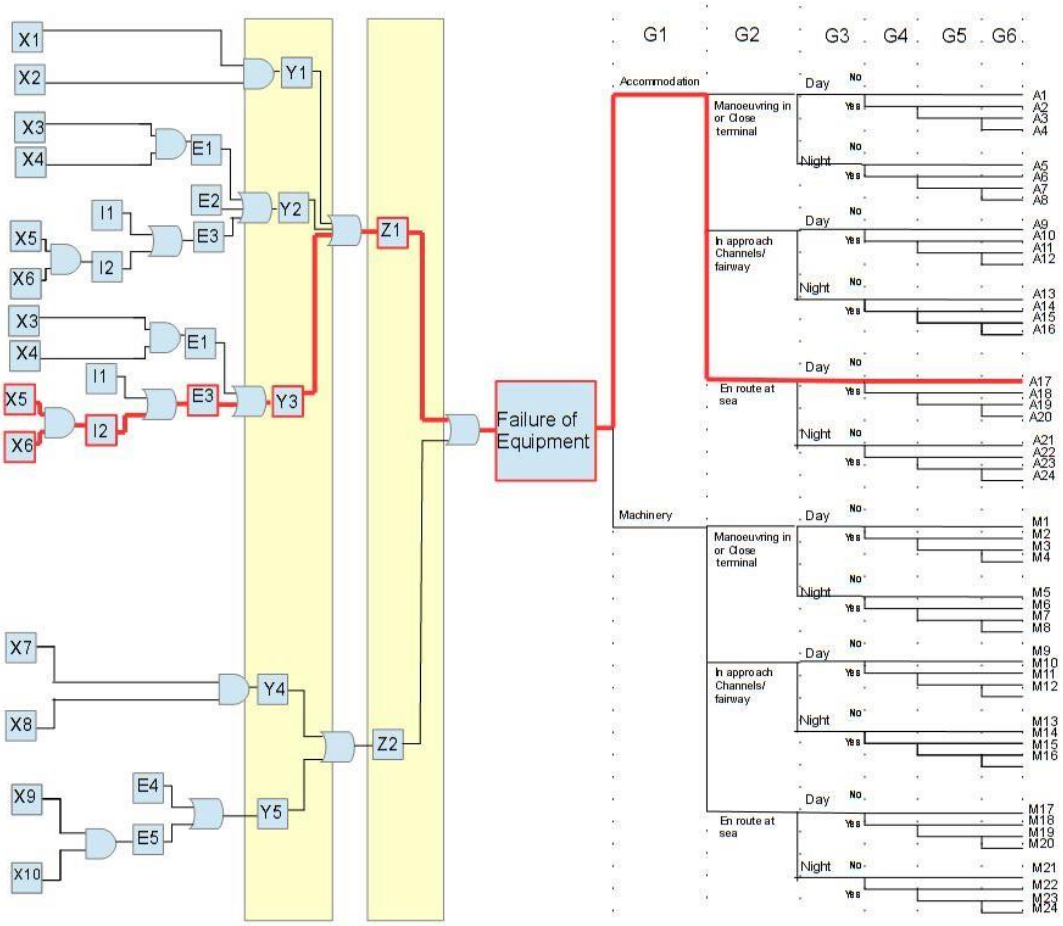
Scenario of general cargo ship

X3	Poor maintenance
X4	Poor inspection
I2	Inattentions
E2	Poor condition of equipment
Y2	Corrosion
Z1	Broken off equipment
Top event	Failure of equipment
G1	Machinery space
G2	En route
G3	Night
G4	Consequent accident
G5	Damage to structure
G6	Loss of water tightness
M18	Worst case scenario



