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Developing a Risk Model for Fire in Passenger Ships

Based on Bayesian Belief Network

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Submission date: December 2016
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Preface

This master thesis is the final result of the integrated Master of Science programme within Naval architecture, at the department of Marine Technology at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. The thesis counts for 30 credits, and is written during the autumn semester of 2016.

The thesis is a part of an ongoing project called National Ship Risk Model, which is a collaboration between NTNU, Safetec, Norwegian Maritime Authority and Norwegian Coastal Administration. It is recommended that the reader of this thesis has a basic knowledge of risk analysis, marine systems and the maritime industry.

I would like to thank my supervisor professor Stein Haugen at the Department of Marine Technology at NTNU, for help and guidance during this semester. I would also like to thank fellow students for interesting and helpful discussions.

Trondheim, 18th of December 2016

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Summary

Passenger ships, especially cruise ships, are rapidly increasing in size. With larger vessels, comes a greater risk to the passengers if something where to happen. A fire on a passenger vessel can spread quickly, and with as much as thousands of people needing to be evacuated many things could go wrong. The issue of the safety on board is therefore crucial to consider, seeing as the consequences could be tremendous. There are three types of passenger ships; Passenger vessel, RoPax vessel and cruise vessel. It was found that cruise vessels have a higher incident frequency, than the two other types. This complies well with the cruise vessels becoming bigger, and as such carrying a higher risk.

The National Risk Ship Model project aims to develop risk models for ships in Norwegian waters, based on Bayesian Belief Networks. These networks are a presentation of the causes (nodes) for an incident and the relations (arcs) between them. Such a network can be used both quantitatively and qualitatively, and is able to consider the relation between human, organisation and technology. They have also proven to be more flexible than commonly used fault trees.

Risk influencing factors and risk indicators can be used to quantify the nodes. A risk influencing factor is usually not measurable, and risk indicators are therefore used to quantify the factors. Organisational Risk Influencing Method is proposed as a possible method to quantify indicators, factors and nodes. The method is based on assigning factors with indicators for each node, which then are ranked and weighted against each other in order to give values to the node.

The Bayesian Belief Network presented in this thesis is based on already developed networks in the project, and adjusted to the current evet of fire on a passenger ship. It is chosen to divide between different areas on the ship, and focus on the ones that has proven to have the highest risk. This was found to be machinery spaces, galley, laundry, accommodation and car deck. Machinery spaces, is however not included in the network, since a network for fire in machinery spaces already has been developed. Possible factors and indicators were proposed for cabin, galley, housekeeping (laundry) and car deck, which are the second most immediate nodes. The intermediate nodes are set as collective terms for these areas, and are ignition source, flammable material and firefighting measures. Factors and indicators has also been proposed for electrical system, passive fire protection and active firefighting systems. Some of the nodes were similar to what has been presented in another thesis using the same quantification method, and for this case a summary of these findings were presented. Additional research was presented, if it was found, and the factors and indicators for the node in question was adjusted to the current case.

As for data worth mentioning it was found that the frequency for severe incidents when regarding fire on passenger ships is 4×10^{-3} per ship-year and the expected number of incidents each year was 5.4×10^{-1}. It was also found that the four most hazardous areas stand for 84 % of the areas where a fire occurs. The most common ignition sources were found to be electrical, cigarettes, hot surface or spontaneous combustion, and they stand for 79 % of the incidents.

Sammendrag

Passasjerskip, og da spesielt cruiseskip, øker stadig i størrelse. Med større skip, øker ogs risikoen for passasjerene dersom noe skulle skje. En brann på et passasjerskip kan fort spre seg, og med som mange som tusen passasjerer som trenger å evakuere, kan mye gå galt. Spørsmålet om sikkerhet om bord er derfor veldig viktig å ta i betraktning, ettersom konsekvensene kan være fatale. Det er tre typiske passasjerskip; passasjerfartøy, RoPax-fartøy og cruisefartøy. Det ble funnet at cruisefartøy har en større ulykkesfrekvens enn de andre to typene. Dette stemmer overens med det faktum at cruisefartøy øker i størrelse og dermed også bringer med seg en større risiko.

Nasjonal risikomodell for skip er et prosjekt som har som mål å utvikle en risikomodell som kan benyttes for norske skip og skip i norske farvann. Den baserer seg på Bayesianske nettverk. Disse nettverkene er en presentasjon av årsakene (noder) til en hendelse og forholdet mellom disse (buer). Slike nettverk kan brukes til både kvantitativ og kvalitativ analyse, og de har muligheten til å betrakte forholdet mellom menneske, organisasjon og teknologi. Det har også blitt vist at de er mer fleksible en feiltreanalyser, som ofte blir brukt som årsaksanalyser.

Risikopåvirkende faktorer og risikoindikatorer kan brukes til å kvantifisere nodene i nettverket. En risikopåvirkende faktor er vanligvis ikke målbar, og risikoindikatorer er derfor brukt til å kvantifisere faktorene. Organisatorisk risikopåvirkende metode er foreslått som en mulig metode for å kvantifisere indikatorer, faktorer og noder. Metoden baserer seg på å angi faktorer, med tilhørende indikatorer, til hver enkelt node. Indikatorene og faktorene er deretter vektet og rangert i forhold til hverandre, slik at man kan angi verdier til nodene.

Det Bayesianske nettverket som er presentert i denne oppgaven, er basert på eksisterende nettverk i prosjektet, og deretter justert slik at det passer til den gjeldende hendelsen om brann på passasjerskip. Det er blitt valgt å skille mellom de forskjellige områdene på skipet, og fokusere på de som har høyest risiko. Det ble kommet frem til at dette var maskinerirom, bysse, vaskeri, lugar og bildekk. Maskinerirom, er dog utelatt fra nettverket, da det allerede eksisterer et eget nettverk som tar for seg dette. Mulige faktorer og indikatorer er blitt presentert for lugar, bysse, vaskeri og bildekk, som er satt som nest nærmeste noder. De nærmeste nodene er samlebetegnelser av disse, og er satt som tennkilde, brennbart materiale og brannslukkingstiltak. Faktorer og indikatorer har også blitt forslått for elektrisk system, passivt brannvern og aktive brannslukkingssystem. Noen av nodene i nettverket var like som i en annen masteroppgave der samme kvantifiseringsmetode ble brukt. Her er det presentert et sammendrag av funnen gjort i denne oppgaven, samt at supplerende forskning er presentert dersom dette er blitt funnet. De aktuelle faktorene og indikatorene for disse nodene er justert slik at de passer til hendelsen i denne oppgaven.

Av verdier som er verdt å nevne, så ble det funnet at frekvensen for alvorlige hendelser var per $4x10^{-3}$ skipsår, mens forventet antall hendelser per år var $5.4x10^{-1}$. Det ble også funnet at de mest farlige områdene på skipet sto for å vær opprinnelsesområde for brann i 84 % av tilfellene. De mest vanlige tennkildene ble funnet til å være elektrisitet, sigaretter, varm overflate og spontan antennelse. De sto for 79 % av alle tilfellene.

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Nomenclature

BBN	Bayesian Belief Network
BORA	Barrier and Operational Risk Analysis
CAD	Computer-Aided Design
CCTV	Closed Circuit Television
CPT	Conditional Probability Table
DAG	Directed Acyclic Graph
DNV GL	Det Norske Veritas Germanischer Lloyd
FIREPROOF	EU funded project looking at risk for fire in passenger ship
FSS	Fire Safety Systems
FTA	Fault Tree Analysis
GENIE	Graphical Network Interface
GT	Gross Tonnage
HFACS	Human Factors Analysis and Classification System
IMO	International Maritime Organization
ISM	International Safety Management Code
MAIIF	Marine Accident Investigators' International Forum
NASA TLX	NASA Task Load Index
NCA	Norwegian Coastal Administration
NFPA	National Fire Protection Association
NMA	Norwegian Maritime Authority
NPD	Norwegian Petroleum Directorate
NSRM	National Ship Risk Model
NTNU	Norwegian University of Science and Technology
ORIM	Organizational Risk Influence Model
PFP	Passive Fire Protection
PSA	Petroleum Safety Authority in Norway
QRA	Quantitative Risk Analysis
RBD	Risk-Based Design
RIF	Risk-Indicating Factor
ROPAX	Roll on/Roll off Passenger Ship
SOAM	Systemic Occurrence Analysis Methodology
SOLAS	Convention for Safety of Life at Sea
STCW	International convention for Standards of Training Certification and Watchkeeping of Seafarers
SWAT	Subjective Workload Assessment Technique
WMO	World Meteorological Organization

Chapter 1

Introduction

This chapter introduces the reader to the thesis, with some short background information, information of the "National Ship Risk Model" (NSRM), which the thesis is a part of, the objectives of the thesis, the limitations and the structure of the thesis.

1.1 Background

There has been an increased focus on safety in the maritime industry, ever since the Titanic disaster in 1912 where an unnecessary number of people died due to lack of simple safety measures. As a reaction to this, the International Convention for Safety of Life at Sea (SOLAS) was adopted in 1914 and ever since then it has been amended several times, lastly in 1998, to keep up with changes and developments in the industry. The norm within risk management have always been a tendency to learn from the past, after disasters has happened. However, lately it has become more common to implement risk into the design process, where safety is used as an objective rather as a constraint. This makes it possible to come up with new and innovative designs that does not necessarily meet the regulations in a direct way, but still are more than good enough seeing as risk analyses prove that they are more than good enough. This use of risk management makes for the possibility to make safer ships, and with the fast change and development in technology today, it may be hard for the regulations to keep up to speed.

Passenger ships, especially cruise ships, are rapidly increasing in size. The cruise industry has become more popular and available to the common man in the last years, and therefore there is a demand for larger vessels to meet the demand in the marked. With larger vessels, comes a greater risk to the passengers if something where to happen. Especially out in the open sea. A fire on a passenger vessel can spread quickly, and with thousands of people needing to be evacuated many things could go wrong. The issue of the safety on board is therefore crucial to consider, seeing as the consequences could be tremendous.

How risk management is performed may vary from business to business, and the Norwegian Maritime Authority and the Norwegian Coastal Administration is collaborating with NTNU and Safetec in making a joint risk model for the ships in Norwegian waters and for Norwegian Ships. The project is called "National Ship Risk Model" (NSRM), and in the long term it aims to be utilized to calculate the risk for Norwegian ships and ships in Norwegian waters. One also hopes that the model can be utilized as a tool for investigation of accidents/incidents. The model uses Bayesian Belief Networks (BBN) to calculate the risk, prioritize improvements in regulatory framework, prioritize the supervising activity, to determine acceptable deviations from the regulatory framework etc. An important prerequisite for many of the areas of use is to establish relevant data so that quantification of the model is possible.

Up until today the project has developed risk models for collision between ships, grounding, fire in machinery room and capsizing. Another important situation to consider is the case of fire in large areas, other than machinery room. Here, passenger ships are particularly important to consider. Seeing as, mentioned above, the consequences can be tremendous in such a vessel with many humans on board. The BBNs on grounding and uncontrolled fire in machine room where researched further in two master thesis's ((Azizpour, 2016) and (Baumgärtner, 2016)), written during the spring semester of 2016, at department of production and quality engineering here at NTNU. Some of the research found in these thesis's is used further in this thesis.

1.2 Objective

The objectives of this thesis are as follows:

- Develop a risk model for fire in passenger ships. The model is to be based on BBN and be built with a basis in the other already developed models.
- Perform a literature study to find relevant data sources for the different nodes in the model.
- Identify missing data and suggest possible sources for data and methods for collecting data.

1.3 Scope and limitations

The thesis is limited by the knowledge and data gathered through the literature study performed. It is focused on the hotel functions of the ship, only looking at the most hazardous areas, accept from machinery spaces which is covered in an already developed network that focus on only this.

As a result of only a certain amount of knowledge and time available for this work, it is hard to determine how good, valuable and measurable the factors, indicators and the network is. This validation of the proposed solutions, is discussed and proposed as further work.

1.4 Structure of the thesis

The thesis starts with an introduction to passenger ships and fire safety within these, presenting some relevant research papers and their main findings. Chapter 3 is the result of the literature study of Bayesian Belief Networks, and give some introductory information on this subject. Chapter 4 presents the theory of risk influencing factors and risk indicators. It describes the different types of factors and indicators, and ends with a proposed quantitative method of quantifying the RIFs and nodes in the network. Chapter 5 gives some information on the developed network for fire in passenger ships, discussing why certain choices were made and how it is built up. Chapter 6, then presents the proposed factors and indicators for different nodes. Chapter 7 and 8 presents further work and conclusion, respectively.

The developed network is attached in Appendix A.

Chapter 2

Fire safety in Passenger ships

According to Cai, Konovessis, and Vassalos (2014), investigations has shown that fire-related scenarios, together with flooding, makes for more than 90 % of the total risk regarding loss of life on a passenger ship. These types of events leads to the decision of abandoning ship almost 100 % of the time (Cai et al., 2014), making them quite important to consider.

A few definitions that are important to notice, when talking about risk for fire in passenger ships are the definitions of passengers, passenger ship and fire. SOLAS' definition of a passenger is that

> A passenger is every person other than (i) the master and the members of the crew or other persons employed or engaged in any capacity on board a ship on the business of that ship; and (ii) a child under one year of age (IMO, 2002).

Which implies that a passenger is not trained personnel on board the ship, i.e. they are not drilled on what to do in case of different types of emergencies and incidents. A passenger ship is defined by SOLAS as "a ship which carries more than twelve passengers" (IMO, 2002). Meaning that a passenger ship, by this definition, could be everything from a small car ferry or a high-speed craft carrying at least thirteen passengers, to a large cruise vessel carrying thousands of passengers. A fire has four stages; ignition, growth, full development and decay (Themelis & Spyrou, 2012). Meaning that before there is fire, one may have smoke, sparks, heat or other sources that could lead to the first stage of a fire; ignition. This has been an important aspect to consider when constructing the BBN in this thesis.

Passenger ships exist in different types, typically passenger vessel, RoPax vessel or cruise vessel (Eleftheria, Apostolos, & Markos, 2016) . RoPax stands for Roll on/Roll off Passenger vessel, meaning that it Is a combination of a passenger and cargo vessel. Roll on/Roll off, means that it can roll the cargo on and off with ramps in e.g., the stern and are able to bring passenger cars on the trip (Amdahl et al., 2015). Passenger and RoPax vessels are smaller vessels, built for shorter trips. Whilst cruise vessels are larger, and built for longer trips, typically for a week or two. A passenger ship can be divided into two different functions; Hotel functions and ship functions. Hotel functions typically consists of passenger cabins, restaurants, bars and shops. Ship functions are the functions required to bring the vessel and hotel operations from one port to another. A simple sketch, showing the different functions and their elements is presented in Figure 1 (Lois, Wang, Wall, & Ruxton, 2004).

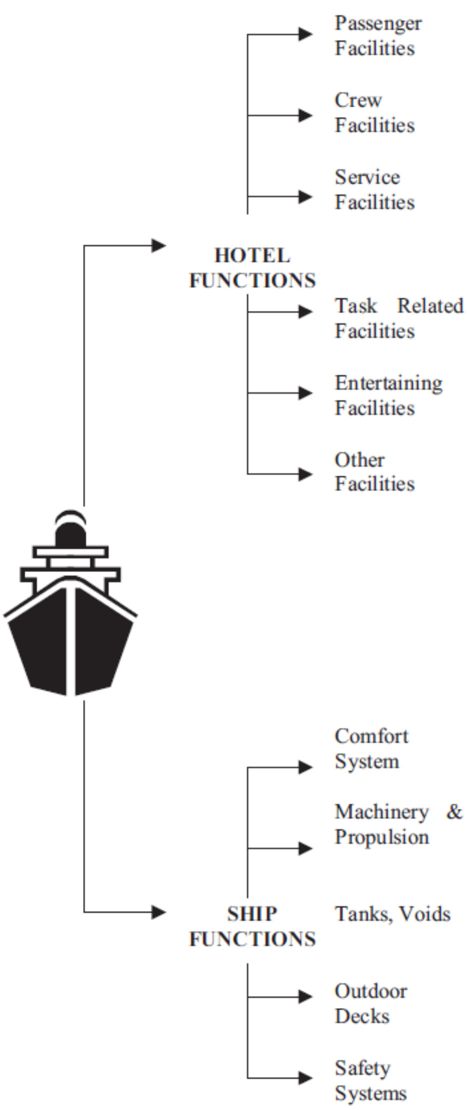

Figure 1 - Sketch showing the different elements of hotel functions and ship operation on a passenger cruise ship (Lois et al.,2004).

Fire safety on passenger ships is mainly governed by the SOLAS convention, adopted by the International Maritime Organization (IMO) (IMO, 2016b) and the Fire Safety Systems (FSS) Code (IMO, 2016a) & (Themelis & Spyrou, 2012). In addition, IMO has the International Safety Management (ISM) Code for passenger ships and the International Convention on Standards of Training, Certification and Watch keeping for Seafarers (STCW). These conventions takes the human element side of shipping into consideration (IMO, 2016d). Newer design of passenger ships tends to be bigger and bigger, carrying more and more passengers and a significantly higher risk for loss of life than old vessels. Even though passenger ships only stand for 6 % of the total fire incidents among ships, the risk is much higher on these vessels due to the high number of passengers (Vassalos, 2006). Seeing as fire on board passenger ships usually leads to abandoning ship, and evacuating a large number of passenger at sea is a complex and difficult task, looking at causes for fire and what may prevent it is an important aspect, when designing such a vessel.

Passengers are not trained on what they should do or where they should go in case of a fire, thereby increasing the risk for bigger consequences than for trained personnel (IMO, 2016d). It is also well established that during evacuation, the consequences for human life are high. With poisonous gases, exposure to heat and poor visibility due to smoke, the fire exposes the humans on board for a great risk (Vassalos, 2006).

The fire accident on the Scandinavian Star in 1990 (Store Norske Store Norske Leksikon, 2016), is an example of how bad the outcome can be when there is a fire on board a passenger vessel. As much as 158 passengers died, and in the aftermath of the incident, a number of concerns regarding the fire protection and evacuation was raised (IMO, 2016a). With novel ship designs being bigger, there has been an issue with traditional fire safety regulations being inadequate. There are two main causes for this, where the first is that the regulations impose inapplicable and unnecessary constraints to these designs. Further, they are usually not able to keep up with the new developments that has been made, and so the design does not satisfy the regulations. This may lead to unsafe design, because they are freed from the rules by default (CORDIS, 2015). The trend in other industries such as aviation and civil architecture is that there is a performance-based design code. Such a trend is being observed more in the maritime industry

as well, making it possible to make novel designs that are safe enough even though they do not comply with the regulations (Vassalos, 2006).
Risk-based design (RBD) has through the last few years become a state-of-the-art design methodology that supports the focus on safety in the design process. Instead of treating safety as a constraint, RBD treats safety as an objective. This makes it possible to make more cost-effective designs that satisfies the safety demands, which is particularly important for safety-critical ships such as large cruise ships (Papanikolaou, 2009).

An EU funded project called FIREPROOF aimed to consider the issue of new regulations and recent development in designs not keeping up with each other. The objective of the project was to develop a probabilistic regulatory framework for maritime fire safety. The framework aims to be similar to the already established probabilistic damage stability (CORDIS, 2015). The research from this project has been the basis for several articles focusing on fire safety in passenger safety (Ventikos, 2013), (Themelis & Spyrou, 2012), (Spyrou, Themelis, & Nikolaou, 2013), (Pawling, Grandison, Lohrmann, Mermiris, & Dias, 2012).

