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Executive Summary

Accurate quantification of risks for vessel-to-platform collisions has been a goal of the petroleum industry for many years; however, technological advances in collision avoidance systems have not been reflected in current models. Additionally, new modeling theories have been developed which capture the complexities of modern socio-technical systems. This paper recommends that a new collision model be developed to reflect current collision avoidance systems.

Today's navigation tools

Current models for collision probability between platforms and passing vessels were developed prior to the rapid expansion of GPS, electronic charts and AIS.

Causal factors of ship- platform collisions

Accidents are often the result of multiple factors. Causal factors considered by current models are still very relevant today; but, because voyage planning procedures have changed in response to new technology, causal factors may have changed as well.

Barriers to prevent collisions with platforms

Technological advances have enhanced detection and communication barriers to prevent collisions. GPS and electronic charts offer the vessel's navigator improved situational awareness. With AIS, both the vessel and the platform are able to detect each other faster at a distance of approximately 40 nautical miles, compared to the 12 nautical mile radius offered by conventional radar.

Alternative modeling theories

Today's accident models are based on fault trees and event trees. They provide a sequence of events that must occur prior to a collision. As technology improves and the complexity of socio-technical systems increases, these models will become less relevant.

Suggested structure for a revised collision risk model

Flexible simulation software is available and should be utilized to model the complexity behind a vessel-platform collision. The suggested structure presented in this paper starts with four main systems: the vessel, the platform, VTS, and external conditions.

Contents

Abbreviations

AIBN	Accident Investigation Board Norway
AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
ATA	Automatic Tracking Aid
COAST	Computer Assisted Shipping Traffic database
COG	Course Over Ground
CPA	Closest Point of Approach
CRASH	Computerised Risk Assessment of Shipping Hazards
CRM	Collision Risk Management
CTOD	Crack Tip Open Displacement
DFU	Defined situations of hazard and accident
DSC	Digital Selective Calling
ECDIS	Electronic Chart Display and Information
DWT	Deadweight Tonnage
ERRV	Emergency Response Rescue Vessel
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GRT	Gross Register Tonnage
GWT	Gross Weight Tonnage
HSE	Health and Safety Executive (UK)
IMO	International Maritime Organization
IMR	Installation and Inspection/Maintenance and Repair
LTA	Less than Adequate
m	Meter
MAH	Major Accident Hazard
MMSI	Maritime Mobile Service Identity
MTO	Man, Technology and Organization
NCS	Norwegian Continental Shelf
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory)
NPD	Norwegian Petroleum Directorate
OIM	Offshore Installation Manager
OOW	Officer of the watch
PSA	Petroleum Safety Authority
RABL	Risk Assessment of Buoyancy Loss
RACON	RAdar beaCON
SBV	Stand-by Vessel
SOLAS	Safety Of Life At Sea
SOG	Speed Over Ground
TCPA	Time of the Closest Point of Approach
TOPAZ	Traffic Organization and Perturbation AnalyZer
UKCS	United Kingdom Continental Shelf
UKOOA	UK Offshore Operators Association
VDR	Voyage Data Recorder
VHF	Very high frequency
VTS	Vessel Traffic Service

Definitions and Terminology

500m Exclusion Zone:
A safety area established around all active surface installations (and some subsea installations) which extends to 500m from any part of the installation.

Blind vessel:
A vessel with inadequate radar (either by malfunction or human error), and also experiencing poor-visibility conditions.

Blunt End:
The organization(s) that shapes the work environment through providing resources and developing policies and procedures.

Charpy impact test:
A mechanical test which determines the amount of energy absorbed by a material during breakage.

Collision:
A general term used to describe any contact between a vessel and an offshore platform.

Cut Set:
The set of components which if they all fail will cause the system to fail.

Drifting Vessel:
A vessel in the vicinity of a platform that has lost power and the ability to steer.

Epidemiological Model:
A model based on the theory that an accident occurs when latent and active failures align.

Errant Vessel:
A vessel which is on a collision course with a platform, but unaware of it due to inadequate watchkeeping.

Near-miss:
An accident which could have potentially occurred if it had not been interrupted.

Passing Vessel:
A vessel on route to somewhere other than the platform.

Sequence of Events Model:
A model based on the theory that an accident is caused by a chain of events and that removing one event will prevent the accident.