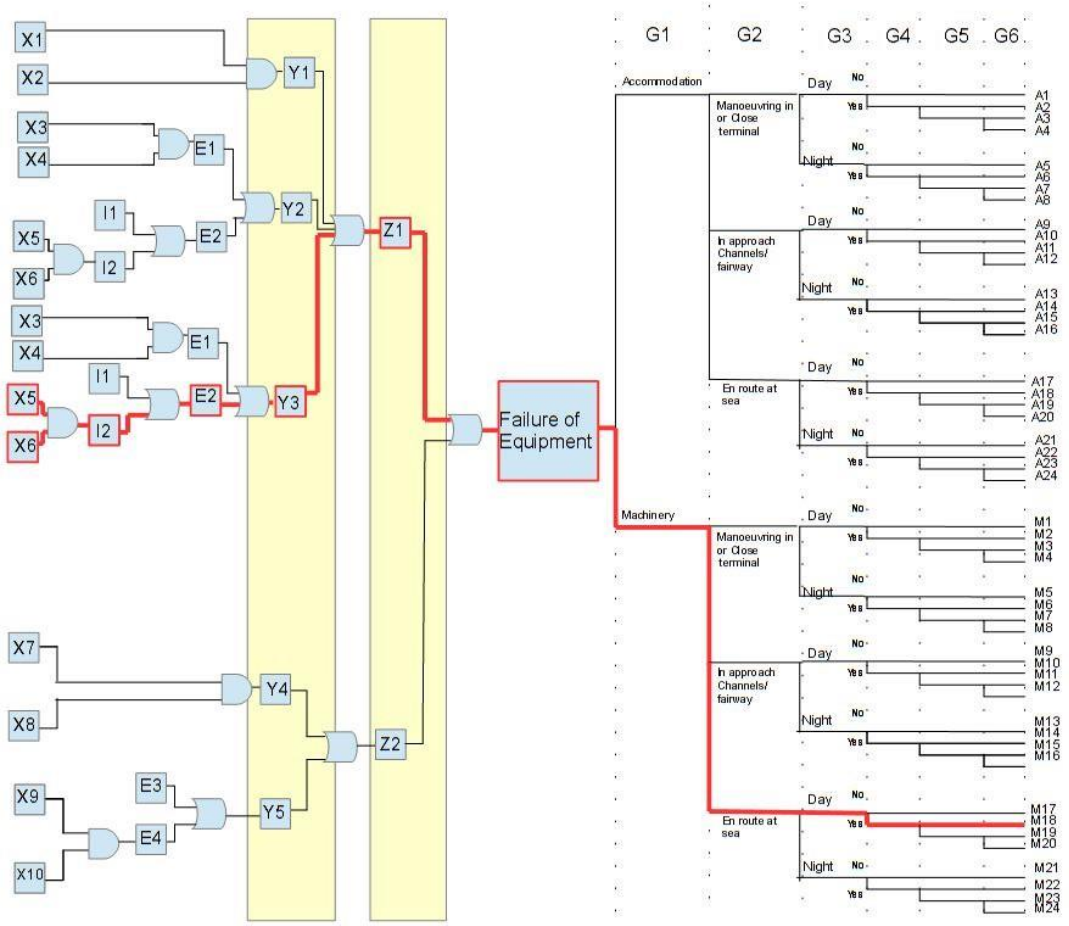
Scenario of container ship

X1	Poor maintenance
Y1	Corrosion
Z1	Broken off equipment
Top event	Failure of equipment
G1	Machinery space
G2	Close to a terminal
G3	Day
G4	Consequent accident
M2	Extended damage to machinery/ Possible injuries



Scenario of passenger ship

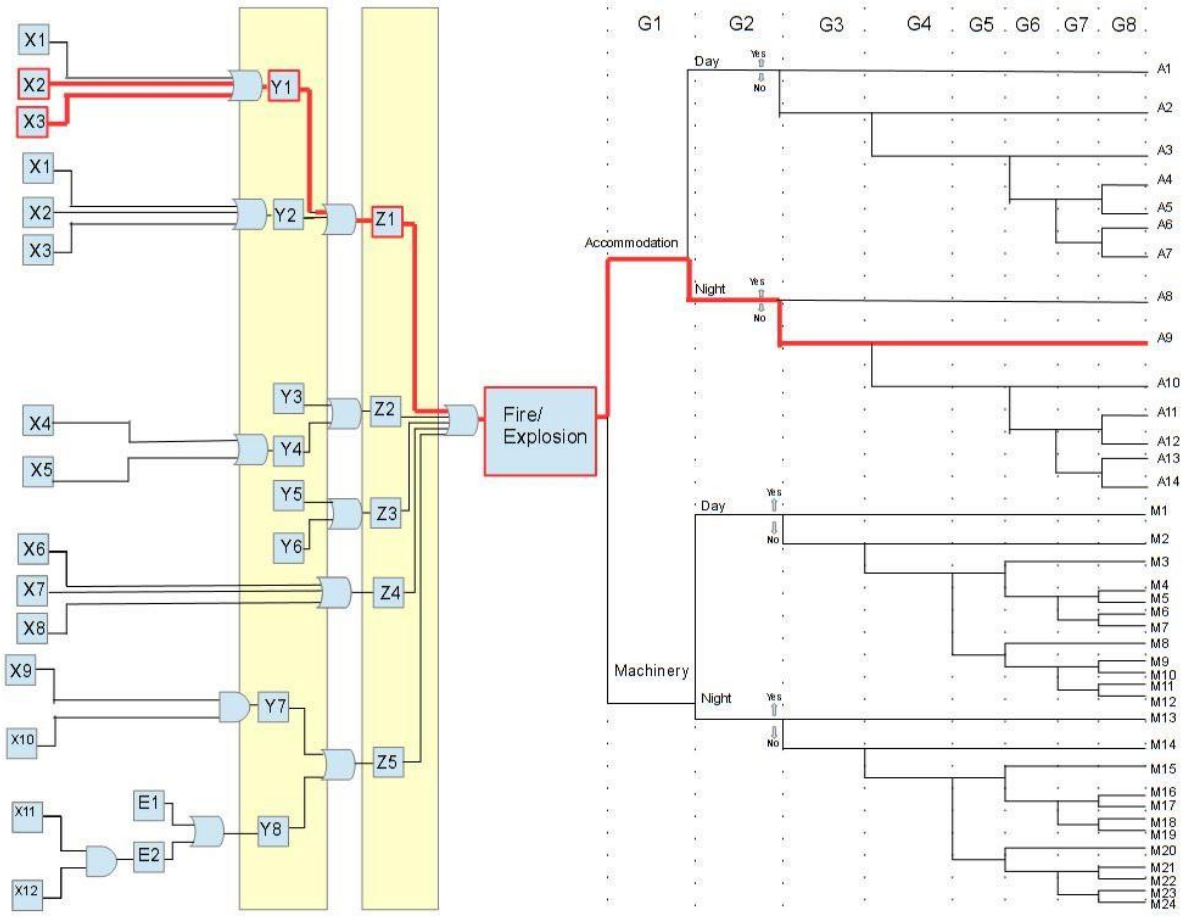
X5	Poor maintenance
X6	Poor inspection
I2	Inattentions
E2	Poor condition of equipment
Y3	Cracking
Z1	Broken off equipment
Top event	Failure of equipment
G1	Accommodation space
G2	En route
G3	Day
G4	No consequent accident
A17	Minor repairable damage to accommodation/ Possible injuries