Ventikos (2013) used data retrieved in FIREPROOF, and developed a database. From this it was observed when and where most fire accidents in passenger ships happen. The research showed that most of the fires in passenger ships happens in machinery spaces and galleys, workshops and laundry rooms, accommodation spaces for moderate fire risk and accommodation for greater fire risk. Accommodation spaces for moderate fire risk are cabins, for both crew and passengers, whilst accommodation spaces for greater fire risk are crew areas and common areas such as casino and dining room. All in all, these four space categories stand for a total of 84 % of areas where fire occurs in passenger ships. Further the most common ignition sources where electrical chargers, cigarettes, hot surfaces and spontaneous combustion, which in total stand for 79 % of the causes for fire occurrence (Ventikos, 2013). Table 1 shows the accident frequencies presented by Ventikos (2013), for both all incidents and severe incidents, in the case of fire on passenger ships.

Table 1 - Frequency rates for risk of fire on passenger ship (Ventikos, 2013)

	All incidents	**Severe incidents**
Average frequency/ship-year	3.284	$4x10^{-3}$
Expected number of events/year	410.25	$5.4x10^{-1}$

A study by Eleftheria et al. (2016), did statistical analysis of the risk level of the operating world fleet. The study found the frequency of total losses, in a RoPax vessel in case of fire/explosion, these are presented in Table 2.

Table 2 - Frequency for total loss in case of fire or explosion of different passenger ships (Eleftheria et al., 2016)

Vessel type	**Freq. of total loss**
Cruise vessel	4.77E-04
Passenger vessel	2.30E-04
RoPax vessel	3.96E-04

As seen in Table 1 and Table 2, the frequencies differ some. However, Ventikos looks at all types of passenger vessels as one and Eleftheria et.al., differs between the three types. As seen in Table 2, the cruise ships have a significantly higher frequency than the other vessels tyoes. This corresponds well, to the issue of cruise vessels getting bigger and bigger and carrying a bigger risk.

Themelis and Spyrou (2012) looked into failure probabilities for insulation and extinguishment, obtaining a method for ranking different designs. Spyrou et al. (2013) looked further into this, and both of these articles used the case of the same passenger cabin and a fire propagating from there (Spyrou et al., 2013) (Themelis & Spyrou, 2012). Pawling et al. (2012) developed a Ship Product Model (SPM) to demonstrate the requirements for future CAD tools, so they would be compatible with a risk-based approach.

The aforementioned articles will be used and discussed further later on, in chapter 6.

Chapter 3

Bayesian belief network

A lot of the research propagating from the FIREPROOF project uses BBNs as a tool in their risk assessments. BBNs have been quite common in other industries for many years, it has however not become more common to use within the maritime industry until recent years. The networks have proven to be better to use than other commonly used analysis tools, such as fault trees, given that they can consider the human and technical element and take into consideration that all questions cannot be answered with a simple yes or no or that the knowledge is incomplete (Rausand, 2011b). This chapter will first give an introduction into Bayesian Belief Networks, before challenges, along with some of the advantages and limitations, of using such networks will be presented.

3.1 Introduction

BBN are directed acyclic graphs, meaning that there can't be any cycles in the network (Hänninen, 2014). A BBN can illustrate the causal relationship between causes and one or more final outcomes in a system. By assigning probabilities to the graph, one will be able to find the probability of the outcome (Rausand, 2011b). A BBN may be either qualitative or quantitative, or both. It is commonly used in risk analysis, and over the last few years it has become more and more common to use with regard to analysing maritime traffic (Hänninen, 2014).

The network is built up by nodes and arcs. The node describes a state or a condition, whilst the arc, which goes between two nodes, illustrate the direction of influence. Figure 2 shows a simple example of a network (Rausand, 2011b).

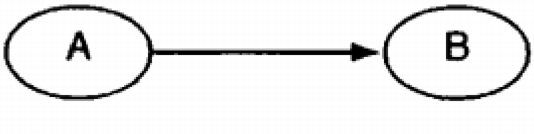

Figure 2 – Simple example of BBN (Rausand, 2011)

Here, node A is the parent node for node B, and node B is a child node. A node with no parents is called a root node, meaning that in this case node A is also a root node. Nodes that can be reached directly from A are the descenders of A, whilst nodes that leads directly to A are called ancestors of A. The arc between the two nodes indicates the direct influence between them, in this case meaning that B depends on A (Rausand, 2011b). By assigning variables to each node, the arcs between them would also specify the independence assumption that must hold between these random variables (Charniak, 1991). Each variable may have two or more states, e.g. true or false, which is one of the most important properties of the BBN. I.e. the fact that one is able to model a situation where the understanding of what is actually going on is incomplete, but causality plays a role (Charniak, 1991).

The calculation of the probabilities in the BBN is based on the theorem called Bayes' rule, provided by the mathematician Thomas Bayes (1702 – 1761). Bayes' rule is given in (1) (Kjærullf & Madsen, 2013).

$$P(X|Y=y) = \frac{P(Y=y)|X)\cdot P(X)}{P(Y=y)} \tag{1}$$

Where $P(Y=y) = \sum_x P(Y=y|X=x) \cdot P(X=x)$. The rule plays a significant role in the calculation of the probabilities in the networks because once the effect of the probability of a cause has been observed, the probability can be inferred. Since the BBN represent causal relationships between the nodes, where one node X is affecting another node Y, the posterior probability distribution P(X | Y = y) needs to be derived. This is where the Bayes' rules comes in handy, and is able to describe this relation between influencing factors (Kjærullf & Madsen, 2013).

As mentioned above, a BBN may be either qualitative or quantitative. In order to analyse the network in a quantitative way, a few assumptions need to be made. Firstly, it is assumed that if the state of node D, in Figure 3, is known, then the probability of node F will not be affected by the knowledge about the state of node A. I.e. when there is knowledge about a node's parents, then the node is independent of its other ancestors (Rausand, 2011b).

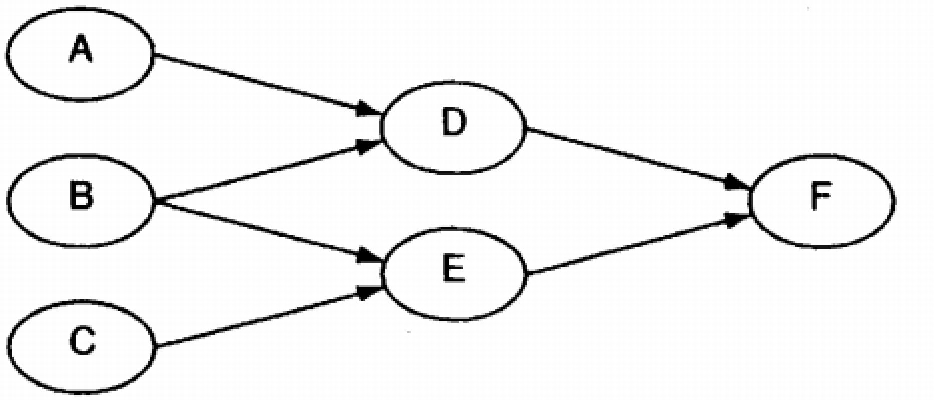

Figure 3 – Bayesian Network (Rausand, 2011).

Another assumption is that when the state of a node's parents is known, each node in the graph is conditionally independent. E.g., node D and E in Figure 3 – Bayesian Network (Rausand, 2011).

are independent when the state of nodes A, B and C (parents of D and E) is known (Rausand, 2011b).

According to the chain rule, the BBN gives the joint distribution over all the variables in the network. Marginal and conditional probabilities may be computed for every node, and an equation for joint probability is given in (2) (Trucco, Cagno, Ruggeri, & Grande, 2008).

$$P(X_1 = x_1 \cap \ldots \cap X_n = x_n) = \prod_{i=1}^{n} P\big(X_i = x_i | Parent(X_i)\big) \tag{2}$$

The last assumption is that two nodes with no arc between them, are conditionally independent (Rausand, 2011b). Further, each node must have a conditional probability table (CPT) assigned to them. These probabilities use prior information or experiences to represent the different likelihoods. For each combination of parent states, the CPT gives the distribution of the variable. The values of the entries in the CPT can be decided from expert judgement, estimated from data, be given rom external sources, or a combination of these. It is important to notice that as the network becomes more complex with regard to interactions, the more conditional probabilities need to be specified (Rausand, 2011b). Trucco et al. (2008), gives a simple example of a small BBN with a corresponding CPT. This is shown in Figure 4 and Table 3.

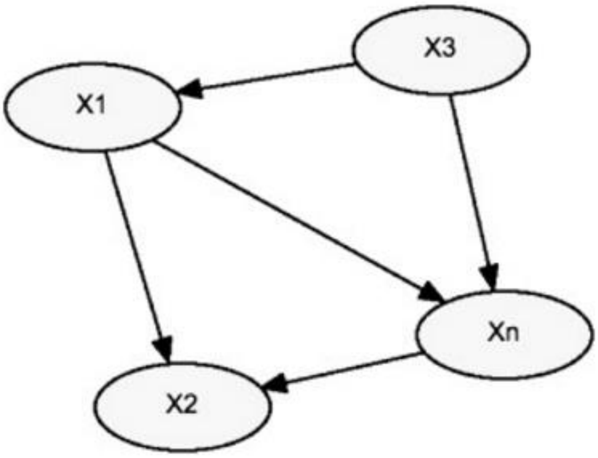

Figure 4 - Simple BBN, with corresponding CPT in ***Feil! Fant ikke referansekilden.*** *(Trucco et al., 2008).*

Table 3 - CPT corresponding to node Xn in the BBN in Figure 3 (Trucco et al., 2008).

	X_1	**State 1**		**State 2**	
	X_3	*State 1*	*State 2*	*State 1*	*State 2*
X_n	*State 1*	0,9	0,2	0,5	0,3
	State 2	0,1	0,8	0,5	0,7

Feil! Fant ikke referansekilden. Table 3, shows the CPT of node X_n in the BBN in Figure 4. Each node has only two states, and only node X_1 and X_3, influence X_n. If each node would have one more state, or if X_2 where influencing X_n as well, the table would increase in size. With an extra node, the table would go from a 2x4 table, to a 2x8 table, and with an extra state instead the table would become a 3x9 table. This shows how, what could seem like a small change, would affect the table in a great way, given that one needs to consider all the different combinations of states and influences. This would also affect the complexity of the network later on, seeing as the states of each parent node will affect the child node (Hänninen, 2014).

3.2 Challenges, advantages and limitations

For a long time, it has been quite common to use fault trees to analyse what happens prior to an event regarding safety. However, with BBNs being more generic (Papanikolaou, 2009) and able to consider causal connections that are not absolute (Charniak, 1991), they have become more popular within safety applications (Papanikolaou, 2009) and also the maritime traffic safety modelling (Hänninen, 2014).

As for all analyses, BBNs have its advantages and limitations. Rausand (2011a) and Hänninen (2014) discusses this, the latter focusing on the challenges of implementing the method in maritime transportation industry. Firstly, a BBN is more flexible than a Fault Tree Analysis (FTA), which also is a risk analysis for detecting causes for a hazardous event. This is due to the BBNs not being based on a binary representation, and a BBN could replace the FTA in a risk analysis (Rausand, 2011a). BBNs are able to model complex systems, with thousands of nodes while it at the same time presents causal relationships in a graphical representation that is easy to understand (Hänninen, 2014). This makes it easy to use a BBN in a quantitative way, while at the same time one can include data to each node and use it in a qualitative way (Rausand, 2011a). The possibility to combine expert knowledge with expert judgement, and being able to include more data when this is updated is another advantage (Hänninen, 2014). The drawback with BBNs is that the workload increases exponentially as the number of nodes increase, and therefore requires the use of software even for small models (Rausand, 2011a).

A common challenge in the maritime industry, is the retrieval of accident and incident data. Studies have shown that the amount of available data varies, and that underreporting of accidents is a common problem (Hassel, Asbjørnslett, & Hole, 2011). That, combined with maritime accidents being rare events, makes maritime data limited. Another challenge is that data can only be used for a certain period of time, because of changes in regulatory framework and safety culture, leading to data not being able to represent the current phenomenon if it is based on too long a period of time (Hänninen, 2014).

Hänninen (2014), also expresses that another challenge with BBNs is its possibility to use expert judgement. Such knowledge is subjective, and the various experts can interpret the factors in their own way. It is therefore recommended that several experts are used, in order to provide a richer information on the factor in question. Another challenge with using expert judgement, is the expert's area of knowledge. Some experts might have a very locally limited knowledge, and not have the understanding of how a small change locally can affect the whole system in total (Hänninen, 2014).

Chapter 4

Risk-Indicating Factors and risk indicators

Risk indicators for occupational incidents have existed for many years, and it was for a long time assumed that occupational incidents and major accident could be analysed in the same way. However, after the disaster at BP Texas City refinery in 2006, high awareness was raised towards the fact that management of major accidents cannot be handled the same way as management of occupational accidents (Vinnem, 2014). This, together with and increased focus on major accidents specifically, has led to an increased demand for more extensive and reliable indicators for major accident risk (Haugen, Seljelid, Nyheim, Sklet, & Jansen, 2012). The difference between major accidents and occupational incidents is that major accidents happens rarely and the causes for the two accident types have little to nothing in common with each other. Also, occupational incidents happen on a more regular basis and will therefore have a much better set of data than major accidents, which will need to have data from a national or international level in order to have enough usable information (Vinnem, 2014). Major accidents can be defined in many ways, but the petroleum safety authority in Norway (PSA), choose to define it as follows:

> A major accident is defined as an acute incident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets (PSA, 2016).

Since all the consequences mentioned in the definition above usually happens in a fire in passenger ships, such an accident can be defined as a major accident. Using risk indicators and risk-indicating factors (RIF) to describe major accident risk is a topic with high attention (Vinnem, 2014). They are also common in BBNs, in order to implement data in the nodes (Rausand, 2011a). This chapter will therefore present a literature review on RIFs and risk indicator, and how these can be used in BBNs. First, there will be a part that defines what RIFs and indicators are. Then the different types of factors will be presented, before the indicators are presented. At the end, the selection of factors and indicators will be presented, before a method for the quantification of indicators in BBN is presented.

4.1 Definition of factors and indicators

Hokstad, Jersin, and Sten (2001), define a risk-indicating factor as a relatively stable condition that has an influence on the risk. Since this is a theoretical variable, it is not necessarily measurable. Risk indicators are therefore often used to measure RIFs (Øien, 2001b). Risk indicators are parameters that are estimated through the use of risk analysis models and the use of generic and other available data. Such indicators presents knowledge or belief about a certain part of the risk of an activity or a system operation that happens in the future (Rausand, 2011b). Øien (2001b) gives a good example on the difference between the two; a RIF is “process leaks”, whilst a risk indicator is “the number of all leaks per period”. Risk indicators will be discussed further in chapter 4.3.

4.2 The concept of risk identifying factors

In a BBN, the nodes can be thought of as RIFs, with the arcs showing the direct and indirect influence on the probability of the event in question. The factors can be divided into technical, human, organizational, operational, regulatory or environmental influencing factors. A typical technical factor are technical systems such as barriers, which are established to prevent or reduce the impact of an event (Rausand, 2011a). Organizational factors are usually factors that may have an influence on the risk or safety of e.g. the ship at an organizational level. An example may be factors that influence the level of competence or supervision in the organization. Operational factors are usually operations that are safety critical. This might be operations like maintenance and inspection (Haugen et al., 2012). Human factors are as the name implies factors that affect the performance of the humans, e.g. fatigue or competence (Akhtar & Utne, 2014). Figure 5 shows an example of this, where the relation between human, organizational and technical factors are illustrated (Rausand, 2011b). These are the factors that primarily will be focused on throughout this thesis.

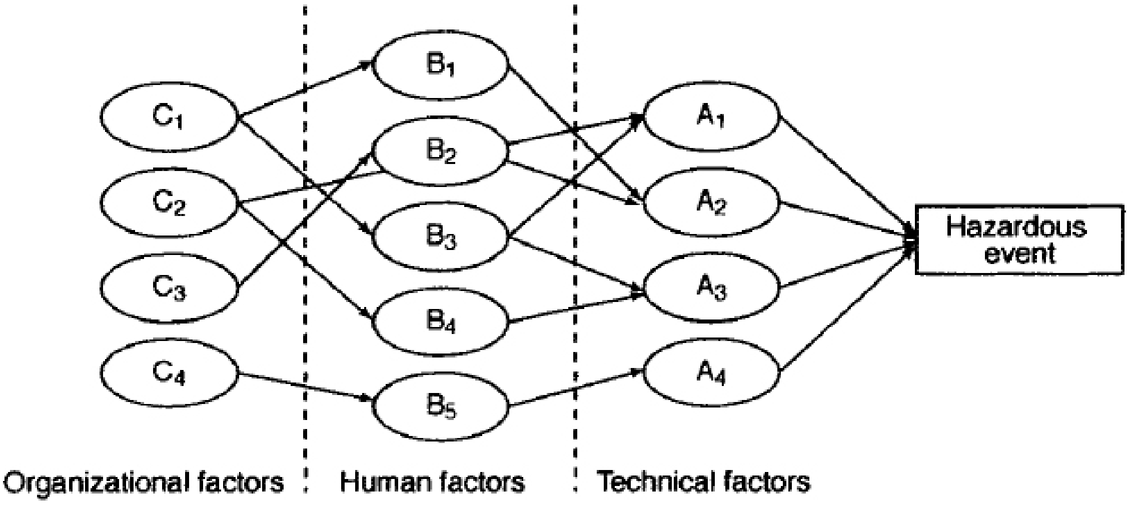

Figure 5 - BBN showing the relation between different RIFs (Rausand, 2011b)

The figure shows how the organizational factors has a direct influence on the human factors, and the human factors has a direct influence on the technical factors, which again has a direct influence on the hazardous event (Rausand, 2011b).

Aven, Sklet, and Vinnem (2006), has through the BORA project presented a set of different risk indicating factors. Some of these factors are presented in Table 4, as an example of different types of factors for different scenarios.

Table 4 - Example of RIFs from the BORA project (Aven et al., 2006)

RIF group	**RIF**
Personal characteristics	Competence
	Work load/stress
	Fatigue
	Work environment
Characteristics of the technical system	Equipment design
	Material properties
	Process complexity
	Human machine interface
	Maintainability/accessibility
	System feedback
	Technical condition
Organisational factors/ operational philosophy	Programs
	Work practice
	Supervision
	Communication
	Acceptance criteria
	Simultaneous activities
	Management of changes

4.2.1 Human and organisational factors

The contribution of human factors in incidents did not achieve a high priority within psychological research until two major industrial accidents in the mid-seventies. It then became evident that human failure may have an effect on, and may even be the initiating event of, an accident (S.-T. Chen et al., 2013). Later, it became well known that human errors often are the dominant factor to influence the risk for incidents in the maritime industry (Akhtar & Utne, 2014). The United States Nuclear Regulatory Commission (NUREG) define human error as:

> An out-of-tolerance action, or deviation from the norm, where the limits of acceptable performance are defined by the system. These situations can arise from problems sequencing, timing, knowledge, interfaces, procedures and other sources (NUREG/CR-6883, 2005).