Sharp End:
The people in direct contact with the daily vessel operating conditions.

Support vessel:
An attendant vessel which has a bona fide reason for approaching the platform and has been granted permission from the platform to approach.

Systemic Model:
A model based on the theory that accidents are the byproduct of a normal system and occur as the result of imperfect knowledge and resource constraints.

Waypoint:
A set of coordinates or physical structure used for navigation.

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Most of all I would like to thank my husband, Matthew, for his support and encouragement.

1 Introduction

The primary intent of this thesis is to discuss the current models used to predict vessel-platform collision frequency and to determine if they are satisfactory in assessing the risk posed by passing vessels. The secondary purpose is to review alternate modeling theories which could be applied if it is necessary to update the collision risk model. By reflecting on the causal factors of recent collisions and reviewing the current accident models, it is possible to see where improvements could be made to the current models.

Although the North Sea has not experienced a major collision between passing merchant vessels and offshore platforms, the accident potential is significant. With every new hydrocarbon discovery, the risk of ship- platform collision increases. The platform operator has little influence over the collision potential beyond the selection of the platform's location.

Platforms are designed to withstand smaller impacts from supply vessels, but passing vessels generally travel at higher speeds and consequently the displacement will likely be greater than that of an attending vessel. Even at modest speeds, the inherent energy transfer to the platform can easily cause deformation of structural members and possibly a total failure (17). Although only a small fraction of collisions recorded in the UKCS Ship/Platform Collision Incident Database involved passing vessels, the consequences of this type of accident are significant.

Accurately modeling vessel-to-platform collision risk is a problem which has challenged the industry for over 20 years. There are numerous social, technical, and environmental variables which influence the highly complex interactions between the captain and the vessel. Estimates from collision models are widely used as input for risk analysis; however, the models were developed in the late 1980's and have not been updated to reflect recent technological advances. Improvements such as GPS, electronic charts and AIS are tools used as aid in voyage planning and navigation. VTS assists with monitoring and can give an early warning when a platform appears to be at risk (17).

1.1 Specification of Need

In the last twenty years, there have been numerous advancements which allow the navigator to perform his job in a safer manner. As safe practices are continuously improved, one path to catastrophe may be removed but new error opportunities and sequences to failure are introduced (8). For this reason, there is a need for the vessel-platform collision models to periodically be reviewed and updated to reflect improvements in technology and safe work practices. The assumptions and judgment used when the current models were developed have has gradually become less relevant.

1.2 Objectives

This aim of this paper is to improve the overall model structure for vessel-platform collision risk. Answering the following questions will help to determine which factors should be considered when updating or developing a new model:

- Have improvements in technology reduced the frequency of passing vessel-platform collisions?
- What are the causal factors of ship- platform collisions?
- What barriers are in place to prevent such an event?
- Should newer modeling theories be used to capture the socio-technical relationships?

1.3 Boundaries and Exclusions

With focus on high speed collisions caused either by technical errors (e.g. machinery) or human errors (e.g. misinterpretation, watch keeper asleep, inattention), this paper includes a review of the primary contributors to collision risk caused by passing vessel traffic only.

- Vessel-vessel collisions are excluded since they involved two moving objects. Platforms are assumed not to be able to change position.
- Supply and standby vessels specific to the platform are not included. These vessels are assumed to be traveling at lower speeds when inside the 500 m safety zone. For this reason, the impact energies from these types of vessels are assumed not to have catastrophic consequences.
- Navy vessels and submarine traffic are typically excluded since the probability for collision with these two vessel types is negligible compared with the probabilities for collision with other vessel types (9).
- Acts of terrorism are also outside of the scope of this paper.

2 Background

A collision between a vessel and a platform is a relatively foreseeable event. Although the probability of a passing vessel collision is two orders of magnitude lower than an attendant vessel, the impact energy is expected to be much higher. The safety, environmental, and business consequences of such a collision could be catastrophic (48).

Since the early 1970s, efforts have been made by several organizations to quantify the risks of vessel-platform collisions. Technica was commissioned by the UK's Department of Energy to carry out a study on the risks of collisions between passing merchant vessels and fixed platforms on the UKCS in 1981. As part of this study, the theoretical model CRASH was developed based on historical accident data and a detailed survey of the UKCS shipping traffic (43).