Scenario of cruise ship

X5	Poor maintenance
X6	Poor inspection

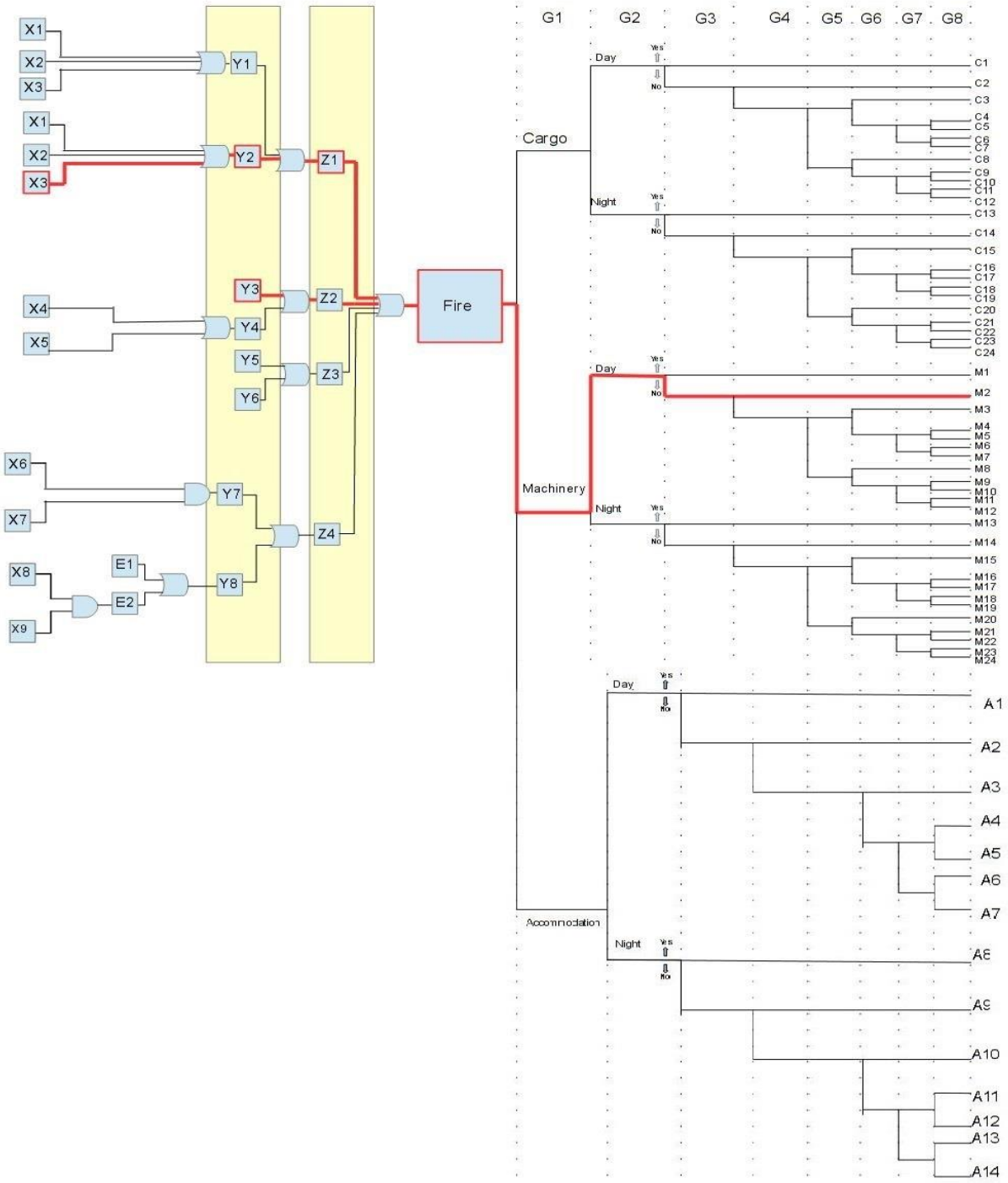
I2	Inattentions
E2	Poor condition of equipment
Y3	Cracking
Z1	Broken off equipment
Top event	Failure of equipment
G1	Machinery space
G2	En route
G3	Day
G4	Consequent accident
M18	Extended damage to machinery/ Possible injuries