It is important to notice that human factors and human errors are not the same thing (Gordon, 1998), but knowing what a human error is help understand the concept of human factor. Gordon (1998) define human factor as "the scientific study of the interaction between man and machine". Example of human factors that may influence the probability of an incident occurring are fatigue, poor physical fitness, poor eyesight and excessive alcohol use (Kristiansen, 2005). Fatigue has been proven to be the main factor, contributing to the risk for accidents to happen within the maritime industry (Akhtar & Utne, 2014). I.e. human factors influence human errors. For instance, a crew member that is tired will probably not have as good a reaction time as a person who is well rested. Making the factor "fatigue" affect whether the person makes an error that could possibly lead to an incident. Two commonly used systems/methodologies that investigate and analyse human factors in an accident, within the aviation industry, are Human Factors Analysis and Classification System (HFACS) and Systemic Occurrence Analysis Methodology (SOAM). The IMO has later followed the aviation industry, and recognized the importance of considering human errors in accidents, by adopting the ISM code (S.-T. Chen et al., 2013). Trucco et al. (2008) presents a figure, Figure 6, that shows the main causes for accidents at sea. According to this figure, human factors stand for 74 % of the main causes in accidents at sea, showing just how important it is to attend to these factors.

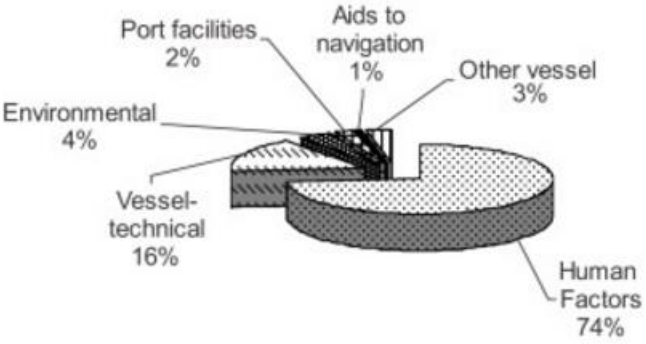

Figure 6 - Diagram showing the main causes for incidents at sea (Trucco et al., 2008)

The capsize of the Herald of Free Enterprise in 1987 is a good example of an accident where human errors played an important role. In the investigation of the incident it also became evident that the interaction between organisation and human is an important aspect to consider. The investigation showed amongst others that the management put pressure on the master to keep a tight schedule and there was a policy or culture on board to accept negative reporting (Kristiansen, 2005). As a reaction to this the IMO adopted the ISM code. It was added as a chapter in the SOLAS convention, and requires that "the ship owner, or any person in charge of a ship, needs to establish a Safety Management System (SMS)" (Chauvin, Lardjane, Morel, Clostermann, & Langard, 2013). Studies show that the interaction between human and organisational factors are closely related to each other, where organisational factors often affect the human factors. Research on risk prediction has mainly focused on the technical and human part of the risk picture, however there has been a few efforts explicitly concentrating on the organisational aspects (Øien, 2001a). Studies have shown that human error is often the main cause for an accident. Such errors are often affected by human and organisational factors. Example of such factors are shown in Table 4, where human factors might be competence and fatigue, and organisational factors might be work practice or communication (Aven et al., 2006).

4.2.2 Technical factors

Technical factors are as previously mentioned connected to the technical systems, such as barriers (Rausand, 2011a). Trucco et al. (2008) states that technical failures stand for 20 % of the main causes for marine incidents at sea. This can also be seen in Figure 6.

Causes for technical failures might be failure of different technological systems on the ship, such as the sprinkler system or smoke and heat detectors. I.e. technical factors can therefore be the condition of these system or their reliability. Some example of technical RIFs are presented in Table 4.

4.3 Risk indicators

As mentioned above, each factor may be represented by indicators. If the factor is measurable, then an indicator is not necessary, however in other cases one or more indicators are needed to describe the factor. Figure 7 is a good illustration that shows the relationship between the indicators, factor and the event (Haugen et al., 2012).

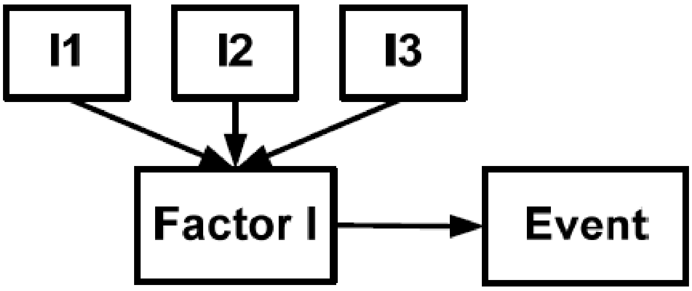

Figure 7 - Illustration of the relationship between indicators, factor and event (Haugen et al., 2012)

The indicators and their status, influence the state of the factor, which then influence the probability of the event occurring. One challenge with using indicators to measure factors, is being able to measure all aspects of the factor. Usually, it will not be possible to measure all aspects. One will only be able to measure a certain part of the factor, leading to a certain amount of uncertainty (Haugen et al., 2012). Haugen et al. (2012), shows this in a simple illustration presented in Figure 8Figure 8 - Illustration showing how it is difficult to describe all aspects of a factor, using indicators (Haugen et al., 2012). The figure shows that the indicators only cover a certain part of the factor, and the rest is left to uncertainty.

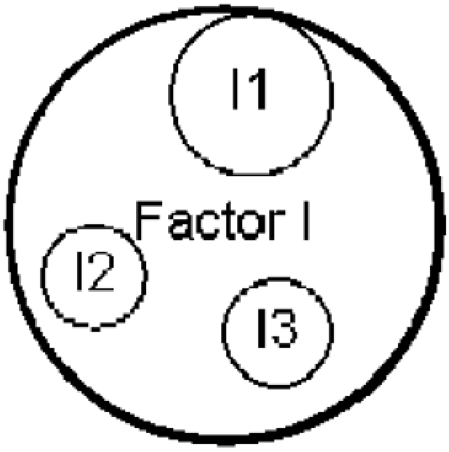

Figure 8 - Illustration showing how it is difficult to describe all aspects of a factor, using indicators (Haugen et al., 2012)

The Norwegian Petroleum Directorate (NPD, now the PSA) initiated a project in 1999 to develop necessary methods to develop major hazard indicators. The project showed that using risk indicators is an efficient way of monitoring the risk level in the operational phase (Vinnem, 2014).

There are a number of different indicators, depending on what they measure or what their property is. Two common definitions are safety indicators and risk indicators. These are often used interchangeably, but it could be useful to have a clear meaning of the difference between them. Risk indicators or risk-based indicators are indicators that measure the value of a RIF that is part of a risk model where risk metrics are used. Safety indicators are associated with other measures than risk metrics. This could for instance be number of accidents, or merely a qualitative analysis or model (Øien, Utne, & Herrera, 2011).

Hopkins (2009) states that there are two different types of safety indicators; personal safety indicators and process safety indicators. A personal safety indicator measures the safety of the personnel working at the facility or vessel, and how well the hence this indicator measures how well the organisation manages personal safety hazards. The indicator could therefore be measuring number of injuries or fatalities. Process safety indicators however, measure the process activity in the facility. This might be release of a toxic substance or damage to the process plant (Hopkins, 2009). Another common pair of indicators is leading and lagging indicators. More on that in the next chapter.

4.3.1 Leading and lagging indicators

A quite relevant discussion regarding risk indicators is about leading and lagging indicators. The discussion is about how to define these indicators and whether it is important to distinguish between the two or not. Some of the issue has been that what before used to be called a proactive indicator, now is called a leading indicators, and that the safety field has not taken in the full range of consequences that may come from this change (Kjellén, 2009). Hopkins (2009) stated that having a precise meaning of the two indicators was pointless since the two terms are used in different contexts, and that not having a clear definition would have little consequence. Several article where published as a respond to this. Dyreborg (2009) is one of them, and states that he disagrees with Hopkins. Saying that what Hopkins states, basically means that the industry should go back to being a purely reactive industry and not try to be proactive anymore. Hopkins does not consider the causal relation between lead and lag, which could help avoid the confusion many have of the practical use and definition of lead and lag indicators (Dyreborg, 2009). A lot of the discussion and research define leading and lagging indicators in some way, many of them quite similar, however there is some disagreement on how important they are and how they should be used, depending on the exact definition.

Kjellén (2009) defines a leading indicator as “an indicator that changes before the actual risk has changed”. This definition corresponds well to the definition used in economy, where the use of the word “leading” is taken from (Kjellén, 2009), and is supported by Vinnem (2014). Lagging indicator is defined as “a direct measure of harm” (Hopkins, 2009), meaning that lagging indicators are detected as result from an incident (Kjellén, 2009). Leading indicators can be evaluated through lagging indicators, and it should therefore be an association or relation between the two (Kjellén, 2009). This is also supported by Haugen et al. (2012), which mentions this as a property that is important to consider in relation to the indicator sets. This is mentioned more in the next chapter. Reiman and Pietikäinen (2012) emphasizes the importance of separate leading indicators into two different types. That is leading indicators that drive safety and those that monitor safety. Lead drive indicators are defined as indicators that aim to improve safety, while lead monitor indicators "indicate the potential of the organization to achieve safety" (Reiman & Pietikäinen, 2012). Figure 9 shows a simple box diagram that illustrate the relation between lead drive indicators, lead monitor indicators, lagging indicators and the sociotechnical activity in the sociotechnical system.

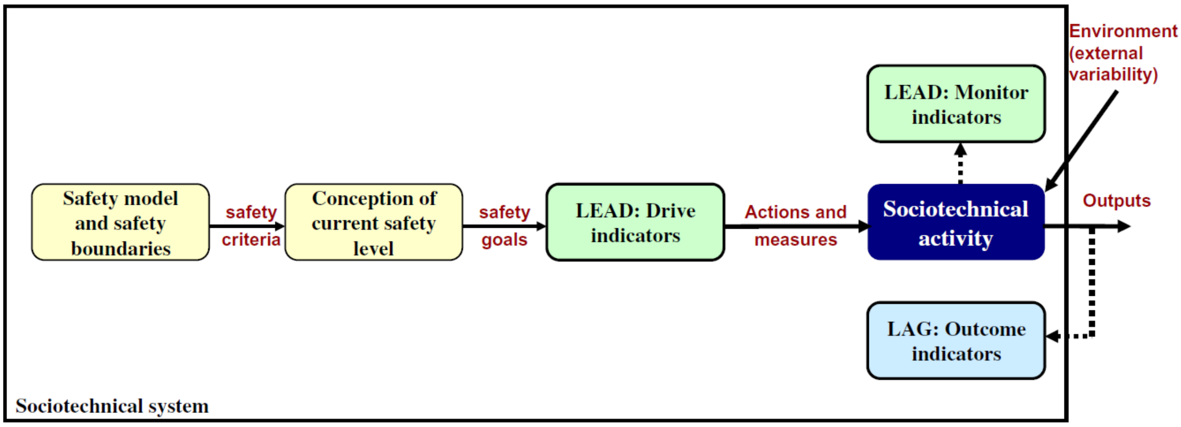
Environment (external variability)
LEAD: Monitor indicators
Safety model and safety boundaries
safety criteria
Conception of current safety level
safety goals
LEAD: Drive indicators
Actions and measures
Sociotechnical activity
Outputs
LAG: Outcome indicators
Sociotechnical system

Figure 9 - Illustration showing the relation between the different types of indicators and the activity in the sociotechnical system (Reiman & Pietikäinen, 2012).

The illustration gives a clear image of what each indicator do, and what Reiman and Pietikäinen (2012) means by the two different leading indicators. From the figure one clearly see that lead drive indicators are actions influencing the system, while the lead monitor indicators come from looking at the system itself, providing information on the dynamics of the system. The lagging indicators, here referred to as outcome indicators, are measures of the output of the sociotechnical activity or incident (Reiman & Pietikäinen, 2012).

4.3.2 Properties if indicators and indicator sets

Kjellén (2009) emphasizes the importance of correct understanding and definitions of the different indicators and their properties in order to identify and use them correctly. Both Kjellén (2009), Vinnem (2014) and Haugen et al. (2012) lists different considerations and properties to regard when identifying indicators. Both as individual indicators and as complete indicator sets.

Haugen et al. (2012) gives the clearest overview, and lists the following properties for each indicator:

- Validity: The indicator must be able to reflect the changes, i.e. be a valid measurement, of the status of the factor.
- Measurability: It must be possible to quantify the indicator in some way, so it is possible to compare with past and future results. Quantification with real data is preferred, but it is also possible to classify the indicator as e.g. good/ok/bad.
- Comprehensibility: The meaning of the indicator must be easy to understand, and the link or relation between the indicator and the factor must be a given.
- Reliability: The measured results must be reliable, since comparing with past and future data is important in order to know what to do and monitor the indicators properly.
- Useful: It must be possible to influence the status of the indicators, so they have a range of use.
- Cost-effective: The cost of the indicator cannot be higher than the benefit gathered from having this indicator.

For each indicator set, the following properties are important to consider (Haugen et al., 2012):

- Size: The larger the set of indicators are, the costlier they are. With major hazards being complex, it is important with enough indicators to measure all the factors. However, the size should be evaluated.
- Dual assurance: This has to do with leading vs. lagging indicators, which was discussed in the previous chapter. Indicator sets can consist of only leading or lagging indicators, or both types. Having a dual assurance with both types can often be useful, seeing as leading indicators measure something before an incident, while lagging indicators can measure something after it has happened.
- Alarm and diagnosis: It is important to have a combination of both types of indicators in a set, to have something telling you what is wrong (alarm) and that something is wrong (diagnosis).
- Frequency of measurement: How often an indicator needs to be measured may vary from indicator to indicator. It is important to consider this, along with usefulness and cost-effectiveness when setting these frequencies.

4.4 Selecting factors and indicators

As mentioned before, indicators can be human, technical or organisational. Other types also exist, but these are the most commonly used. Øien (2001a) and Øien (2001b) presents two methodologies for finding technical and organisational factors and indicators. A method called Organizational Influencing Risk Model (ORIM), which quantifies indicators, is based on these methodologies. ORIM will be presented in chapter 4.5.

4.4.1 Technical factors and indicators

Øien (2001b) presents a general methodology for identifying the RIFs and thereafter the risk indicators. The methodology is consistent with risk-based approaches, by focusing on the aspects that have most effect on the risk. This gives the two first steps, which are:

1. Selection of categories of accidental events contributing most to the total risk. This is the first screening.
2. Identification of RIFs modelled in the QRA for the accidental events.

That risk control may be achieved through indicators that measure the changes in RIFs, is a hypothesis that gives the basis for the following three steps of the approach.

3. Assessment of potential change in RIFs, which is the second screening of the approach. A potential change in a RIF is important if it has an effect on the risk.
4. Assessment of the effect of change of each RIF on the total risk. QRAs with causal analyses are able to describe the causal relationship between the RIFs and the risk, and by using these QRAs and sensitivity studies, the effect of change of each RIF on the total risk can be assessed.
5. Selection of significant RIFs, which is the third and final screening. What is important to consider in this step is whether the change of the risk is large enough to require risk indicators to be established for a given RIF.

The next two steps focus on the previously mentioned measurement problem of RIFs.

6. Initial selection of risk indicators for each selected RIF.
7. Testing and final selection of an appropriate set of risk indicators. Testing of the selected indicators is important, as experience has shown that it is difficult to choose the best possible indicators without testing them.

The final step is basically how to use the selected set of risk indicators, thus giving the following step:

8. Establishment of routines for the use of risk indicators.

4.4.2 Organisational factors and indicators

Øien (2001a) describes a way of establishing organisational factors and indicators, and emphasizes the importance of researching organisational factors. The last decades of accident investigation, have shown that such factors has a much higher effect on an accident, than what was previously assumed (Øien, 2001a). An example of this is the previously mentioned accident with the Herald of Free Enterprise, mentioned in chapter 4.2.1. Øien (2001a) presents a framework for establishing organisational factor and indicators, the different elements are categorized as presented below. The method is closely related to the Organisational Influencing Risk Model (ORIM), which is a method developed for quantifying factors and will be presented in chapter 4.5 (Øien, 2001a):

1. *Organizational model/factors* describe the organization, either by a list of factors or a model such as a BBN that shows the causal relationship between the factors.
2. *Rating of organizational factors* is performed in order to assess the quality of the factors. This is done by use of expert judgement, available data or indicators.
3. *Weighting of organizational factors* is performed in order to assess the effect the factors have on personnel performance or an intermediate factor.
4. *Propagation method/algorithm* is the way the weights of the factors are combined. A possible way of doing this is by the use of the influence diagram technique, where the factor is given a rate and a weight that are multiplied and summarized.
5. *Modelling technique* is the way of modelling the factors, for instance influence diagrams such as BBNs.
6. *Link to risk model* in the QRA, for instance a more technical one.
7. *Adaption of risk model* for it to fit to the effect of the organizational factors.
8. *Re-quantification of risk* to obtain new values for risk that reflects upon the inclusion of the effect of the organizational factors (Øien, 2001a).

4.5 Quantifying indicators

The proposed quantitative methodology for assessing the risk indicators and RIFs for each node, ORIM, is presented further in this chapter. A simple sketch presented in Figure 10, shows the relation of RIFs, node and event. In the figure, λ is the parent node of the child node "Event", which in the current case could be "Fire on passenger ship". The RIFs are presented as OF1, OF2 and so on, and are the RIFs for the node, λ (Øien, 2001a).

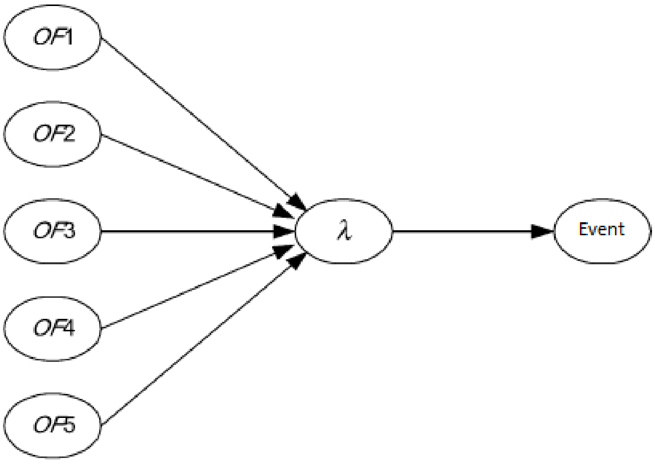
OF1
OF2
OF3
OF4
OF5
λ
Event

Figure 10 - Simple sketch of the relation between RIF, node and event in ORIM (Øien, 2001a)

As previously mentioned, RIFs are not measurable, and thus the indicators need to be presented as well. This is shown in Figure 11.