In 1988, the Norwegian Risk Assessment of Buoyancy Loss (RABL) project was completed. The purpose of the project was to investigate the causes of buoyancy loss for semisubmersible drilling platforms in Norwegian and results were also applicable to fixed platforms. RABL found that the main hazards which could impact platform buoyancy were ship collisions, ballast system failures and blowouts. Furthermore, RABL concluded that the probability of a high-energy ship collision was greater than earlier estimates. One of the technical recommendations made by the project was to focus on collision prevention measures, such as warning systems (15).

RABL also aimed to develop a new analysis methodology be to assess platform safety levels and the COLLIDE project was initiated. In 1989, the phase I of the COLLIDE project, which was limited to the Norwegian Continental Shelf (NCS), was completed. Phase II of COLLIDE extended the model to the entire North Sea and was completed in 1991 (12). The CRASH model was updated in 1988 with improved shipping traffic data from the Commission of the European Communities COST-301 programme of research (43).

2.1 Existing Collision Models

Today, there are several commercial collision models that are used to estimate the frequency of collisions between passing merchant vessels and offshore platforms. Table 2-1 summarizes the main models and the organization which developed them (48). CRASH and COLLIDE are the most commonly used within the NCS.

Table 2-1: Current Collision Risk Models

Model	Organization
CRASH	DNV
COLLIDE	CorrOcean Safetec
COLRISK	Anatec
MANS	MSCN (Netherlands)

A platform is vulnerable to collisions from several different vessel types, including:

- Navy vessels
- Submarines
- Shuttle tankers
- Fishing vessels
- Supply vessels
- Standby vessels

- Merchant vessels

The method used to calculate the collision risk frequency is not based upon the vessel type, but rather the way the vessel traffic travels in the area around the platform. Vessel collisions may occur when the vessel is under power or when it is drifting. With the exception of standby vessels, the drifting vessel collision frequency is low and is normally not included in the analysis (47).

Existing models generally do not include navy vessels and submarines because the probability for collision with these two vessel types is negligible in comparison to the probabilities for collision with the other vessel types. The collision risk from shuttle tankers is normally assessed separately (47).

The models only predict the frequencies of vessel-platform collisions. Presently, the consequences are not yet included (47).

In general, the collision frequency calculation is based on the following factors:

- The number of vessels that pass the location annually
- The probability of the vessel heading towards the platform
- The probability that avoidance planning was not used during voyage planning
- A watch-keeping failure occurs
- The vessel is not alerted in time by the platform or its standby vessel
- The vessel fails to recover from the collision course
- The field's collision risk reduction measures

Merchant vessels will generally sail in dedicated shipping lanes during passage from one destination to another. The position of the vessel is assumed to have a normal distribution within these lanes as illustrated in Figure 2-1. To give an indication of the potential consequences, the collision frequency estimates are split into 5 size categories of traffic (47):

- 0-1500 dwt
- 1500-5000 dwt
- 5000 - 15000 dwt
- 15000 – 40000 dwt
- > 40000 dwt