Scenario of passenger ship

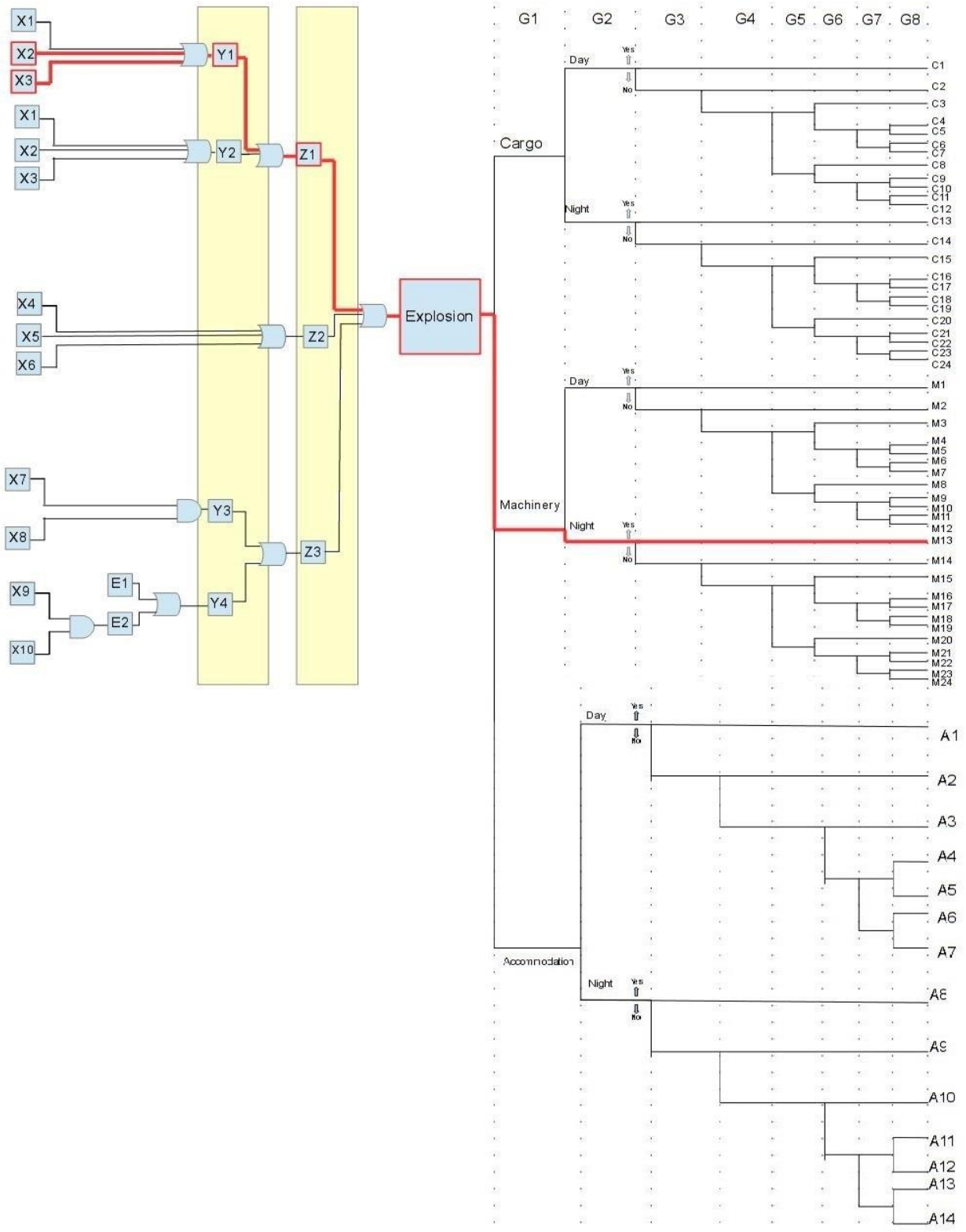
X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Leakage

Top event	Fire
G1	Accommodation space
G2	Night
G3	Automatic firefighting
G4	Manual firefighting
A9	Injuries/fatalities and damage to vessel