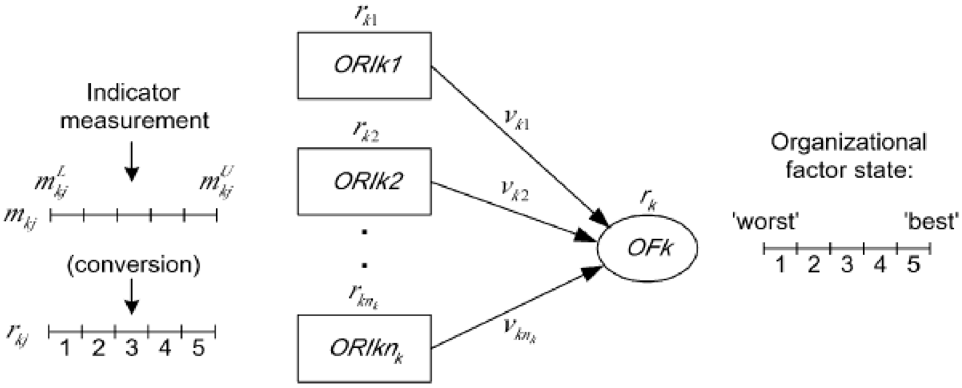
r_{k1}
ORIk1
r_{k2}
ORIk2
r_{kn_k}
ORIkn$_k$
Indicator measurement
m^L_{kj}
m^U_{kj}
m_{kj}
(conversion)
r_{kj}
1 2 3 4 5
v_{k1}
v_{k2}
v_{kn_k}
r_k
OFk
Organizational factor state:
'worst'
'best'
1 2 3 4 5

Figure 11 - Relation between indicator and RIF in ORIM, with rankings and weights (Øien, 2011a)

The indicators in Figure 11 are presented as ORIK1, ORIK2 and so on, and are directly connected with the node, OFk, where k = 1,2, ...,k. As seen to the left in the figure, the indicators are measured by a value, m_{kj}, where k is the number of the node and j is the number of the indicator. This is then converted into ranking values, r_{kj}. Ranking from "Very bad" = 1 to "Very good" = 5, these ranking values are shown in Table 5. The relation between one indicator and its RIF, shown by arrows, are weighted based on importance by expert judgement. These weights are presented as v_{knk}. The sum of the weights of all the indicators for each RIF is always equal to one, and the weights are assumed to always stay constant. The ranking number of the node is calculated by as shown in (3).

$$r_k = \sum_{j=1}^{n_k} v_{kj} r_{kj} \tag{3}$$

Table 5 – Ranking value for the indicators (Øien, 2011a)

Designation	**State value**
Very bad	1
Bad	2
Average	3
Good	4
Very good	5

Each of the ranking values obtained for the RIFs are then rounded off to an integer value, 1 to 5, as shown to the right in Figure 11 by standard rounding off rules. The RIFs are then ranked and weighted the same way the indicators were, in order to get a value for the node λ, shown in Figure 10.

Chapter 5

Building the BBN for risk of fire in passenger ships

When building the BBN that is used in this thesis, the BBN's that were used in (Azizpour, 2016) and (Baumgärtner, 2016) were used as a starting point. These to master theses are a part of the NSRM project, and look at uncontrolled fire in machine room and grounding, respectively. Most of the BBN that was built for risk of fire in passenger ships is therefore based on these two BBNs. The two BBN's in these thesis's, were both given on beforehand from the NSRM project. However, some adjustments had to be made to the BBN in this thesis, to adapt it to its purpose. Research done by (Pawling et al., 2012), (Spyrou et al., 2013), (Themelis & Spyrou, 2012), (Vassalos, 2006) and (Ventikos, 2013) was used as a basis for these adjustments. These research papers are based on the work performed in the research project FIREPROOF, which was mentioned earlier, in chapter 2.

Since the BBN used in (Azizpour, 2016) and the BBN presented in this thesis, both look at fire, the immediate factors are set to be the same. These factors are "Flammable material", "Ignition source" and "Firefighting measures", which from research have proven to be fitting to this BBN. Ventikos (2013) uses SOLAS's space categories, when developing a database and looking at the risk of the different areas of the passenger ship. Since the risk and scenarios varies between the different space categories (Ventikos, 2013), some of these were used as nodes in the BBN to get an evaluation of the whole ship. These nodes are directly linked to the immediate factors, and say something about where on the ship the fire might happen. When analysing a system such a passenger ship, one desire to analyse it in the same level of detail. This so that there won't be a part that is much more analysed in detail than another part, maybe even overlooking something because the analysis is too coarse. Dividing between the different areas was therefore thought of being a good representation. One drawback could however be that there would be difference in the available data. Some of the areas could be related to other industries, such as the hotel industry, and thereby get more data. A few of the areas are less hazardous than others, and would as such have less available data.

Another important aspect of the current BBN, is its limitations. Fire in machine room are a common cause on board passenger ships, however it has not been included in the network since a BBN dedicated to exactly that has already been made. The BBN for fire in passenger ship is limited to areas on the ship where passengers find themselves, or areas that are an important part of the hotel operations on board the vessel. Including galley and laundry, which are areas where passengers normally do not enter, but that are known to be common areas where a fire may occur. Especially on larger passenger ships where there are extensive hotel operations that has larger kitchens and laundries in order to service the guests, thereby increasing the risk further the larger they are. Areas such as tanks and void space are not included, seeing as the probability of a fire occurring in these areas are small (Ventikos, 2013).

As for the rest of the nodes in the BBN, they have all been taken from the BBNs in (Azizpour, 2016) and (Baumgärtner, 2016). These are nodes representing regulations and policies, organisational factors i.e. shipping management and ship management, human and technical factors i.e. organisational conditions, technical condition and technical failure. The only exception is the node “crew presence”, which was not in any of these BBNs and has been included under organisational conditions. The presence of crew on board passenger ships has been proven to be an important influence on whether a fire develops or not. Crew are trained on what to do in such a situation and are more likely to avert a fire, than a passenger that may not know what to do instantly (Lois et al., 2004). The node “Weather”, was first excluded from the network. However, research showed that weather had impact on the risk of fire on cargo and car deck, and was therefore included after all.

The BBN developed in the work of this thesis is attached in appendix A. The nodes are colour-coded depending on the conditional group the corresponds to.

5.1. GeNie

The program that was used to model the BBN was, a program called GeNie (Graphical Network INteligence). The program is developed by Bayesfusion, LLC. GeNie is developed for the soul purpose of modelling Bayesian Networks, with the ability to include CPT’s for each node and calculating the risk (Bayesfusion, 2016).

Chapter 6

Risk indicators and RIFs in BBN

This chapter discusses the different data and research that was retrieved for each of the nodes. For many of the nodes, the previously discussed ORIM-method from chapter 4.5, has been utilized. The following analysis of the BBN combines the theory that was discussed in chapters 3 and 4. Suitable risk indicators and RIFs are discussed for the nodes where these have been found. For nodes where suitable RIFs or risk indicators for some reason have not been found, but usable data and/or research has been retrieved, only the related research and any data is presented. Figure 12 shows how the nodes have been colour coded for when RIFs and risk indicators are used.

The chapter is structured so that the parent nodes for the immediate factors are discussed and so on backwards in the network.

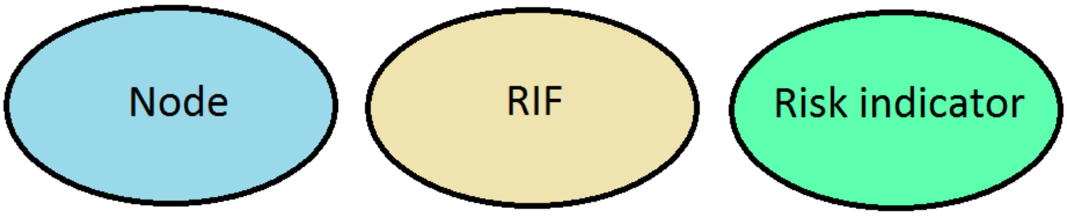

Figure 12 - Colour coding when using the ORIM method

6.1 Human and technical factor

This sub-chapter analyses the human and technical factors of the network. Many of the nodes under this category represent different areas on board the ship, which is a part of the hotel part of the ship. Many of the references used are therefore based on research for hotels and not ships. Even though these are two different things, a passenger ship and a hotel may have the same safety issues regarding for instance kitchen/galley, restaurant, rooms/cabins and laundry. A passenger ship is divided into hotel functions and ship functions, as was mentioned in chapter 2.

6.1.1 Housekeeping

Hassanain (2009) lists the laundry room as one of the most hazardous areas in a hotel. Laundry rooms are a part of the housekeeping department, and they are the location for washing and ironing of clothes and linens. Typical equipment in a laundry can be washer, dryers, ironers and pressers. Most fires in laundry rooms start in the dryer. A dryer has all the essentials, heat, fuel and oxygen, needed to start a fire. Such fires typically occur when the dryer has not been thoroughly cleaned and maintained (Hassanain, 2009). The focus for the housekeeping node will therefore be on the laundry room. Ventikos (2013) found in his research that the expected frequency for fire in laundry room was 2.7×10^{-1} /ship-year, and that the expected number of events each year was 34.01. It should be noted that within this frequency, laundry room was considered together with store rooms, pantries and workshops (Ventikos, 2013). The U.S. Fire Administration reported that there were 2.900 clothes dryer fires in residential buildings in the years 2008 – 2010. Of these fires, three percent occurred in hotels and motels (U.S. Fire Administration, 2012). Meaning that over a three-year period, 87 fires that had its origin in clothes dryers occurred in U.S. hotels and motels. This makes for an annual average of 29 dryer related fires each year. In addition to dryers, another possible fire hazard is careless disposal and storage of used rags and chemicals. Heat can cause these objects to self-combust and start a fire (maiif, 2016). Figure 13 shows the proposed RIFs and risk indicators for the housekeeping node.

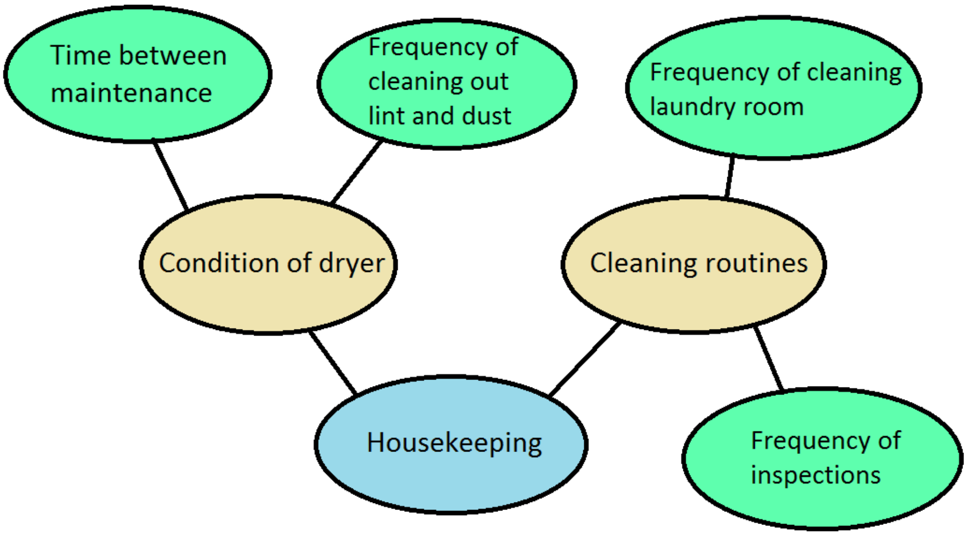

Figure 13 - RIFs and risk indicators for the node "Housekeeping"

In almost half the clothes dryer fires in the U.S., the ignition source was due to operational deficiency. Standing for 46.6 % of the fires. This is mostly due to failure to clean, i.e. removing lint and dust from the dryer between every use. In addition, mechanical failure and electrical failure was the ignition category in 28.6 % and 15.6 % of the cases respectively. Build-up of lint in the screen or areas around the dryer, can cause it to not operate efficiently. This can lead to overheating and possibly fire (U.S. Fire Administration, 2012). Lint is a common bi-product in dryers. Failing to clean the dryers as advised, could cause accumulation of lint in the dryer. This can cause a fire and/or contribute to a fire that has occurred (Bajzek, Pape, & Duvall, 2012). Dust and lint, and clothing in the dryer are the major ignition sources in a dryer fire (U.S. Fire Administration, 2012). Many have also alleged that friction between the moving parts in the dryer, i.e. air blower and venting systems, will friction and cause heat that will make the part self-combust. Duvall, Bajzek, and Koopman (2007) did research on this, where they tested friction between plastic and plastic and metal. They found that the temperature would never get high enough for this to happen. However, the temperature could get high, and with improper maintenance and cleaning, this heating could be contributor to a fire.

For these reasons the RIFs “condition of dryer” and “cleaning routines” are proposed for the node “housekeeping”. For the RIF concerning the dryer, two indicators are proposed. They will measure the frequency of maintenance and the frequency of cleaning out lint. Lint should be cleaned out between every use. The RIF regarding cleaning routines, aims to measure the cleaning and tidiness of the laundry room itself. As previously mentioned, rags and chemicals that are not disposed of and stored in a proper manner, may, if they are close to a heat source, self-combust. The disposal and storage of these objects should happen after they have been used, so measuring the frequency of cleaning could work as an indicator. Another possible indicator could be inspections of the laundry room, to check that level of cleanliness is adequate.

6.1.2 Cabin

According to Ventikos (2013), cabins are the area of a passenger ship where fire most often occurs, with a frequency of 21,4 % of the recorded fires in his database. He found that the average frequency/ship-year for a fire to occur in a cabin was $6.9x10^{-1}$ (Ventikos, 2013). Arvidson, Ingason, and Persson (1997) agrees, stating that among fires in RoPax vessels, 27 % occurs in accommodation. (Troitzsch, 2016) found from statistics that a fire in a passenger cabin would occur once every five years. He does not, however, mention the size of the fleet this number is based on or which type of fires he has considered. It could be safe to assume that he only looks at severe fires, seeing as Ventikos (2013) found that a fire in a cabin would occur with a frequency of 86.10 every year, and he considers all types of fires, both small and severe.

Potential fire hazards in hotel rooms are “smoking, candles, covered lamps, ash trays, coffee machines, irons defective television sets, defective radios, defective refrigerators, overheated hairdryers, electric blankets, fixed and portable space heaters, overloaded circuits and short circuits” (Hassanain, 2009). What Hassanain does not mention is overheated chargers and electrical appliances being charged. There have been numerous incidents over the world where for instance chargers for mobile phones has caught fire and been the ignition source for fires (Wang et al., 2012). Even certain mobile phones have been known to catch fire all by themselves, out of nowhere. This has been the issue of the newest Samsung Galaxy Note 7, which has been banned from aircrafts due to its ability to self-combust (e24.no, 2016) & (nrk.no, 2016). With most people having both mobile phones, tablets and cameras that uses these types of chargers, this is a hazard that also needs to be considered. Passengers might charge their appliances in their cabins during the day when they are not around, or during the night when they are asleep. For both of these scenarios, it would take some time for the fire to be detected and thereby giving the fire to spread. Should the passenger be around and awake when the charger gets overheated, then the passenger could stop the fire from occurring at all.

Another important aspect for cabins is the time of day. Most passengers find themselves in their cabins during night time, while most of the day time is used for instance on outdoor deck, in restaurants, recreational areas or on an excursion onshore. In fire simulations by Spyrou et al. (2013), they said that only 50 % of the cabins where occupied during the day, while at night 100 % of the cabins where occupied. During daytime one could assume most of the passengers that are located in their cabins are awake, however during night time one could assume that everyone are asleep, which means that people are less alert and would give a fire a bigger opportunity to develop (Hassanain, 2009). Taking all of the mentioned into consideration makes for the RIFs and risk indicators shown in Figure 16.

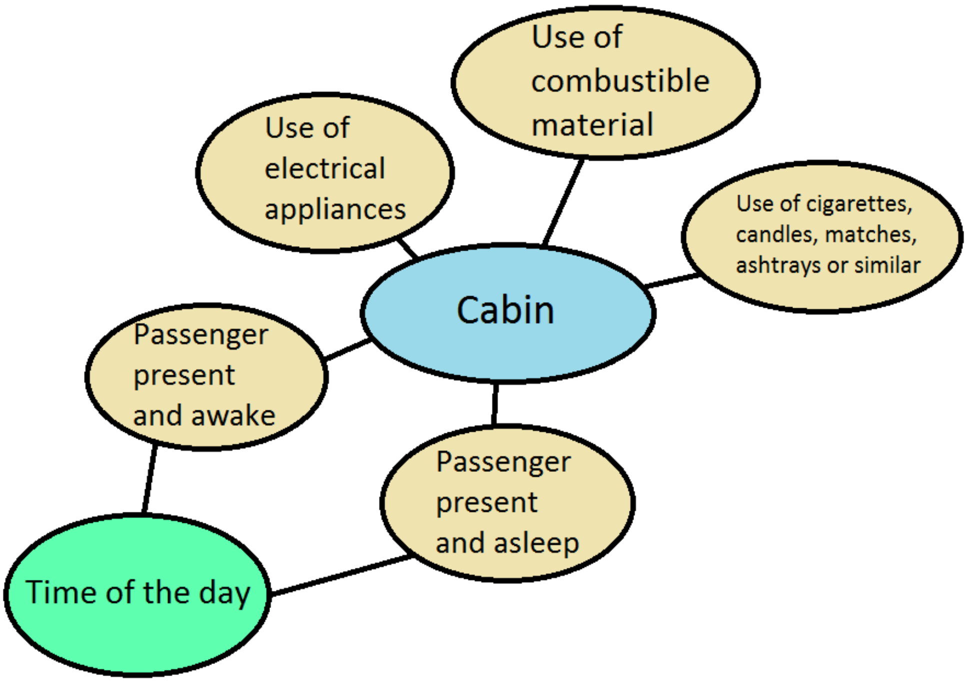
Use of combustible material
Use of electrical appliances
Use of cigarettes, candles, matches, ashtrays or similar
Cabin
Passenger present and awake
Passenger present and asleep
Time of the day

Figure 16 - RIFs and risk indicators for the node "Cabin"

Ventikos (2013) found in his research that “cigarettes, matches or similar smoking material” was the ignition source in 22 % of the investigated incidents, which means that it was the second most common ignition source. However, it is important to notice that this may have been the ignition source other places than the cabin, so it cannot be used as a value for only the cabin. Still, it proves to show that it is a potential hazard that is important to consider. Most cruise ships today have prohibited smoking from most common areas and all cabins and balconies. Smoking is only allowed in certain areas of the ship, for the comfort of all the guest on board (Royal Carribean International, 2014), (Crystal Cruises, 2016) & (Cruiseline.com, 2014). Even though smoking is prohibited in cabins, passengers may smoke there anyway. An example of a passenger’s disobedience is the occurrence of smoking in aircraft lavatories, even though it is forbidden (Bor, 2003) & (Bor, 2007). Bor (2003) looked at incidents with disobedient passengers on aircrafts in the UK, and found that among 106 million annual travellers on average, there were an average of 1040 incidents of passengers having disruptive behaviour. This proves to show that disruptive passengers are not a widespread problem, but incidents may occur (Bor, 2003). It could therefore be speculated that such disruptive behaviour may happen in the cabins of passenger ships as well. It probably helps that there are areas where the passenger is allowed to smoke, which there are not in aircrafts. However, some might want to have a smoke on the bed before they fall asleep or when they have woken up, and might take the chance on not getting caught. It may also be speculated that since passenger ships are bigger and not as compact with people as an aircraft, that the passenger would feel it would be easier to get away with smoking and not being caught, and thereby taking the risk of having a smoke even though it is prohibited.

Measuring the use of cigarettes and similar, may not be the easiest indicator to measure, seeing as it is prohibited and would occur in the closed environment of the cabin. Use of reported events of smoking from the last few years, could serve as a likelihood for smoking to occur. If one choose to use for instance the last five years, one would always regard the newest trends. Bor (2003) found in his research that number of passengers smoking in aircraft lavatories seemed to decrease. This could easily be the case for passenger ships as well.