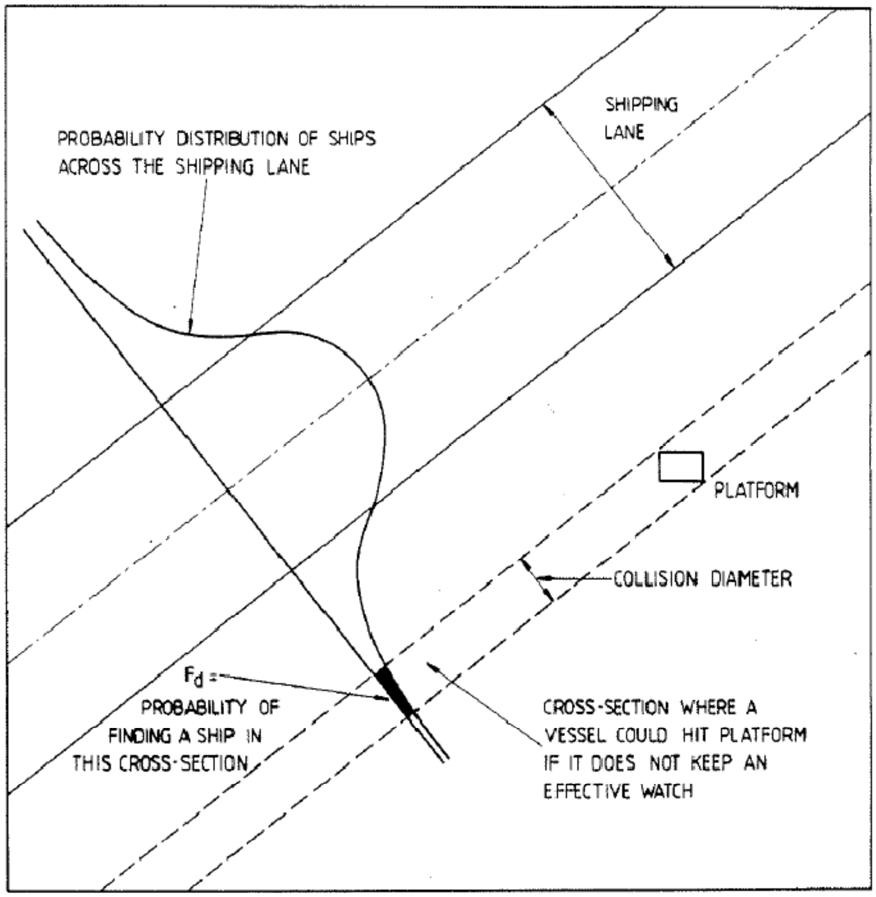


Figure 2-1: Normal Distributed Geometric Collision Probability (47)

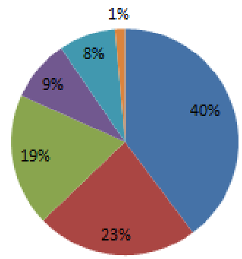
The collision frequency (collisions per year) is calculated is calculated as:

$$CF = N \times F_d \times P_1 \times P_2 \times P_3$$

where:

N	=	annual number of vessels passing in the lane
F_d	=	geometric collision probability, the fraction of vessels that are in the part of the lane heading towards the platform.
P_1	=	probability that voyage planning was not correctly carried out
P_2	=	probability of vessel watchkeeping failure or loss of control,
P_3	=	probability of platform or standby vessel failing to warn or divert a vessel on collision course, or vessel fails to recover from its errant state.

This paper focuses on vessel-platform collisions. Because this type of accident involves a moving vessel with a stationary object, it is assumed to share some of the same causal factors as a grounding accident. Figure 2-2 shows the relative distribution of the casual factors leading to grounding accidents from 1970-78 for Norwegian vessels greater than 1599 GRT. During these years, over 40% of the groundings were due to a navigational failure. Although the review of recent accidents indicates that 'internal communicational failure' is still a problem, some contributors, such as 'error/deficiency in charts', have likely been reduced by the introduction of electronic charts.



Navigational Factors

Description	Relative Losses (%)
Bridge manning and organization	8.4
Error / deficiency in charts or publications	8.1
Internal communicational failure	1.2
Inadequate knowledge and experience	1.0
Bridge design and arrangement	0.2

External Factors

Description	Relative Losses (%)
External influences like channel and shallow water effect.	18.9
Reduced visibility	12.6
Less than adequate markers and buoys	6.4
External conditions influencing navigation and auxiliary equipment	1.9

Navigational Error

Description	Relative Losses (%)
Failure due to navigation and maneuvering	11.7
Wrong use of the information from buoys and markers	8.4
Failure in operation of equipment	2.4
Wrong appreciation of traffic information	0.5

Figure 2-2 Primary Causal Factors in Grounding Accidents for Norwegian Vessels Greater than 1599 GRT from 1970-78 (26)

2.2 Influence of Technology on Major Collisions

While current collision models are useful in their prediction of collision frequency, they are conservative in that they neglect the impact of modern navigational standards. Accident theories have improved since these models were developed which now take into account the socio-technical relationships.

Improvements made to navigational standards include (5):

- **GPS**: In 1994, GPS was declared operational with 18 satellites that transmit signals to a GPS receiver. This enabled the vessels location, velocity and direction to be determined.
- **ECDIS**: Electronic Chart Display and Information System provided a computer based alternative to paper charts. In 1996, IMO introduced ECDIS standards, which means that future SOLAS regulations could possibly approve replacing paper charts with ECDIS.
- **AIS**: An Automatic Identification System became possible with the advent of transponders. In 2004, AIS became a requirement for SOLAS vessels.