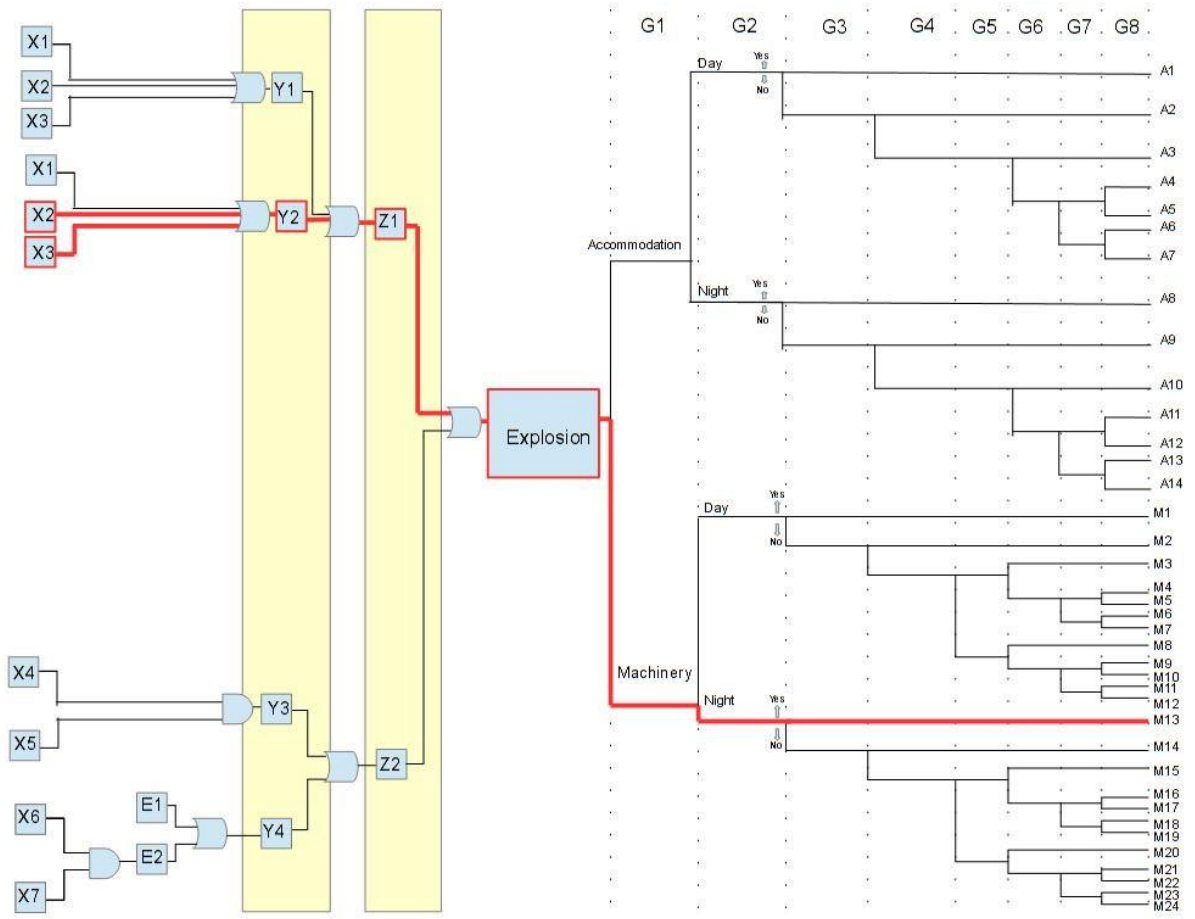
Scenario of general cargo ship

X3	Poor inspection
Y2	Cracking
Y3	Overheating machine
Z1	Leakage
Z2	Inappropriate temperatures
Top event	Fire
G1	Machinery space
G2	Day
G3	Automatic firefighting
G4	Manual firefighting
2	Extended damage to machinery/ Possible damage to vessel