Measuring the use of electrical appliances could also be a somewhat difficult task. Still, most people today have mobile phones, tablets and/or cameras with them on vacation. These appliances would most likely need to be charged during the trip, depending on the length of the trip, and it would be easy to assume that there would be at least one charger per cabin. Even assuming that there would be one charger per passenger could be fair. Ventikos (2013) found in his research that "electrical other than static charges" was the major ignition source, with a frequency of 30 % of the recorded incidents. This number applies to the whole ship, and not only the cabin, Still, it shows that "electrical" is a possible contributing hazard that needs to be considered.

As previously mentioned, "coffee machines, irons, defective television sets, defective radios, defective refrigerators, overheated hairdryers, electric blankets, fixed and portable space heaters, overloaded circuits and short circuits", are all examples of potential fire hazards in a hotel room. A quick search on the cabins of the ships of the cruise companies "Royal Carribean" and "Hurtigruta" show that of these potential hazards, the most common once in passenger cabins on board ships are hairdryer, tv's, radios, refrigerators and hairdryers. In addition, many of the cabins have extra sockets (Royal Carribean International, 2016) & (Hurtigruten, 2016), which could lead to overloaded or short circuits in case of misuse. For simplicity, not all of these hazards will be analysed, but are simply mentioned to be aware of possible hazards. The focus will be on the hazards that are thought to have the biggest safety concern.

The batteries that are commonly used in cell phones and other electrical devices these days are lithium-ion batteries. This is due to their high energy density, however the safety characteristics of these batteries varies (Tobishima & Yamaki, 1999). It has been reported that several laptops and music players have overheated and caught fire, and that tens of thousands of mobile phones have caught fire due to short circuit and overheating amongst other things. These battery cells will heat up before they catch fire, unless something is done to prevent that from happening. Overheating and short-circuit often happens when the phone is being charged, but it could also happen by normal use, due to mal-function or damage of the battery (Wang et al., 2012). A cell phone being charged, laying on the bed and getting overheated may also act as an ignition source on the bed linen. SOLAS has requirements on combustible material on board ships, and require that for instance "bedding components have qualities of resistance to the ignition and propagation of flame" (SOLAS, 2016). The fire resistance is only required to withstand action of small fire setting sources (Dobrzynska, 2009), meaning that enough heat from an overheated phone could possibly make the bedding catch fire.

To sum up, this gives the RIFs “use of electrical appliances”, “use of cigarettes, candles, matches, ashtrays or similar” and “use of combustible material”. Exactly how to measure this, is not presented at the time. They are, however presented in the figure since they are factors that affects the risk of fire in a cabin. These RIFs therefore needs further revising, in order to find suitable indicators. In addition, there are also the RIFs “passenger in cabin and awake” and “passenger in cabin and asleep”, which could be measured by looking at the time of day. Reducing fires in cabins can be quite difficult, and the number of fires in cabins might even increase in the coming years due to the increase in the size of the vessels and number of passengers on board (Troitzsch, 2016). Passenger cabins are especially hard to evaluate, seeing as they are closed and private rooms, where it is impossible to keep track of everything the passenger does.

6.1.3 Car deck

Passenger ships with car decks are typically RoPax vessels. RoPax stands for Roll on/roll of (Ro) and passenger (Pax), and are typically used for short-sea routes (IMO, 2016e). Roll on/roll off means that the cars can be driven on board via a ramp, typically in the bow or stern (Amdahl et al., 2015).

DNV GL (2016) performed a study where they evaluated fire incidents on board ro-ro spaces from the year 2005 – 2016. They found that typical fire hazards in a RoPax vessel are shifting cargo and reefer units. The risk of a fire propagating from a car is very low, especially in newer cars (DNV GL, 2016). Arvidson et al. (1997) agreed, and stated that even though these accidents are rare the consequences can be disastrous. They found that among accidents that leads to serious consequences, a fire on the car deck had the third highest frequency. They found that among fires in vehicles, 75 % started in passenger cars, and that more than two-thirds of the fires started in the engine, running gear or wheel area. Their statistical analysis showed that there was a tendency for an increase in vehicle fires, and stated that this was most likely due to arson (Arvidson et al., 1997). Due to the risk for fires being so low, and new cars being produced in a good manner, it was found that giving recommendations to improve the fire risk was difficult. However, the data studied by DNV GL showed that screening older cars before they were brought on board should be recommended. In addition, improving the securing of the cargo and weather routing, was found to be simple measures to reduce the fire risk in ro-ro spaces (DNV GL, 2016). With RoPax vessels carrying a certain amount of cargo in addition to the passengers, the cargo can have an effect on the risk level of the ship. Another issue is that RoPax vessels often are poorly maintained and operated in less developed countries, which also affects the risk level of the ship (Eleftheria et al., 2016). Studies show that the frequency of a serious fire occurring on a RoPax vessel is 2.45×10^{-2} per ship year, and that 7 % of the fires occur on the car deck (Arvidson et al., 1997). Proposed RIFs and risk indicators for the node “Car deck” are shown in Figure 17.

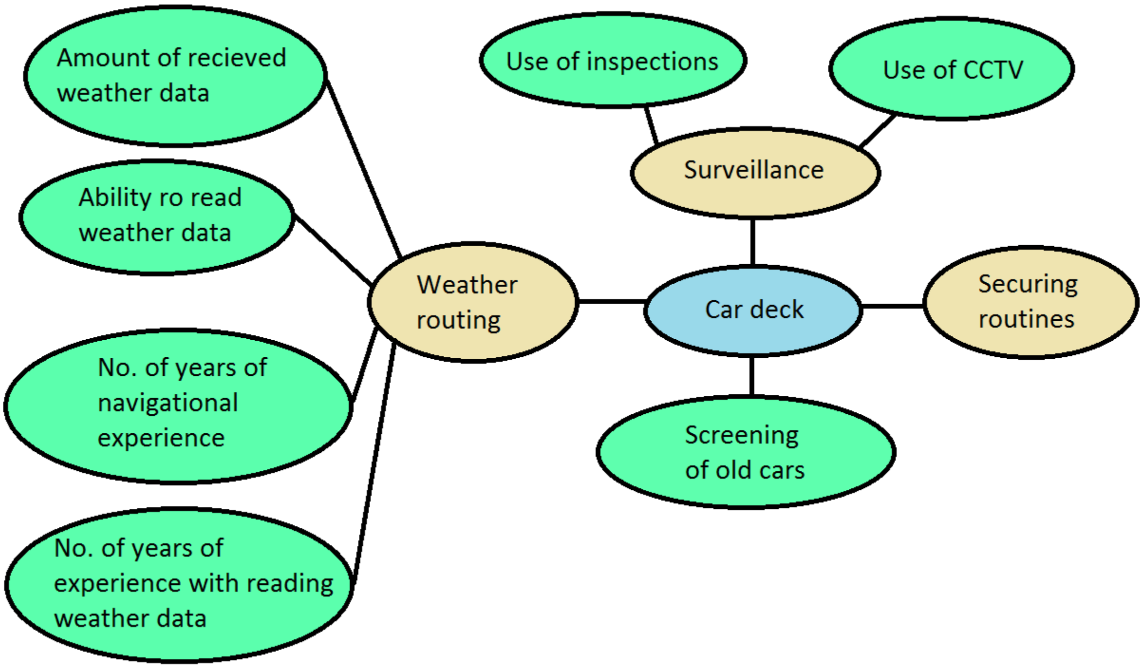
Amount of recieved weather data
Use of inspections
Use of CCTV
Surveillance
Ability ro read weather data
Weather routing
Car deck
Securing routines
No. of years of navigational experience
Screening of old cars
No. of years of experience with reading weather data

Figure 17 - RIFs and risk indicators for the node "Car deck"

“Use of inspections” and “Use of CCTV” are proposed as indicators for the RIF “Surveillance”, with regards to preventing the risk of arson and to make sure that no unauthorized personnel are on the car deck. CCTV (Close Circuit Television) is a surveillance system can be used on the ship. The RIFs “Weather routing” and “Securing routines” are proposed as a means to avoid shifting objects. “Screening of old cars” is proposed, based on the recommendations from DNV GL (2016). How to measure “weather routing” has been proposed. One could suggest that weather routing could be measured in ability to read retrieved data, number of years with navigational experience and reading weather data and amount of weather information received. This however, has not been supported by any research, and so these indicators need to be evaluated and validated further. Securing routines also needs to be evaluated further, in order to find proper indicators.

6.1.5 Galley

The galley is where all the food that is served on the ship is prepared. The larger the ship, the more passengers and people on board and the bigger the galley is. I.e. the chance of something going wrong increases. According to Ventikos (2013), galleys are defined under SOLAS' space category number 12; Machinery spaces and main galleys. The galley is also defined as a service space (SOLAS, 2016). Ventikos found in his research that as much as 42,21 % of fire incidents occurred in this space category. Now, it is important to notice that this also includes machinery spaces, and that there is no distinction between the two in this data. However, it is still noticeable that galley stands for many of the fire locations in a passenger ship. Márquez Sierra, Rubio-Romero, and Rubio Gámez (2012) stated that 37 % of fires in hotels in the USA, had its origin in the kitchen. Showing that there is a significant risk for fire in this area in hotel facilities. This report also showed that fires in the kitchen of a hotel often starts in the cooking equipment (Márquez Sierra et al., 2012). Hot surfaces in the galley stands for 12,29 % of the ignition sources in fires on board passenger ships (Ventikos, 2013). Other fire hazards may be overloading of the electrical system, overheating of the motors in the dishwasher or improper use of gas. With a lot of dust, filth and fat from the cooking, a clogged filter in the air-conditioning may also be an issue (Wu & Chow, 2010). These findings, together with influence of humans, gives the RIFs and risk indicators shown in Figure 18.

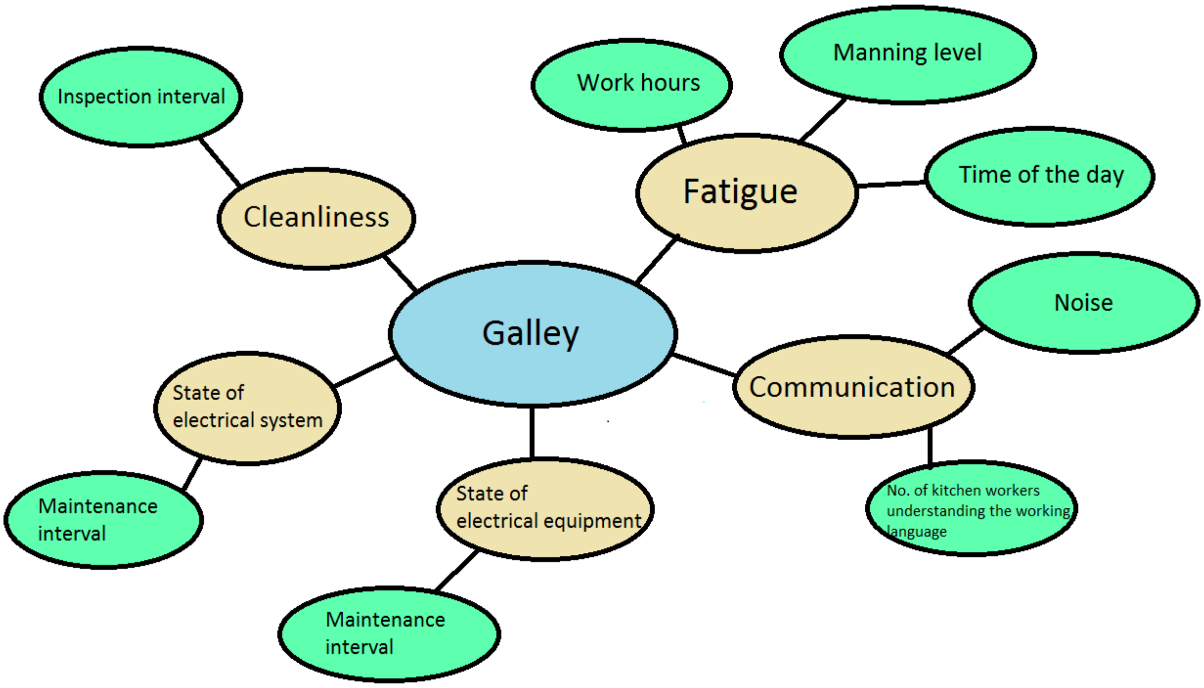
Inspection interval
Work hours
Manning level
Fatigue
Time of the day
Cleanliness
Galley
Noise
Communication
State of electrical system
Maintenance interval
State of electrical equipment
No. of kitchen workers understanding the working language
Maintenance interval

Figure 18 - RIFs and risk indicators for the node "Galley"

Chapter 3 in the Investigation Manual of the Marine Accident Investigators' International Forum (MAIIF), discusses typical causes for fire in the galley. Improper use and stowing of cooking equipment, electrical circuits and improper cleaning of equipment and ducts are pointed out as quite common causes (maiif, 2016). Grease accumulation on equipment and in ducts, have proven to be quite fire hazardous, and so proper cleaning of the appliances is an easy way to reduce the risk for such fires. Grease fires occur in deep-fat fryers, ovens and often at the stove-top grill, where a flare up ignites condensed grease around the vent hoods and ventilation. Fire codes makes active fire-protection inside the vent mandatory. However, such a flare up may be so strong that the fire-protection is not able to control the fire from spreading throughout the ventilation system ("Putting the Wrap on Grease Duct Danger," 2000). An effective indicator for cleanliness in the kitchen would therefore be the interval between each cleaning. A restaurant kitchen is cleaned from top to bottom every day, however one does not take apart the whole kitchen and clean for instance inside vents. Therefore, one would also need an indicator saying how long it has been since last inspection of for instance the vents to look at the amount of grease inside. If a certain amount of grease is found, the vent needs to be cleaned thoroughly. The National Fire Protection Association (NFPA) in the USA requires a qualified vent cleaning service to come inspect the ductwork and fan every six months (Bendall, 1999). It is important to notice that this requirement is set for restaurants, however it may act as a good example of what the interval could be.

The electric appliances used on board a ship are specially approved for this purpose, in order for the equipment to withstand the strenuous conditions at sea. Proper maintenance of both the equipment and the electric system help assure that they keep the preferred condition and does not overheat and for instance ignites flammable material that may be located nearby (maiif, 2016). The RIFs "State of electric equipment" and "state of electrical system" therefore has the indicator "Maintenance interval", i.e. time between maintenance.

Fatigue could easily affect a crew member's ability to react and communicate as it normally would be able to. It could easily affect a person anywhere on the ship, however it would be more critical in a hectic or more focused environment such as on the bridge where one needs to be focused or in the galley where it is hectic and a lot happens. The IMO's MSC/Circ.1014 describes fatigue as "a state of feeling tired, weary, or sleepy that results from prolonged mental or physical work, extended periods of anxiety, exposure to harsh environments, or loss of sleep" (IMO, 2001). Several aspects have proven to influence human fatigue. This might be repetitive work, working hours, lack of sleep, hour of the day or stress. Fatigue is a main concern in all industries, however it has an even more concern in the maritime industry seeing as the working conditions of the crew member is different from for instance a worker onshore. A crew member on a ship live and works there for a certain period of time, with long work hours, and even though they have a certain amount of time off from work it may still be hard to divide work and free-time from each other. This may have a significant effect on the stress level of a human, thereby affecting the feeling of fatigue (IMO, 2001). Studies show that knowledge, training or skill does not matter when it comes to the effect of fatigue (Xhelilaj & Lapa, 2010). People with fatigue does not consider risk in the same way as people with no fatigue, and may choose the performing of a task based on what is easiest and not necessarily on what is less risky. Fatigue affects a person’s attention, and their ability to respond, solve problems (IMO, 2001). As previously mentioned, fatigue may be influenced by factors such as working hours, hour of the day or stress. Working hours and resting time, are regulated through the law with mandatory registration (Forskrift om arbeidsanordninger på skip, 2007). Studies show that time of the day has an impact on the feeling of fatigue amongst humans. Our biological clock makes us humans subject to heavy sleep between midnight and 6 am, and this time of night is said to be the most dangerous with regards to maritime accidents (Xhelilaj & Lapa, 2010). A survey conducted by St. Olavs Hospital - Arbeidsmedisinsk avdeling (2013) showed that the stressful environment in a hotel kitchen is one of the main reasons why a chef would prefer to find other work. The survey also showed that chefs use more than half of their time frying food, i.e. doing repetitive work, and many kitchen workers experience physical struggles such as sore neck and shoulders (St. Olavs Hospital - Arbeidsmedisinsk avdeling, 2013). With stress, physical aches and repetitive work being known factors that affect the feeling of fatigue, it comes to show that fatigue is an important factor to consider when assessing the risk of fire in the galley. Thus, the RIF “Fatigue” has the indicators “Work hours”, “Time of day” and “Manning level”. The issue of fatigue will be discussed further in chapter 6.1.7.4.

What should be noticed is that how humans react to fatigue varies for each individual, which makes measuring fatigue difficult. One may measure work hours, resting time and so on, but with many different elements affecting the crew members in different ways it becomes difficult to measure the fatigue perfectly. Measuring the fatigue in the best possible way cannot be generalized, and must be adapted to the each individual (Bal BeşİkÇİ, Tavacıoğlu, & Arslan, 2016).

It should be noted that the proposed RIF “Communication” and its corresponding risk indicators have not been supported by any research. However, it is thought of as a possible factor, that could influence the risk level in the galley. It is a hectic environment, and lack of communication due to noise and misunderstandings because everyone does not speak the working language as well as they should, could easily lead to misunderstandings and situations that could possibly be hazardous.

6.1.7 Organisational conditions

As for the organisational conditions in the BBN, all of the nodes except for “Crew presence” are similar to the nodes presented in both (Azizpour, 2016) and (Baumgärtner, 2016). A lot of the research found in these theses is relevant for the current thesis as well, and so a summary of what was found in these to theses will be presented for the similar nodes. In addition, research that has been found to be important for the current thesis will be presented as well, if this has not been presented in the other two theses. The most important references from each of the two theses will also be presented under each sub-chapter. The RIFs and risk indicators for each node will be based on what is presented in Baumgärtner (2016). Some RIFs and indicators may be removed and new ones may be presented, in order to adjust to the current BBN.

6.1.7.1 Competence

The International Convention on Standards of Training and Watchkeeping for Seafarers, 1978 (STCW) aims

> to promote safety of life and property at sea and the protection of the marine environment by establishing in common agreement international standards of training, certification and watchkeeping for seafarers (IMO, 2016c).

The convention contains minimum requirements for the competence of the on board personnel and recommended guidance for implementing the convention (IMO, 2016c).

Baumgärtner mentions that a couple of research papers has criticized the convention, saying that the criteria for competence is highly subjective and free to interpret, and that the convention does not state what an adequate level of competence actually is. It was also found that as much as 35 % of casualties have happened due to lack of general technical knowledge. This may result in errors when using the equipment, and avoid using different sources to gather information. Job rotation is also listed as a factor to consider. Crew working on different ships, with different sizes and equipment can lead to lack of ship-specific knowledge. This is listed as a problem by 78 % seafarers. Training is listed as an important factor, in order to maintain the level of competence and professionalism. “On-the-job training” assures the professionalism, while “training and re-qualification” assures that the competence is maintained (Baumgärtner, 2016). Figure 19 shows the RIFs and risk indicators for the node “Competence”, as proposed by Baumgärtner. The only thing different from Baumgärtner is that the RIF “Manning” has been excluded. This RIF had an indicator with the purpose of measuring the number of experts on the bridge, seeing as this affected the way the bridge was operated. However, research showed that type of crew present could have an effect. Main sources used by Baumgärtner for this part was Rothblum (2000) and Nilson, Gärling, and Lützhöft (2009).