In 1999-2000, the Norwegian Petroleum Safety Authority (PTIL) initiated a Risk Level to measure the risk level on the Norwegian shelf, known as "Trends in risk level" (RNNS). Since 2000, there has been a clear decline in potential vessels on a collision course; however, no clear improvement has been observed for major collisions (34).

2.3 Vessels on Collision Course

Most offshore platforms on the NCS can withstand collisions with vessels up to 5,000 tons and traveling at 2 m/s. Major collisions are those which occur with unauthorized vessels, of 5000 DWT or more, traveling with high speed when the impact occurs. As shown in Figure 2-3, there are so few of these incidents that no trend can be identified (36).

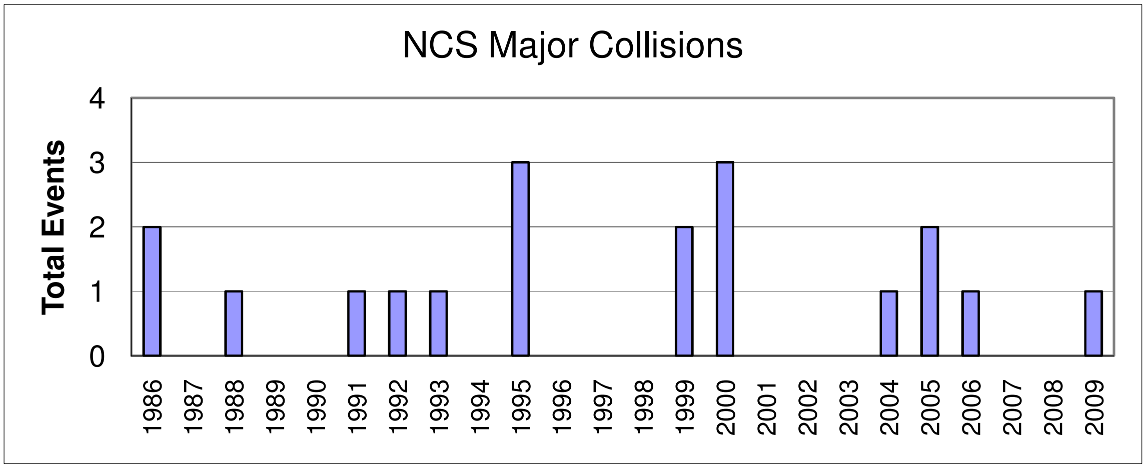


Figure 2-3: The number of major collisions between vessels and platforms from 1986-2009 (36)

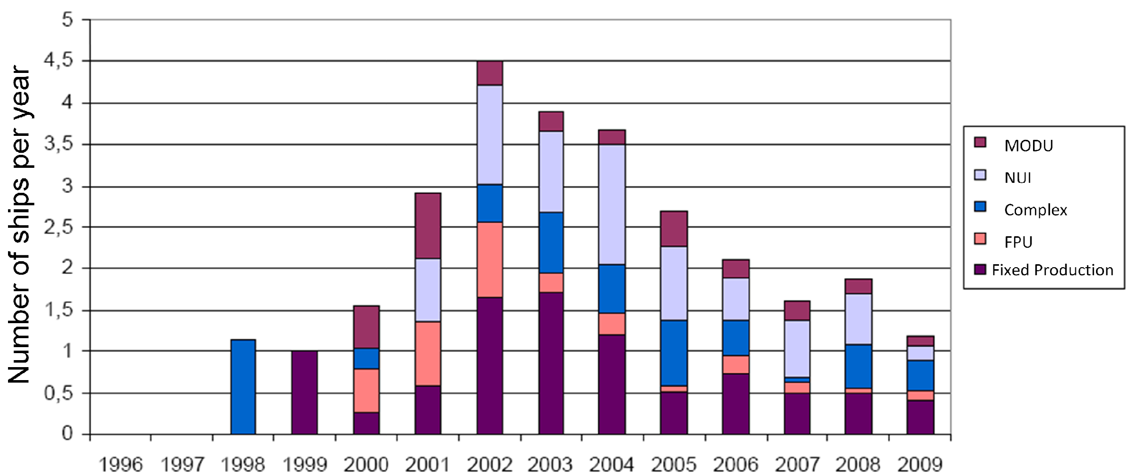


Figure 2-4: NCS Ships on a possible collision course from 1996-2009 (Except H-7 and B-11) (36)

The annual number of ships on a possible collision course in the NCS is shown in Figure 2-4. The increase in the number of vessels on collision course in 2002 is believed to be the result of improved monitoring and reporting of events. As a result of better monitoring, it is possible to get a better understanding of the causal factors and to implement barriers to reduce the probability of collision.