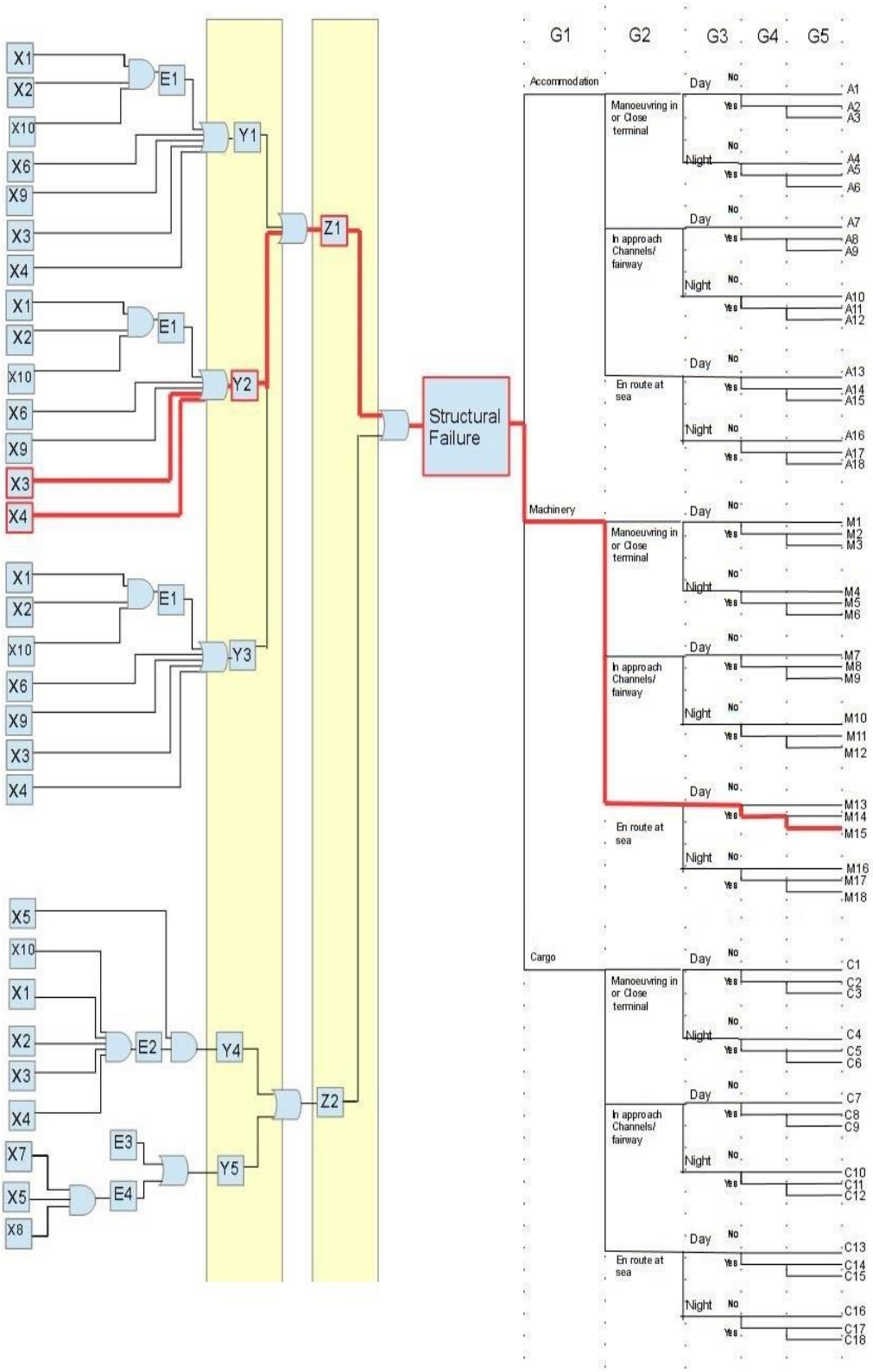
Scenario of container ship

X2	Poor maintenance
X3	Poor inspection
Y1	Corrosion
Z1	Leakage
Top event	Explosion
G1	Machinery space
G2	Night
G3	Automatic firefighting
M13	Minor damage to machinery