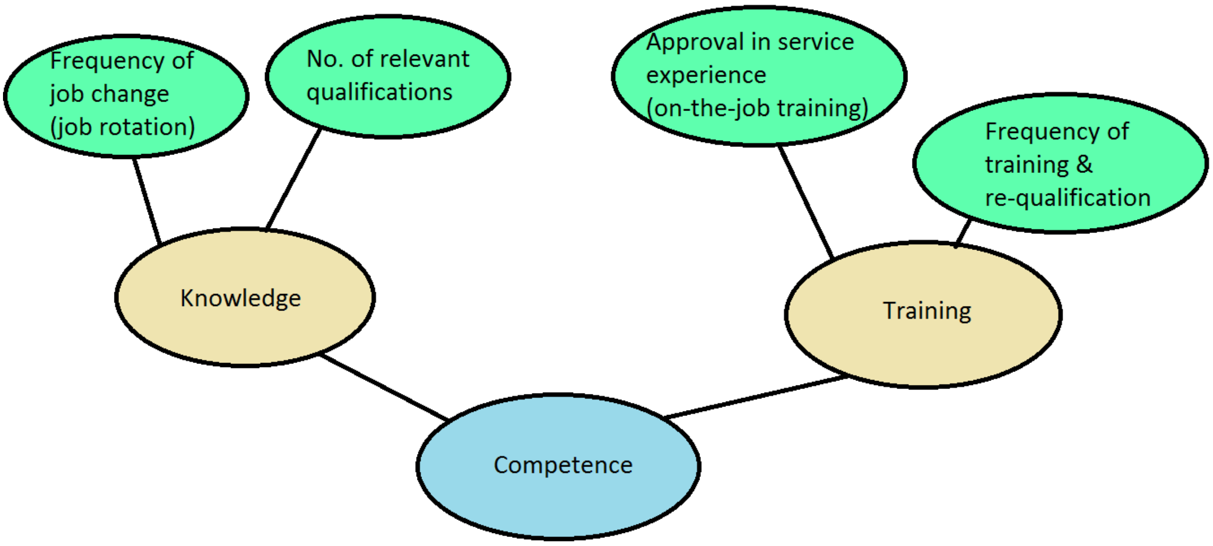
Frequency of job change (job rotation)
No. of relevant qualifications
Approval in service experience (on-the-job training)
Frequency of training & re-qualification
Knowledge
Training
Competence

Figure 19 - RIFs and risk indicators for the node "Competence", partially taken from (Baumgärtner, 2016)

Competence in the context in this thesis, is thought of as the competence to implement fire reducing measures, so that a fire does not develop. It also includes the competence of doing the job correct. I.e. having the right knowledge about the job, for instance that a housekeeper cleans the dryer for lint after it has been used or that a chef cleans the galley as it should. This would also help prevent the risk of a fire occurring.

6.1.7.2 Communication

The findings in Baumgärtner (2016), are very much related to operations on the bridge. However, much of it can be transferred to the current thesis. The proposed RIFs and risk indicators are the same, except for one RIF. Baumgärtner's proposed RIF "Implementation of BRM" has been removed. BRM stands for Bridge Resource Management, an organisational tool that teach officers on the bridge to work as a bridge team. Instead, the RIF "Crew-passenger correspondence" has been added. The purpose of this RIF is to be able to measure the information given to passengers, regarding fire safety. This could for instance be information on how to act if smoke is detected and how to prevent this from turning into a fire, or proper signing of where smoking is allowed and not to prohibit passenger from smoking in e.g. their cabin. Considering the interaction between passenger and crew, with regard to communication, is important seeing as passengers can have a great deal of impact on preventing a fire from happening.

Baumgärtner found in her research that communication affects situation awareness, working behaviour and effective decision making. Language problems are often mentioned as a reason for misunderstanding or communication between crew members. STCW requires a certain level of fluency in work language, this is often not complied with. Miscommunication may lead to anything from mild annoyance to formation of potentially hazardous situations (Baumgärtner, 2016).

The following behavioural markers, here referred to as indicators, presented by Gatfield (2006), was used as indicators in Figure 20.

- Ratio of degree of feedback control to the degree of predictive control (indication of the level of awareness)
- Number of unfinished sentences
- Number of alternative hypotheses and actions communicated to tea members
- Communicating in a way that shares the same mental model

It may be discussed whether or not the first three indicators are measurable or not, and these are therefore modelled with a dotted line in Figure 20 (Baumgärtner, 2016). The main sources used by Baumgärtner in this part are Gatfield (2006) and Hetherington, Flin, and Mearns (2006).

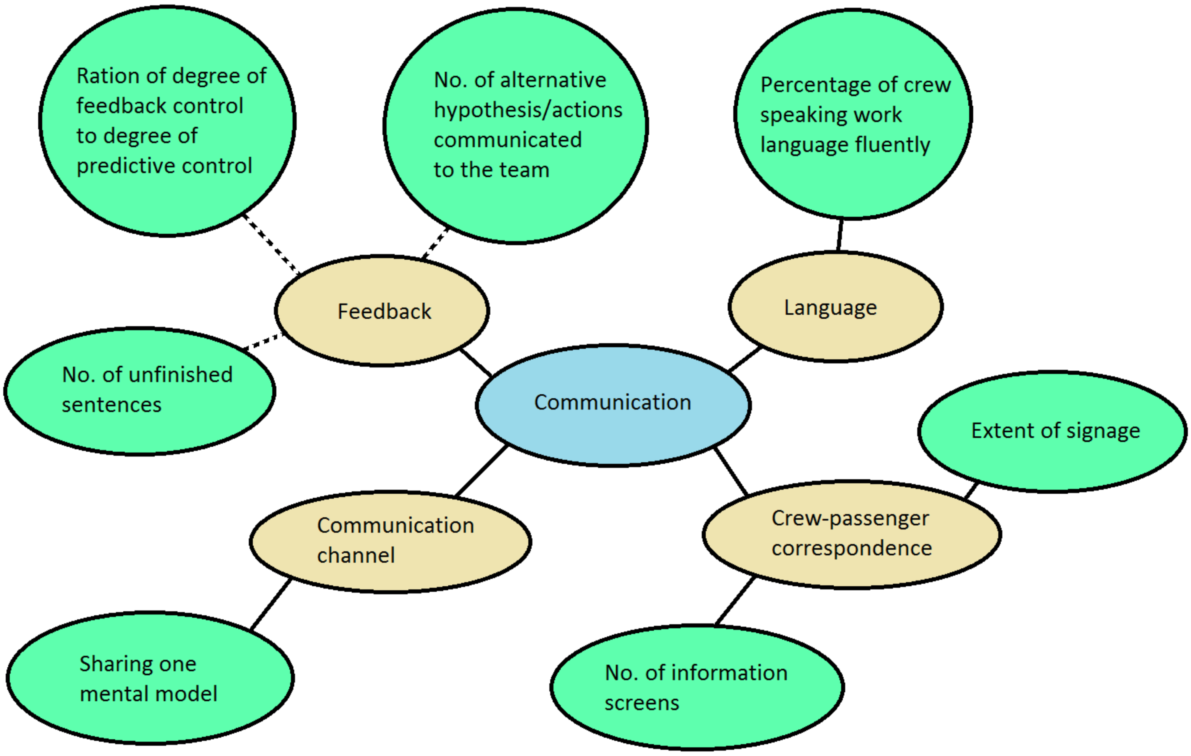
Ration of degree of feedback control to degree of predictive control
No. of alternative hypothesis/actions communicated to the team
Percentage of crew speaking work language fluently
Feedback
Language
No. of unfinished sentences
Communication
Extent of signage
Communication channel
Crew-passenger correspondence
Sharing one mental model
No. of information screens

Figure 20 - RIFs and risk indicators for the node "Communication", partially taken from (Baumgärtner, 2016)

6.1.7.3 Physical and cognitive capabilities

The node "physical and cognitive capabilities" aims to describe a person's capability to undertake physical and mental tasks.

Baumgärtner mainly uses an article by (Wolbers & Hegarty, 2010), which gives an overview of the psychological prospect and tries to answer the question *"What determines our navigational capabilities"*. Navigational in this context does not refer to the navigation of the ship, but to how humans navigate and orients themselves through the environment. The following bullet points, presented by Baumgärtner (2016) are the main influencers on such capabilities in a human. They were used as a basis for the RIFs, which are presented in Figure 21 along with the risk indicators.

- *Navigational strategies* relate to how a person will gather information about the surroundings, in order to navigate oneself. A good navigator need few cues to navigate and is flexible to change navigational strategies.
- *Self-motion perception* is how accurate a person is able to keep track of its orientation and position in relation to the environment.
- *Age* have proven to have an impact on a person's ability to navigate. Older people have often more inefficient search strategies and use longer time to navigate themselves from one point to another.
- *Experience* have not yet been proven to affect the navigational capability. It has only been proven that experience leads to structural changes in the brain.
- *Gender* has proven to make a difference in the ability to navigate. Women tend to prefer local and familiar landmarks and routes, while men typically prefer cardinal directions, metric distances and environmental geometry.

Another factor mentioned by Baumgärtner is fatigue, which can have an effect on the mental states of humans. Studies have showed that fatigue was a contributor in 16 % of vessel casualties and 33 % of the injuries. A person that experience fatigue may have decreased alertness, mental concentration and motivation. In addition, it may also lead to reduced speed of the cognitive processes and increased reaction time. Length of sleep, wakefulness, work hours and workload was proven to significantly influence the feeling of fatigue. Measures that can reduce fatigue are regular meals, enough sleep, reduced administrative tasks and enough free time. In order for these measures to be feasible, a sufficient manning level is needed. Alcohol and occupational stress was also proven to affect the cognitive and physical capabilities. The latter influencing productivity, personnel health and welfare (Baumgärtner, 2016). Main sources used by Baumgärtner in this section are Wolbers and Hegarty (2010), Hetherington et al. (2006), Kristiansen (2005) and Dorrian, Baulk, and Dawson (2011).

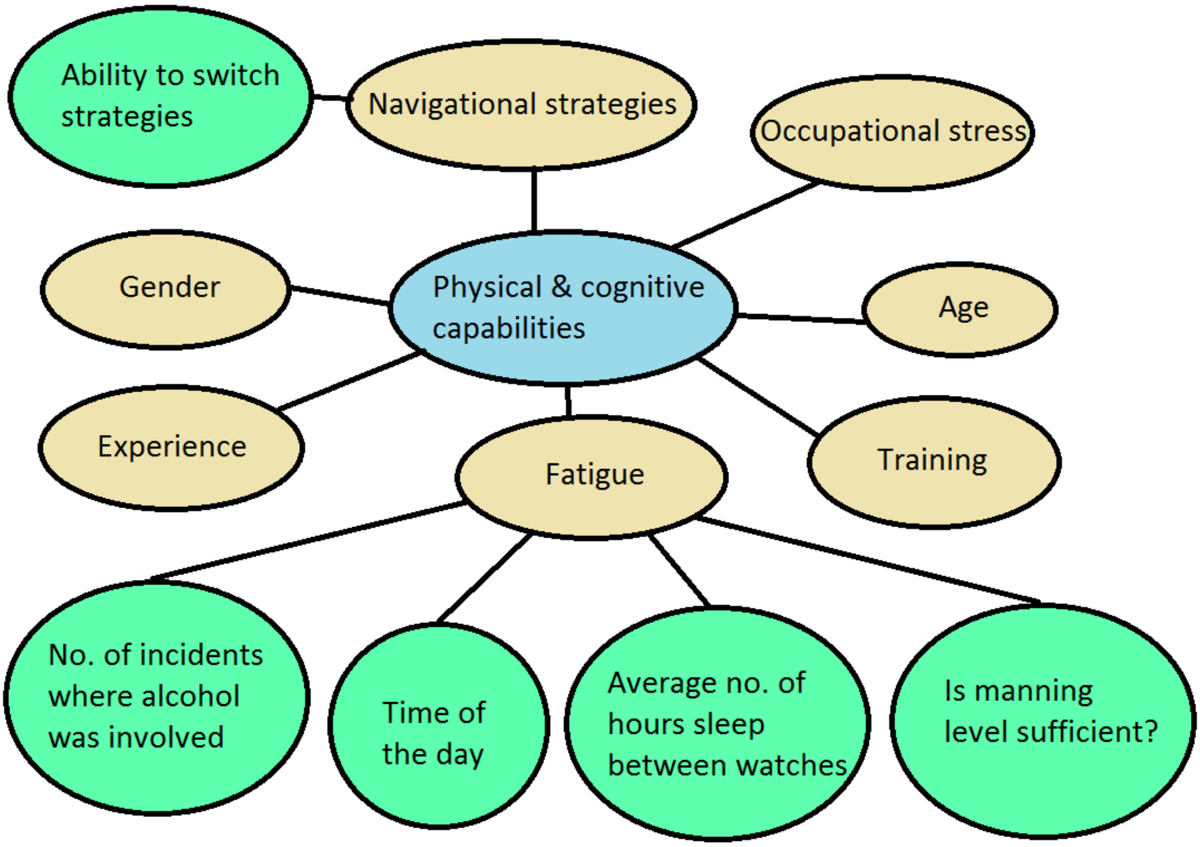
Ability to switch strategies
Navigational strategies
Occupational stress
Gender
Physical & cognitive capabilities
Age
Experience
Fatigue
Training
No. of incidents where alcohol was involved
Time of the day
Average no. of hours sleep between watches
Is manning level sufficient?

Figure 21 - RIFs and risk indicators for the node "Physical & cognitive capabilities" (Baumgärtner, 2016)

Fatigue was also discussed in chapter 6.1.5, regarding fatigue in the galley. It was found that humans biological clock, makes us more susceptible to fatigue between midnight and six in the morning. Therefore, "time of the day" has been proposed as an indicator.

6.1.7.4 Number/Complexity of tasks

A high workload may over time lead to exhaustion, and overwork over time may lead the crew to do dangerous failures. Thus, having a good balance between work time and pause time, and not having too many days of overwork in a row are important indicators to consider. Baumgärtner uses NASA Task Load Index (NASA TLX) to define workload as "the cost incurred by human operators to achieve a specific level of performance" (Baumgärtner, 2016, p. 67). Standardized questionnaires are used to assess the workload of the operators on the bridge, which is an important to consider in Baumgärtner's case of grounding/collision. The bridge system is not that important to consider in the current thesis, however questionnaires could be feasible to use to assess the workload of e.g. the kitchen workers in the galley, which has a hectic work environment.

Subjective Workload Assessment Technique (SWAT) is mentioned as another approach to measure the mental workload. It assesses the difficulty of the task, how much effort was put into it and if the crew member felt it was under pressure at any time. By using this approach together with an assessment of situation awareness, it has been shown that due to an increased workload the operator might have reduced monitoring behaviour, increased omissions and increased prospective memory errors (Baumgärtner, 2016). The proposed RIFs and risk indicators for the node “Number & complexity of tasks” are presented in Figure 22.

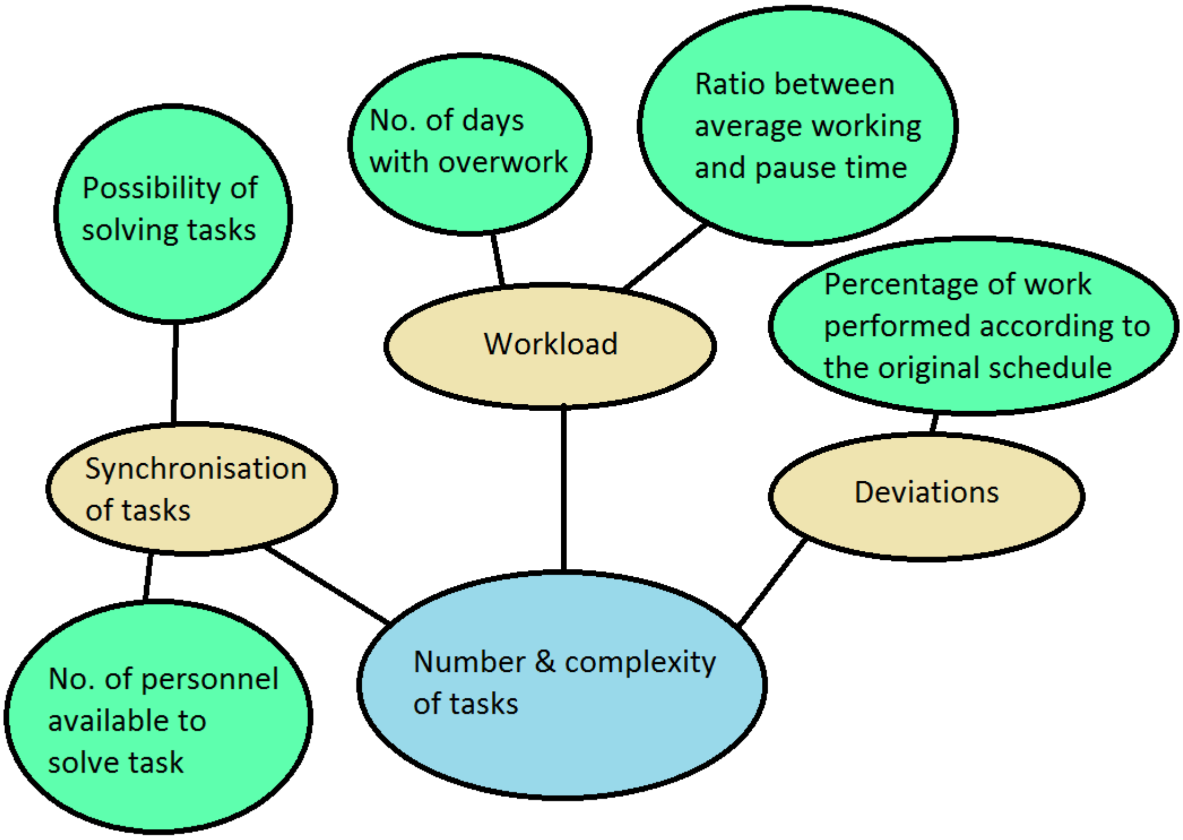
Possibility of solving tasks
No. of days with overwork
Ratio between average working and pause time
Workload
Percentage of work performed according to the original schedule
Synchronisation of tasks
Deviations
No. of personnel available to solve task
Number & complexity of tasks

Figure 22 - RIFs and risk indicators for the node "Number & complexity of tasks (Baumgärtner, 2016)

Main sources used by Baumgärtner in this section was Nilson et al. (2009) and Sauer et al. (2002).

6.1.7.5 Crew presence

The presence of crew can have a significant effect on whether a fire develops. The crew are trained on what to do in emergencies and know the lay out of the ship. The IMO’s International Convention for the Training, Certification and Watchkeeping of Seafarers (STCW) provides a minimum standard for competence in crisis management amongst others (STCW, 2016). An issue with passenger ships is that passengers are not as known with the lay out of the ship as the crew are. In addition, the level of training within the crew also varies. A professional seafarer has more extensive training and certification than personnel from the hotel part of the ship. This might be an entertainer that only have the bare minimum of training, and may not know much more than a passenger does when it comes to the life at sea. This was addressed as an issue by the Secretary-General of the IMO, in a speech regarding the safety of large passenger ships (O'Neil, 2000). Gatfield (2006) states that the criteria regarding human behavioural skills and crisis management that is detailed within the code is open to interpretation and are very much subjective. Since the level of experience of the crew could vary on a passenger ship, some knowledge about the human behaviour in case of fire could be useful.