Based upon this data, it could mean that the introduction of new navigational technologies (GPS, AIS, ECDIS) have very little influence over the passing vessel-platform collision probability.

2.4 Maritime

For centuries, shipping has played a vital role for trading goods and services between regions. Most shipowners make safety an objective, but there are other objectives besides safety. Occasionally, the vessel and crew standards are lowered to make a profit. The shipowner may choose a particular classification society for economic reasons. Another controversial way for the shipowner to reduce costs is to register the vessel in different country from where it normally operates. This practice is called 'flagging out' and the main reasons for choosing this option are shown in Figure 2-5. An obvious consequence of selecting a lower standard flag is that safety is compromised. Mediterranean flags for example, have twice the loss rate of Northern European flags (26). Flagging out is discussed further in section 4.1.3.

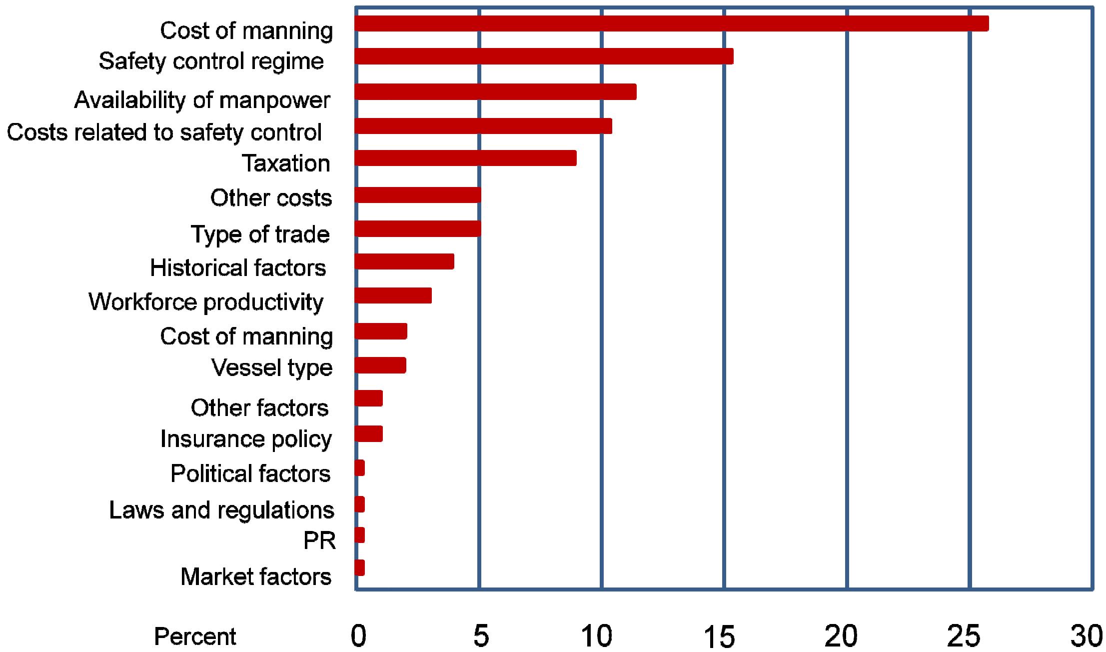


Figure 2-5: Reasons for "flagging out" (Based on (26))

2.4.1 Regulations

In 1948, the United Nations established the International Maritime Organization (IMO) to address maritime matters. The 'International Code for the Safe Operation of Ships and for Pollution Prevention', was produced by the IMO, and is normally referred to as the International Safety Management (ISM) Code. This code establishes an international standard for the maritime industry, but it is the responsibility of the Flag states to enforce the safety requirements.