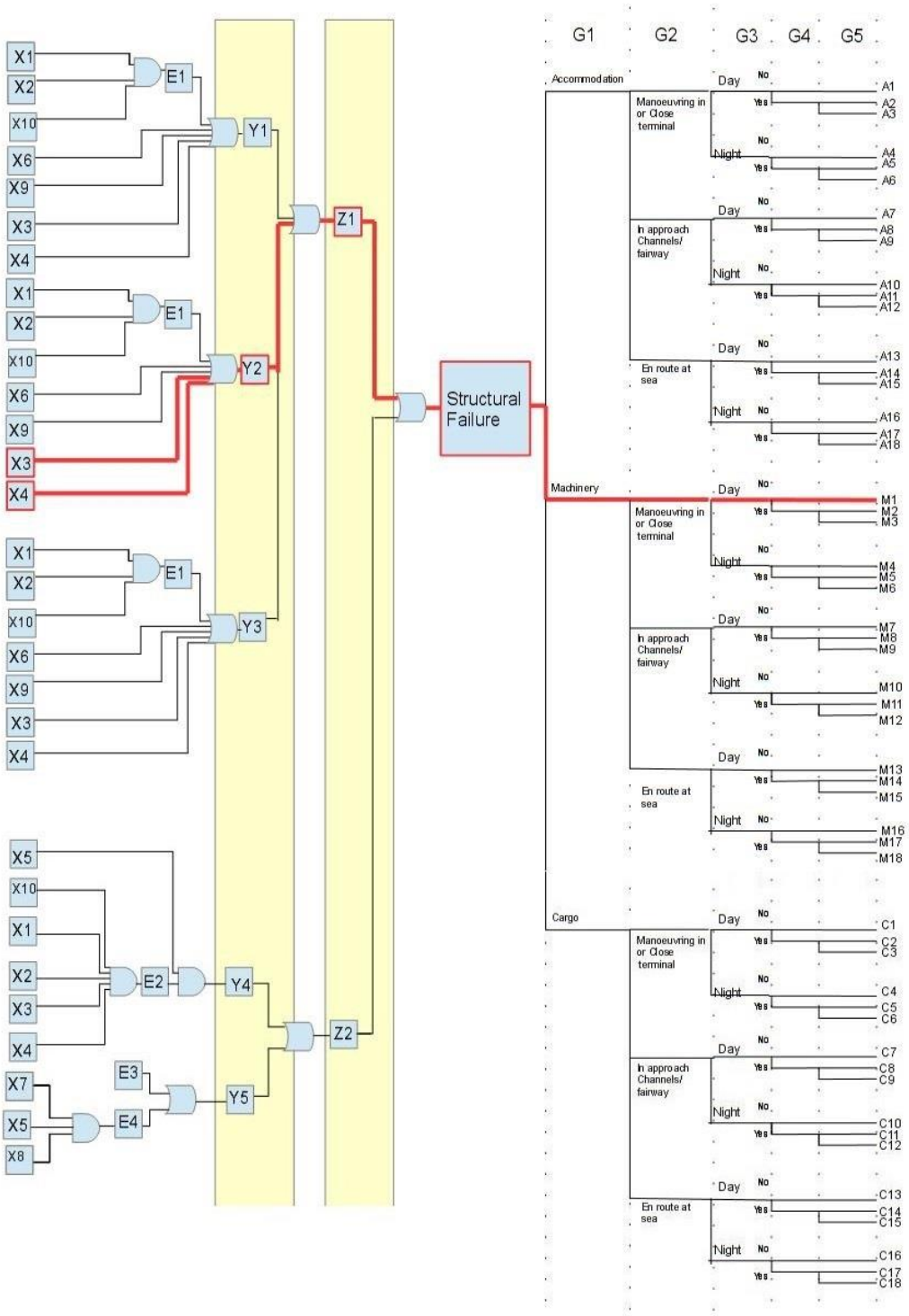
Scenario of cruise ship

X2	Poor maintenance
X3	Poor inspection
Y2	Cracking
Z1	Leakage
Top event	Explosion
G1	Machinery space
G2	Night
G3	Automatic firefighting
M13	Minor damage to machinery



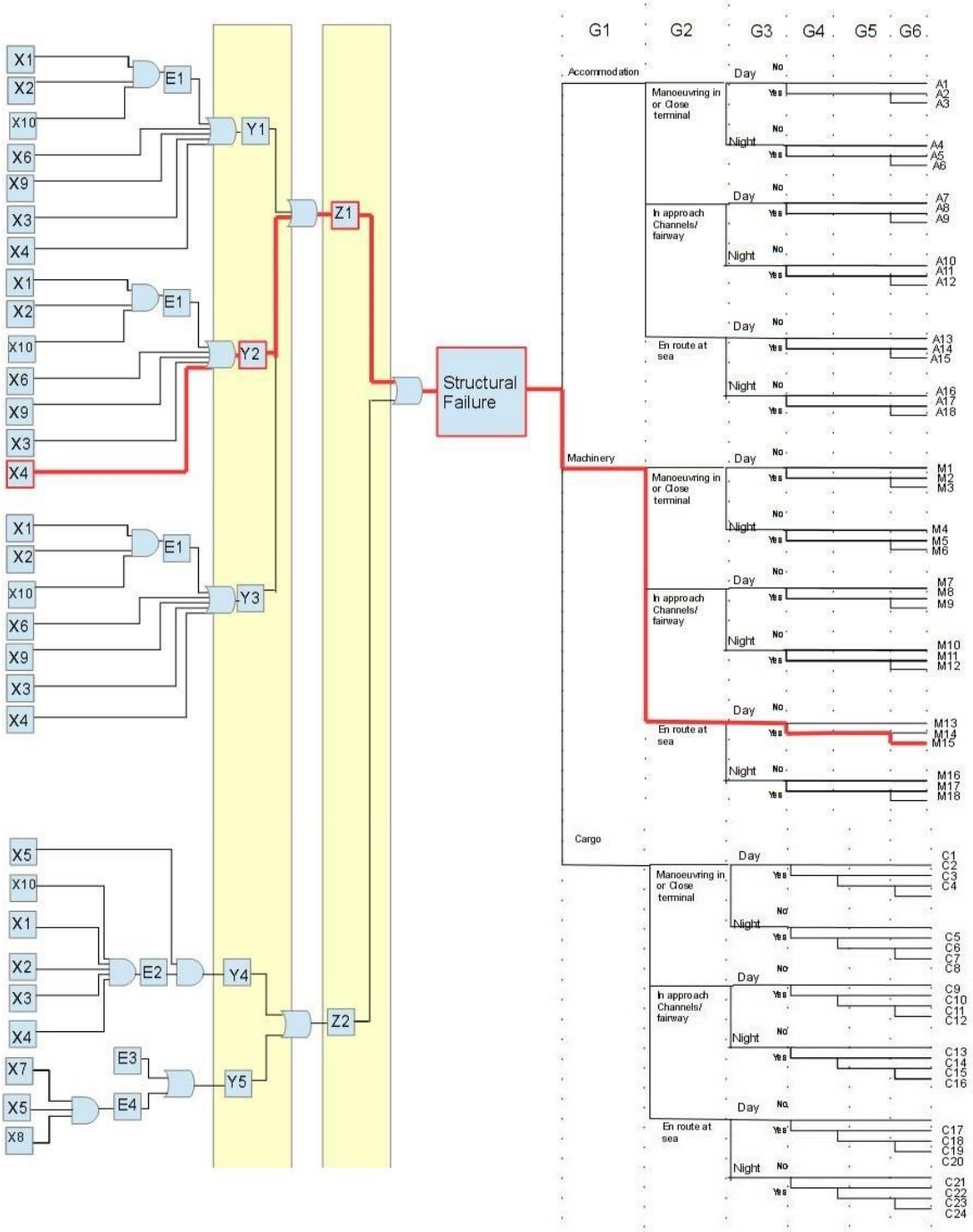
Scenario of container ship

X3	Poor maintenance
X4	Poor inspection
Y2	Cracking
Z1	Poor condition of structure
Top event	Structural failure
G1	Machinery space
G2	En rout at sea
G3	Day
G4	Consequent accident
G5	Loss of water tightness
M15	Worst case