A study executed by Kobes, Helsloot, de Vries, and Post (2010) looked at the human behaviour in case of a fire. They found that how a human respond in case of a fire, depends on three features; human, building and fire. Human features could be ability to move, awareness and personality. Building features could be lay out, materials and size of building. While fire features could be visual, smelling or audible features. The relation between these three features are presented in Figure 23.

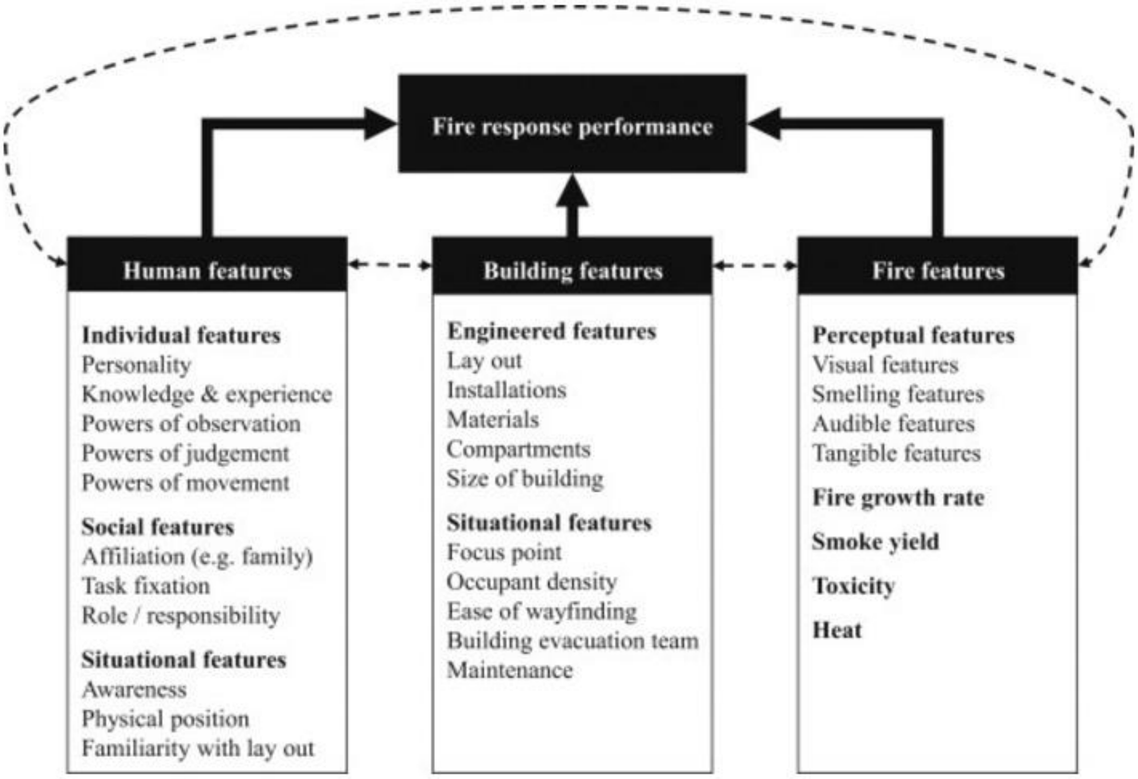
Fire response performance
Human features
Individual features
Personality
Knowledge & experience
Powers of observation
Powers of judgement
Powers of movement
Social features
Affiliation (e.g. family)
Task fixation
Role / responsibility
Situational features
Awareness
Physical position
Familiarity with lay out
Building features
Engineered features
Lay out
Installations
Materials
Compartments
Size of building
Situational features
Focus point
Occupant density
Ease of wayfinding
Building evacuation team
Maintenance
Fire features
Perceptual features
Visual features
Smelling features
Audible features
Tangible features
Fire growth rate
Smoke yield
Toxicity
Heat

Figure 23 - Fire response performance and its features

The study focused mainly on reactions in case of a fire, there is however some mentions of fire preventions. And Figure 23 gives a good overview of different factors that affect the human behaviour in a crisis. No RIFs or risk indicators have been developed for the node of "Crew presence, seeing as not much research on the area was retrieved. However, the found research that is believed to possibly be of importance have been presented.

6.1.8 Technical failure

Technical failure in the electrical system or in fire protections systems can be a cause for fire in a ship. A failure in the electrical system can lead to a fire, whilst failure of the fire prevention and firefighting systems can lead to a fire being able to develop. Most of the properties of the firefighting systems is applicable to the consequence side of a risk analysis, and not the causal side that is being analysed in this case. However, some of the properties of such fires can keep a fire from occurring at all, by detecting smoke and heat before it develops into a fire. The aforementioned systems will be discussed further in the following sub-chapters.

6.1.8.1 Electrical system

Ventikos (2013) found in his research that electricity is the main ignition source on passenger ships, stating that it was the main cause in 30 % of the incidents. Hu (2016) agrees with Ventikos, stating that for hotel facilities, one of the main contributors to fire is the electrical equipment and wiring. The most common sources for electrical fires are (Gillman & Le May, 2007):

- Arcing, which can occur in a series or a parallel. If the arcing happens in a series, there is a decrease in the current. Whilst in a parallel arc, there is an increase in the current. The arcing can happen in short circuits, breakdown of insulation due to carbonization or ionization of air (Gillman & Le May, 2007).
- Excessive resistance heating in the absence of arcing, which may occur due to poor connections, excessive insulation or inadequate cooling amongst others (Gillman & Le May, 2007).
- External heating, which can cause the insulation to break down or the conductor material to embrittle (Gillman & Le May, 2007).
- Discharge of static electricity, which commonly happens when the insulating material get in contact with each other and especially when there is a relative motion between them. This can cause a build-up of electrons, which can be discharged and come in contact with the ground and make sparks (Gillman & Le May, 2007).

As for the prevention of electrical fires, Hu (2016) lists inspections and proper maintenance as the best way of avoiding electrical fires. From this research is seems as though the main contributing factor for whether or not a fire occurs in the electrical system is the condition of electrical equipment and wiring. Thus, there is only proposed one RIF for this node, namely "condition". The proposed RIFs and risk indicators for the node are presented in Figure 24.

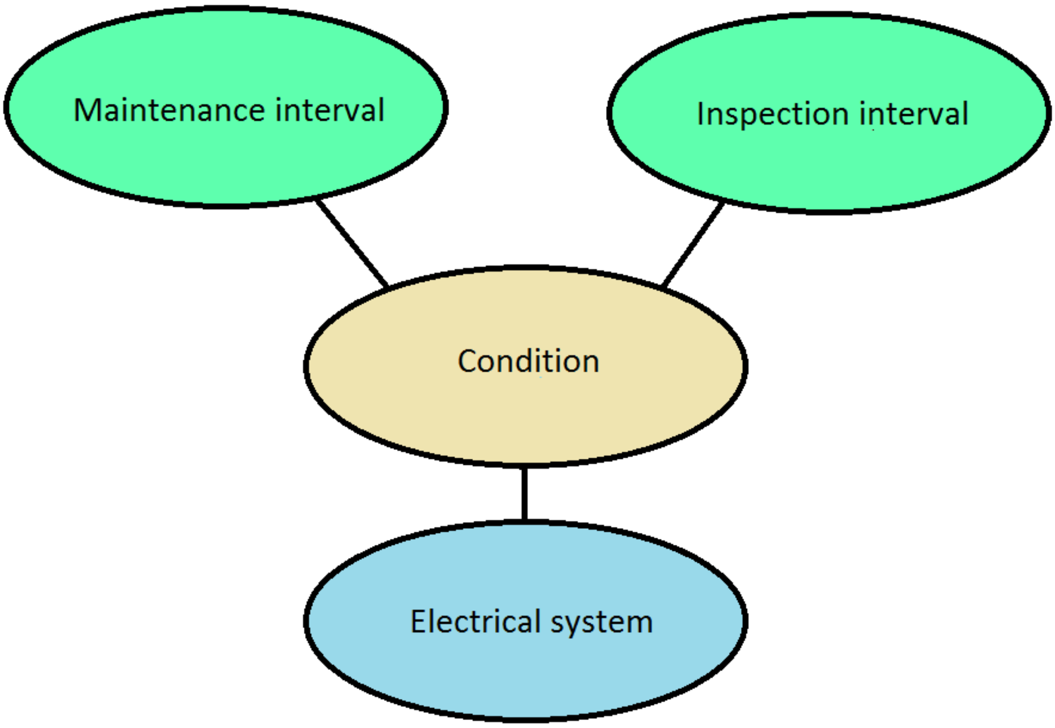

Figure 24 - Proposed RIF and risk indicators for the node "Electrical system"

6.1.8.2 Passive fire protection

Passive fire protection (PFP) is installed to prevent fires from occurring or slow the accumulation of fires. It can be classified in two ways, based on its protective action (Landucci, Rossi, Nicolella, & Zanelli, 2009):

- *Thermal coatings* that are applied directly on the material.
- *Thermal shields*, which are physical barriers that shield the flame source and keep it from spreading.

SOLAS sets requirements towards having both vertical and horizontal zones, by using thermal and structural division, that aims to keep the fire in the space of its origin (SOLAS, 2016). Organic or inorganic materials are commonly used, however inorganic-based materials have proven to become brittle after exposure to fire. Organic-based materials have proven to be subject to thermal degradation du to exposure to fire (Landucci et al., 2009). A study performed by (Landucci et al., 2009) showed that basalt-based panels had full structure integrity, lower purchase cost, lower weight losses and better thermal behaviour. I.e. the type of material used may have an effect on the safety of the passive fire protection.

Roberts, Shirvill, Waterton, and Buckland (2010) did a study on the deterioration of PFP. There was a concern in the offshore industry that the PFP might deteriorate over time. The study showed that no of the coatings tested had corrosions that affected the fire resistance of them. However, some requirements were made in order for the PFP coating to resist weathering (Roberts et al., 2010);

- Proper preparation of the substrate
- Closely controlled application within the specified environmental range
- A resilient topcoat with timely renewal
- Proper treatment of edge features to prevent corrosions
- Adequate inspection, maintenance and repair

As previously mentioned, the risk for fire in passenger cabin is quite high. The cabin contains furniture, mattress and beddings amongst others. Items which are less flame retardant and catch fire more easily. Considering the materials used, is therefore considered to be important.

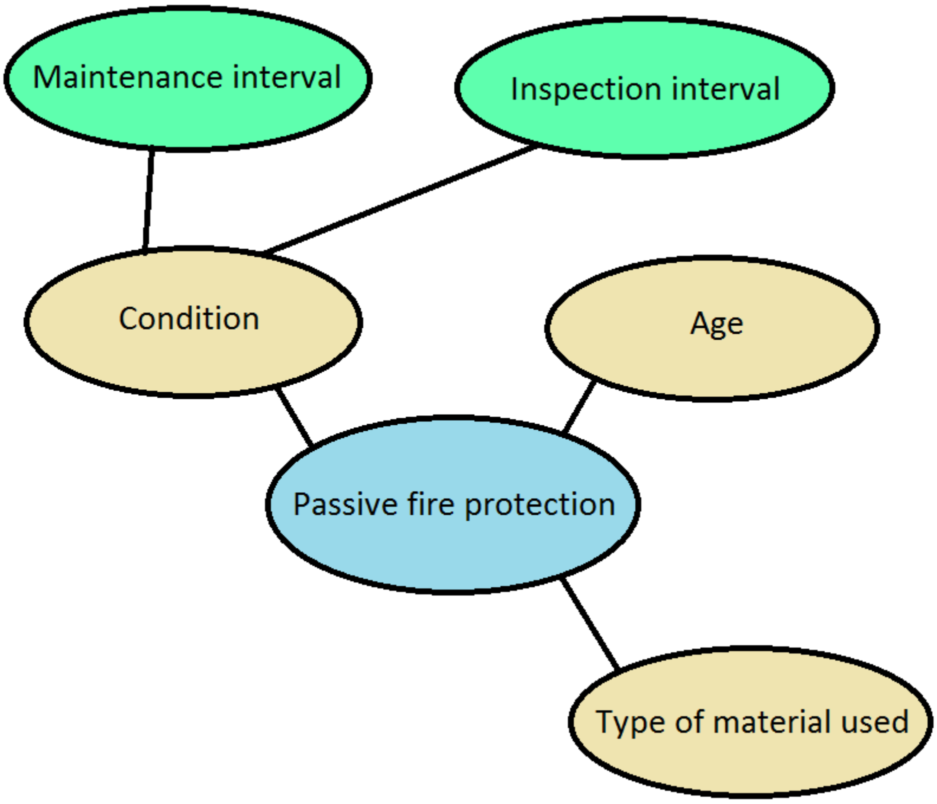

Figure 25 - RIFs and risk indicators for the node "Passive fire protection"

6.1.8.3 Active fire-fighting system

"The function of a shipboard fire-detection system is to give reliably the earliest possible warning when unwanted fire conditions are present on board" (Kuo & Chang, 2003). An active firefighting system aims to detect and suppress/prevent a fire from occurring. This can be smoke and heat detectors, sensors, extinguishing systems amongst others. As previously mentioned, the aim of the firefighting system in the current case is to prevent a fire from occurring. Thus, it is important to consider the parts of such systems that are able to that. For instance, smoke detectors and heat detectors must be able to detects smoke and heat as early as possible, so it is possible to prevent a fire. Either by automatic firefighting measures, alarm or human intervention amongst others. The desired characteristics of such systems is increase in the detection sensitivity, decrease in detection time and increase in system reliability by achieving improved nuisance alarm immunity. I.e. the system should only be able to detect the real fire and fire hazards, and not be alarmed by nuisance sources, for instance damp from hot showers. Improvement in reliability is important to integrate the fire detection system with remote, automatic fire suppression systems with the ability to decide how much suppression is needed and where (Rose-Pehrsson et al., 2003).

Fire detection systems use algorithms that, with the help of data from sensors measuring temperature, smoke and combustion products, are able to detect smoke, heat and fire (S.-J. Chen, Hovde, Peterson, & Marshall, 2007). Research show that use of such multi-sensor detectors improves life safety, as they are able to detects hazards much faster than a conventional smoke detector, with a difference in detection time of several minutes. In addition, these systems have proven to be more reliable, as they are able to eliminate many of the nuisance alarms (Gottuk, Peatross, Roby, & Beyler, 2002). Rose-Pehrsson et al. (2000) agrees, stating that "multi-criteria algorithms are capable of detecting more fires than the conventional smoke detectors, given the same set of data for incipient fires". Research show that, given the same data, a photoelectric smoke detector will detect 31 fires and an ionization smoke detector will detect 56 fires, while multi-sensor detectors will detect 78 fires. In addition, the multi-sensor detectors will detect less nuisance alarms than the conventional smoke detectors (Rose-Pehrsson et al., 2000).

Based on the desire to have a lowest possible detection time, highest possible detection sensitivity and as few false alarms as possible, the RIFs and risk indicators shown in Figure 26 are proposed. Condition is also included, seeing as maintenance and inspection of such systems are always important to make sure that they have the desired condition.

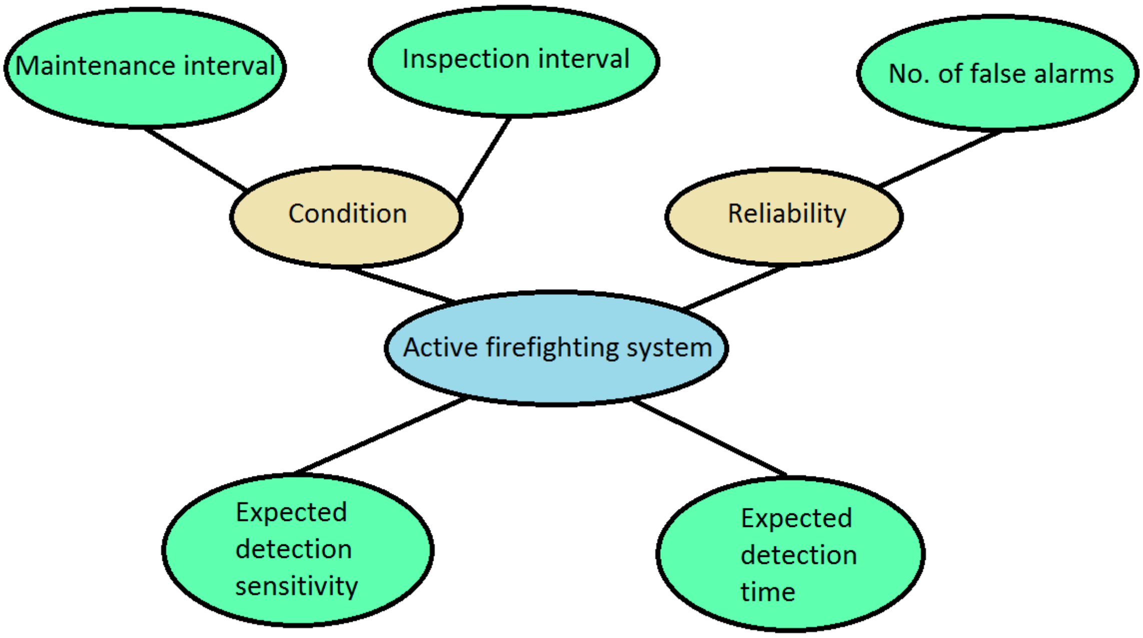
Maintenance interval
Inspection interval
No. of false alarms
Condition
Reliability
Active firefighting system
Expected detection sensitivity
Expected detection time

Figure 26 - Proposed RIFs and risk indicators for the node "Active firefighting systems"

6.1.9 Age of vessel and size of vessel

Age of vessel and size of vessel are two different nodes in the BBN. They are, however, discussed separately and together in the same sub-chapter. This is due to the relation they have with each other when regarding passenger vessels. Li, Yin, and Fan (2014) did a study where they analysed a large set of accident data, to investigate the safety level of ships based on the age of the vessel amongst others. They started out with the hypothesis that that as the age of the vessel increases, the safety level decreases. Many would believe that this is correct, thinking that as the vessel gets older, its systems would degenerate and be out dated. However, their study showed that the opposite happens. This is believed to be due to the fact that older vessels are maintained and operated well, and that that is the reason they are able to operate for so long. Figure 27 shows a plot of the safety level vs. vessel age, for different types of vessels (Li et al., 2014).

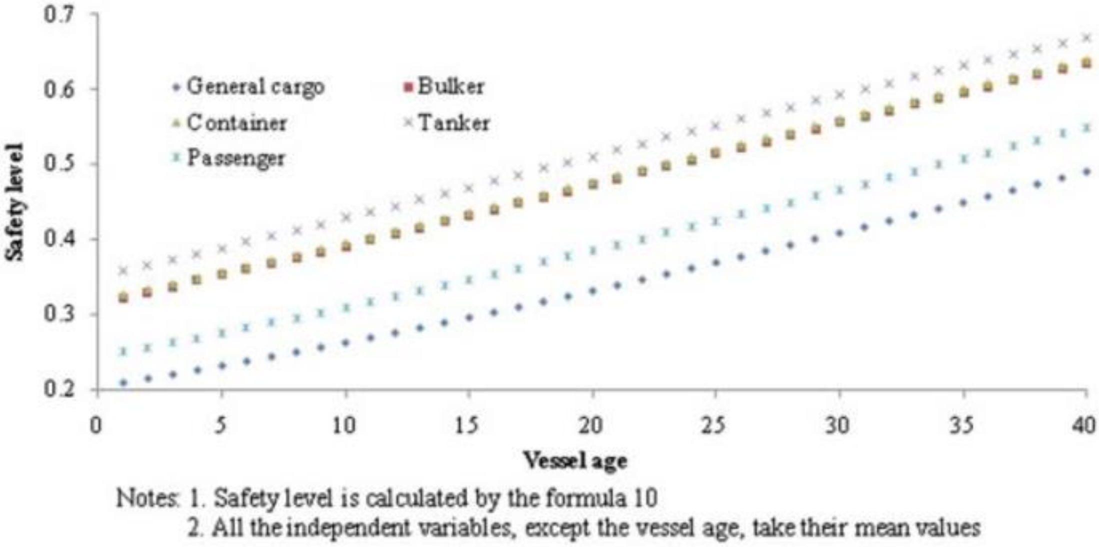

Figure 27 - Safety level vs.vessel age for different vessel types (Li et al., 2014)

In Figure 27, one may clearly see how the safety level increases with age, it could also be noted that passenger vessels are the vessels with the second lowest safety level. This is supported by Cariou, Mejia Jr, and Wolff (2008), which stated that passenger ships have more deficiencies compared to other vessels.

In their study of accident data, Li et al. (2014) also looked at the safety level vs. vessel size, where their hypothesis was that as the size of the vessel increases, the safety level decreases. A bigger vessel is more complicated to operate and manoeuvre, and so the level of safety decreases. This is of particular importance, seeing as passenger ships today, cruise ships in particular, tend to get bigger and bigger. The study performed by Li et al. (2014), showed that the hypothesis was right and that the safety level decreases as the size of the vessel increases. Figure 28 shows a plot of this, for different vessel types. Vessel size is measured in gross tonnage (GT).

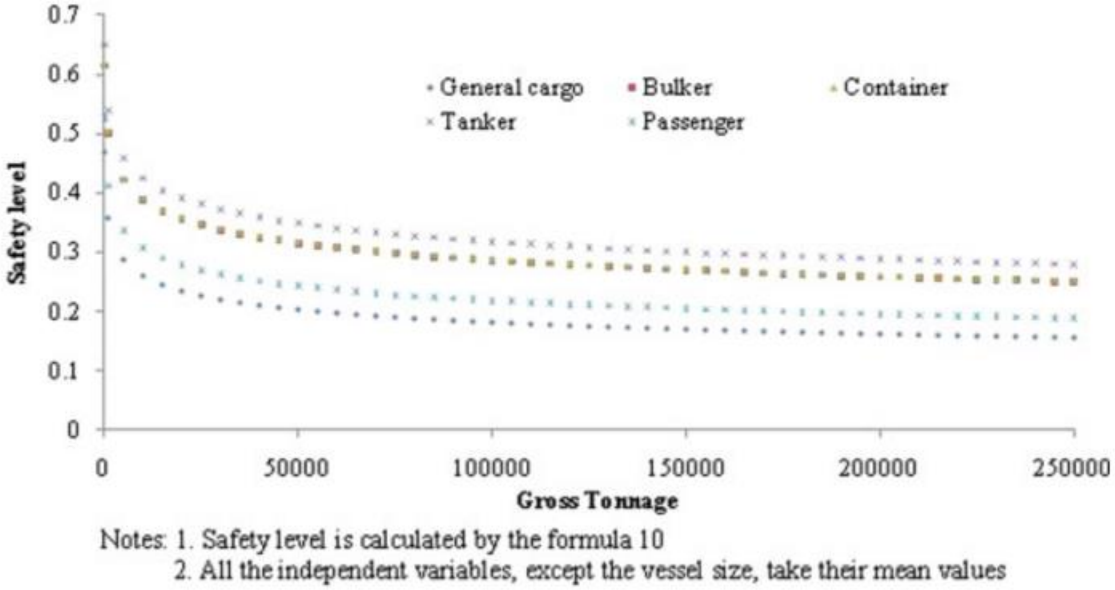

Figure 28 - Safety level vs. vessel size, for different types of vessels (Li et al., 2014)

From Figure 28, it is seen that is not the vessel type with the lowest safety level in this situation. In fact, they are the safest vessel type, when regarding size of vessel. However, the tendency is the same as for the other vessel types. The safety level decreases by increasing vessel size, and tends decrease less as the size gets bigger.

A big concern in the industry today is the increasing size of passenger vessels. For cruise companies, it is more cost-efficient to have bigger vessels, and the increase in size keeps growing. A challenge is then to have the new ships comply with regulations, and also adjusting the regulations to the current development. The trend with bigger passenger vessels could affect the safety of the vessel, thereby making newer and bigger ships even less safe than they already have been proven to be. O'Neil (2000) stated that the issue was not that the vessels did not comply with the regulations, but that the regulations was not always able to keep up to speed with the development of new designs and solutions. The size of the passenger ship also affects the size of the galley and laundry, two hazardous areas. The bigger the ship, the more people are on board and the bigger the capacity needs to be on the food and housekeeping service. The bigger size would also mean more people and more cabins.

6.2 Environmental conditions

Environmental conditions, such as the weather, are external conditions that cannot be influenced by humans. Such conditions will affect the ship and crew on board, and therefore the crew needs to take the weather into consideration in order t operate the vessel in a proficient manner for the safety of both humans and cargo.

6.2.1 Weather

The influence of weather was research in Baumgärtner (2016). A summary of this will be given first, before the relation between weather and fire on passenger ship is shortly presented.

Studies of maritime accidents have shown that the weather conditions may act as a dominant cause for the accident. This is often linked with the crew having a low risk perception or a high-risk acceptance. The weather as a factor can be split into light conditions, sea state, wind direction, wind force and visibility. Studies show that the significant wave height have little influence on the occurrence of accidents. An accident could happen with a significant wave height both larger than 9 metres and lower than 4 metres. However, the sea state, for instance the steepness of the waves, proved to have a significant effect on the ship motion. A rapid change in the sea state should therefore be given attention, when assessing the weather (Baumgärtner, 2016). Baumgärtner therefore listed “sea state”, “wind speed/wind force”, “current” and “visibility” as indicators. However, for the current case, visibility has been left out as it is not seen as influential to the risk of fire. As previously mentioned, “weather” was added as a node in the BBN, due to its influence on the risk of fire on the cargo deck. It was found that a fire could occur on the cargo deck, when objects shifted due to bad ship motion because of weather conditions. I.e. big waves and wind forces. “Weather”, is in this case treated as a RIF. The proposed RIF and risk indicators are presented in Figure 29.

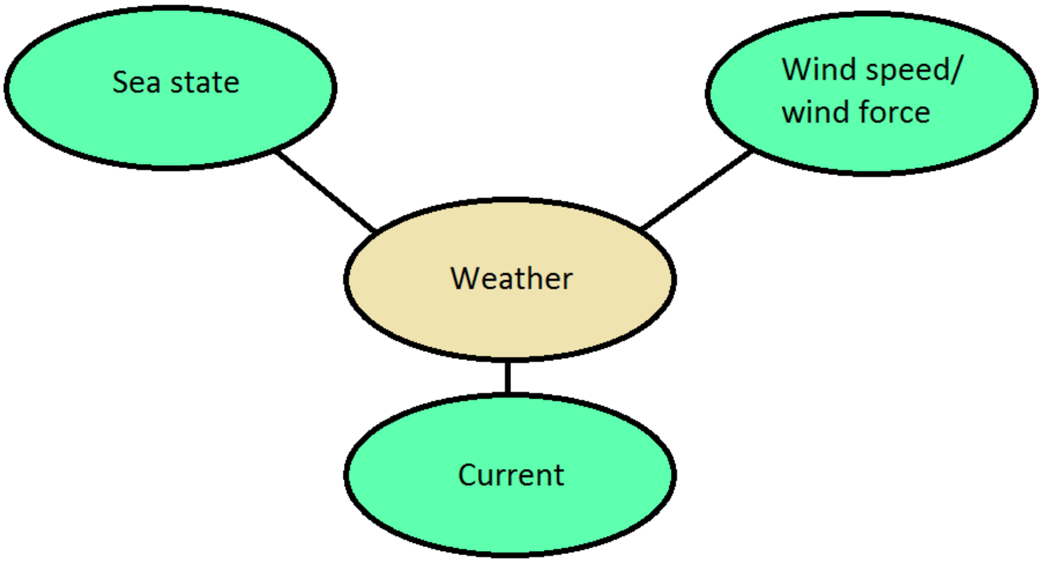

Figure 29 - Risk indicators for the node "Weather", which in this case is treated as a RIF. Taken from (Baumgärtner, 2016) and adjusted to the current case.

Sea state describes the surface conditions of the sea. This includes the effect from winds, swells and currents. The World Meteorological Organization’s (WMO) code 3700, classifies the sea state based on wave height and a description of the waters (Baumgärtner, 2016). This is presented in Table 6.

Table 6 - WMO's code for sea state

Code	Wave height (m)	Characteristics
0	0	Calm-glassy
1	0 – 0.10	Calm-rippled
2	0.10 – 0.50	Smooth-wavelet
3	0.50 – 1.25	Slight
4	1.25 – 2.50	Moderate
5	2.50 – 4	Rough
6	4 – 6	Very rough
7	6 – 9	High
8	9 – 14	Very high
9	Above 14	Phenomenal

Studies also showed that the wavelength could have an influence on the ship characteristics, especially with wave lengths of more than half the length of the ship. Current is suggested to be characterized as “calm”, “slight”, moderate” or “rough”, or by the speed. The Beaufort scale is often used to describe the wind conditions at sea, by estimating the wind forces. Based on this, wind speeds are established empirically. The WMO propose the following characteristics presented in Table 7 (Baumgärtner, 2016).

Table 7 - The WMO's code for wind force

Code	Description	Wind force in knots	Wind force in m/s
0	Calm	0 – 0.9	0 – 0.2
1	Light air	1 – 3	0.3 – 1.5
2	Light breeze	4 – 6	1.6 – 3.3
3	Gentle breeze	7 – 10	3.4 – 5.4
4	Moderate breeze	11 – 16	5.5 – 7.9
5	Fresh breeze	17 - 21	8.0 – 10.7
6	Strong breeze	22 – 27	10.8 – 13.8
7	Near gale	28 – 33	13.9 – 17.1
8	Gale	34 – 40	17.2 – 20.7
9	Strong gale	41 – 47	20.8 – 24.4.
10	Storm	48 – 55	24.5 – 28.4
11	Violent storm	56 – 63	28.5 – 32.6
12	Hurricane	64 – 71	32.7 – 36.9

Stornes (2015) suggests that the WMO's code for sea state and wind force can be divided into larger categories. E.g. wind forces can be divided into "weak winds", "moderate winds" and "strong winds" instead. Main sources used by Baumgärtner in this section are Antão, Guedes Soares, Grande, and Trucco (2009), Kristiansen (2005) and Stornes (2015).

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Chapter 7

Discussion and Further work

Several assumptions are made during the development of the BBN. Such as only focusing on the most hazardous areas of the hotel function of the ship and, excluding machinery spaces. This might have an effect on the result of the BBN. The proposed indicators and factors are limited by the retrieved research and data, and will therefore need further evaluation and validating, to see if they are measurable and usable.

Some of the proposed RIFs are also nodes in the network, it is important to notice that when this is the issue, the RIF is only applicable for node in question. E.g. for galley, the RIF “Communication” is proposed. This is also a node in the network. For this case, the RIF “Communication” is limited to communication in the network, whilst the node “Communication” is applicable to all the communication on the ship.

For further work it is recommended that the structure of the BBN is evaluated and validated. Making sure that the nodes and structure presented, gives a good presentation for quantifying the causal relations that may lead to a fire on a passenger ship. The proposed indicators need to be validated and tested, to make sure that they are measurable and fit the requirements of an indicator. It should also be performed an analysis of the factors, deciding on which ones has the most effect on the risk, to see where measures should be taken in order to lower the risk for fire in passenger ships. Further research should also be done on the possible quantification of indicators, by using research articles, accident databases and expert judgements. Validated indicators should be implemented into the BBN in order to be able to create CPTs and in the end, calculate the risk for fire. It is also recommended that the immediate factors are to be evaluated, so that suitable RIFs and indicators can be proposed.

Seeing as the BBN in the thesis has been limited to hotel functions, areas such as bridge operations has not been considered. For further work, it could be interesting to include this in a way in the network, to see how decisions and actions on the bridge might affect the risk of fire occurring.

During the research done for this thesis, some articles worth mentioning that can be of importance, but have not been utilized should be mentioned. These are articles regarding safety culture, and the relation between organisational management and the seafarers on the ship. These articles focus for the most part, mainly on passenger ships. One of the articles also focus on the effect of different leadership profiles of the master has on the culture and crew on the ship. These articles could be of importance for nodes such as for instance “Crew management”, “HRM” or “SMS”. The articles are written by Santos-Reyes and Beard (2001), Lu and Tsai (2010), Theotokas, Lagoudis, and Kotsiopoulos (2014), Lu and Tseng (2012), Lu and Yang (2011) and Ek and Akselsson (2006).

Chapter 8

Conclusion

The objective of this thesis was to develop a BBN for risk of fire in passenger ships, find relevant data sources for the different nodes, identify missing data and suggest possible sources for data and methods for collecting data.

A risk model for fire in passenger ship was developed using Bayesian Belief Networks. The network was based on previously developed networks in the NSRM project, and adjusted for the current incident.

RIFs and risk indicators were proposed for different nodes, based on retrieved research and data. The focus was on the areas that proved to be most hazardous. The proposed network, RIFs and risk indicators will need further validation. ORIM is proposed as a possible method for quantifying the nodes of the network, where the RIFs and risk indicators are weighted and ranked against each other.

As for data sources, a lot of research on BBN, maritime traffic, passenger ships and risk factors are used. Seeing as passenger ships have a hotel function, it is also possible to use research on hotels and large buildings as sources. Research from aircrafts has also been used, when regarding the behaviour of passengers.

As for data worth mentioning it was found that the frequency for severe incidents when regarding fire on passenger ships is $4x10^{-3}$ per ship-year and the expected number of incidents each year was $5.4x10^{-1}$. It was also found that the most hazardous areas, i.e. cabin, galley, laundry and car deck, stand for 84 % of the areas where a fire occurs. The most common ignition sources were found to be electrical, cigarettes, hot surface or spontaneous combustion, and they stand for 79 % of the incidents.

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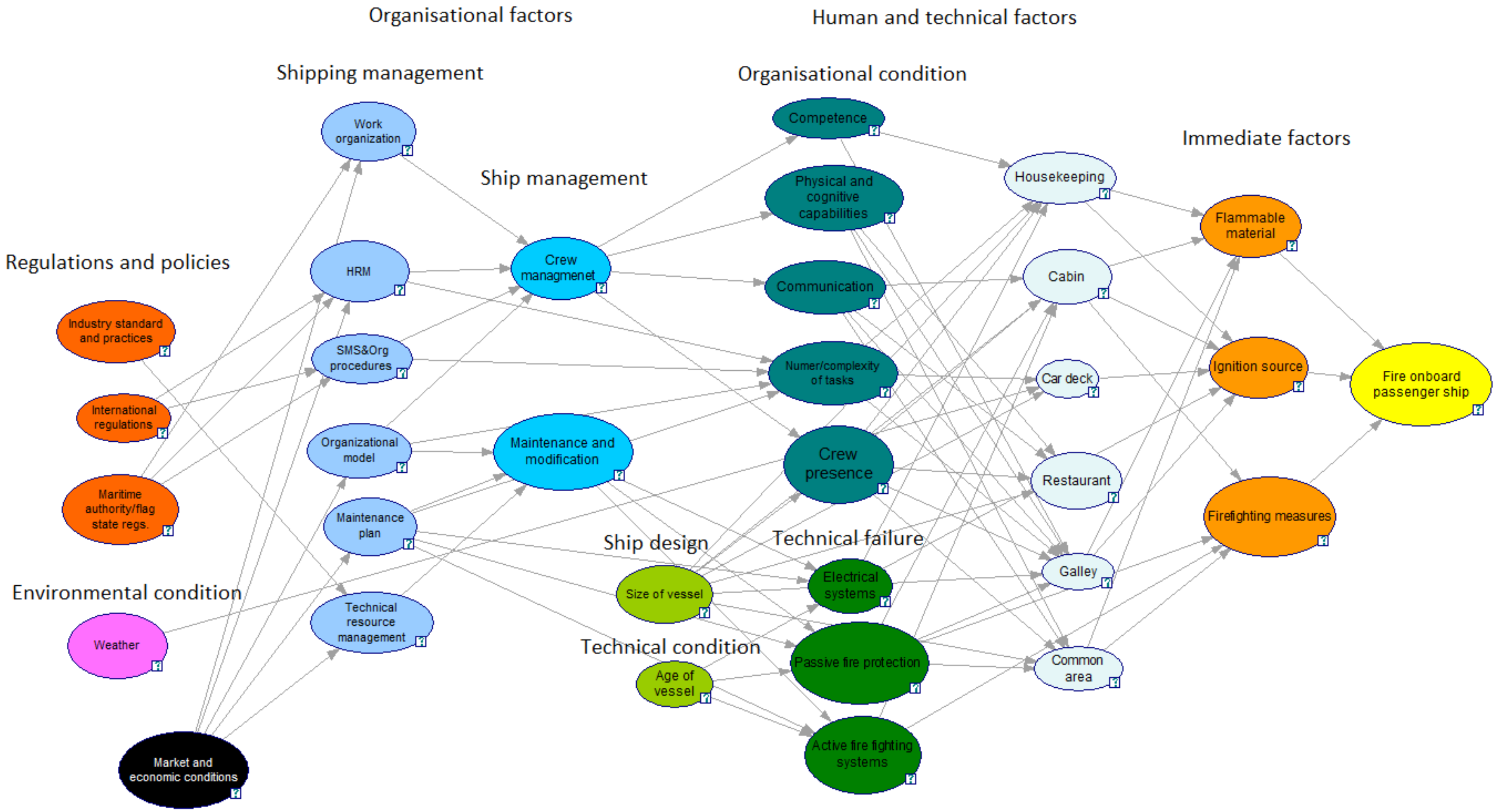
Appendix A – Developed BBN


Organisational factors
Human and technical factors
Shipping management
Organisational condition
Immediate factors
Ship management
Regulations and policies
Environmental condition
Ship design
Technical failure
Technical condition
Work organization
HRM
SMS&Org procedures
Organizational model
Maintenance plan
Technical resource management
Crew managmenet
Maintenance and modification
Industry standard and practices
International regulations
Maritime authority/flag state regs.
Weather
Market and economic conditions
Competence
Physical and cognitive capabilities
Communication
Numer/complexity of tasks
Crew presence
Size of vessel
Age of vessel
Electrical systems
Passive fire protection
Active fire fighting systems
Housekeeping
Cabin
Car deck
Restaurant
Galley
Common area
Flammable material
Ignition source
Firefighting measures
Fire onboard passenger ship