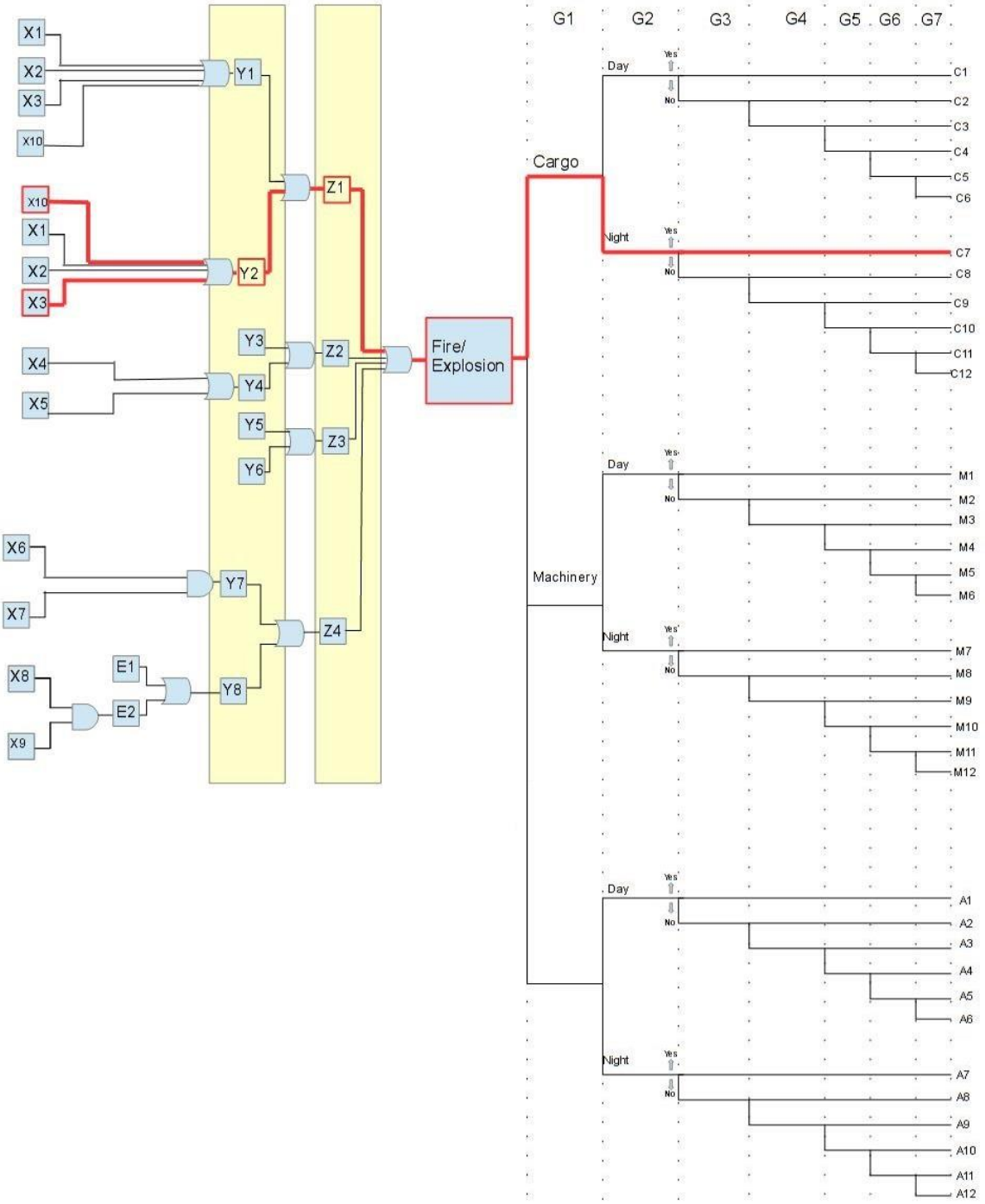
Scenario of general cargo ship

X3	Poor maintenance
X4	Poor inspection
Y2	Cracking
Z1	Poor condition of structure
Top event	Structural failure
G1	Machinery space
G2	Close to terminal
G3	Day
G4	No consequent accident
M1	Minor repairable damage to machinery



Scenario of LNG ship

X4	Poor inspection
Y2	Cracking
Z1	Poor condition of structure
Top event	Structural failure
G1	Machinery space
G2	En route at sea
G3	Day
G4	Consequent accident
G6	Loss of water tightness
M15	Worst case



Scenario of LNG ship

X3	Poor inspection
X10	Sloshing of partially filled tank
Y2	Cracking
Z1	Leakage
Top event	Fire
G1	Cargo space
G2	Night
G3	Automatic firefighting
C7	Damage to cargo area/Possible injuries