The objectives of the ISM Code are:

- To ensure safety at sea
- To Prevent human injury or loss of life
- To avoid of damage to the environment, and to the ship

It is important that the ISM Code and its requirements to company safety management systems are not viewed in isolation. The other main safety conventions which must also be considered are:

- Safety of Life at Sea (SOLAS) and SOLAS Protocol
- Standards for Training, Certification, and Watchkeeping for Seafarers (STCW).
- The International Convention for the Prevention of Pollution from Ships (MARPOL) and its Protocol.
- Convention on the International Regulations for Preventing Collisions at Sea (COLREG)
- The International Convention on Load Lines (ILLC)

The SOLAS Convention was established with the main objective of minimum standards for construction, equipment and operation of ships. Most nations have ratified the SOLAS Convention. As new technologies and safety knowledge are developed, the convention is amended (26).

The concern for vessel-platform collision is reflected in many design codes. Since 1980, the NPD has required that platforms shall be designed to withstand a minimum impact of 5000 tons displacement at a speed of 2m/s for supply vessels. This corresponds to a kinetic energy of 14 MJ for a sideways collision and 11 MJ for bow or stern collisions. However, a passing vessel with 2-3000 tons displacement traveling at a speed of 5.5-6 m/s is capable of transferring 40-50MJ (2).

2.4.2 Risk Profile

Risk profiles, which are essentially simplified fault trees, are preferred by the IMO for the Qualitative Risk Assessment (QRA). Fault trees are used by many models to illustrate the underlying causes of a vessel-platform collision. The risk profile, shown in Figure 2-6, requires less knowledge and experience to construct. Since they are primarily based on historical accidents. Both techniques seek to determine the underlying causes of a collision (26).

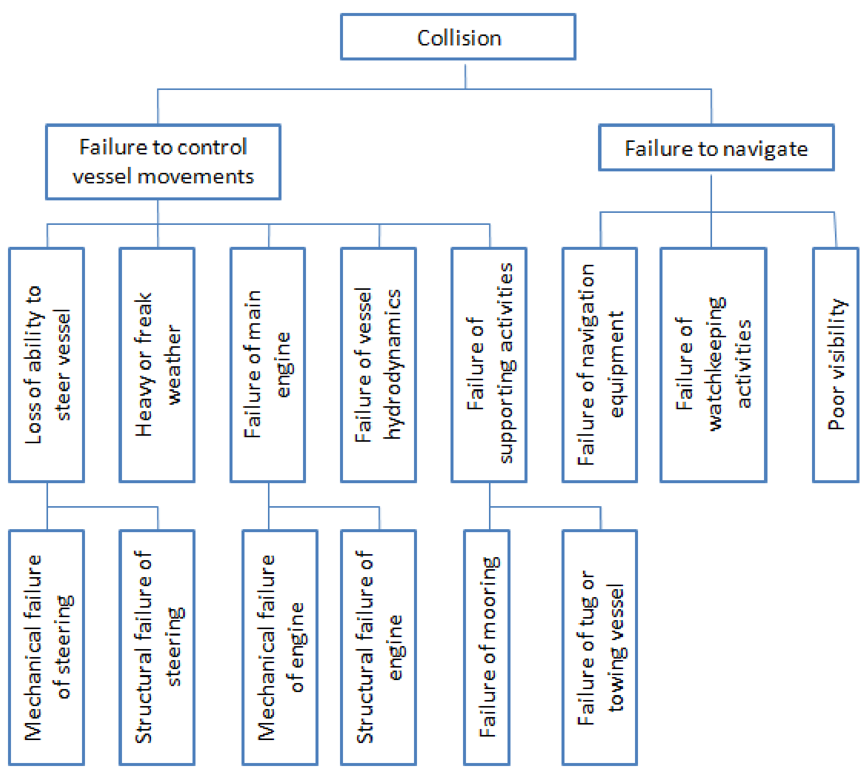


Figure 2-6: Risk Profile for an Accidental Collision (26)

2.4.3 Regulatory Authorities

The regulatory authority for technical and operational safety, emergency preparedness, and the working environment over the petroleum activities in Norway is the PSA. A ship on a collision course is one of the PSA's focus areas and the frequency of this risk has been measured in their report "Trends in risk levels 2009". They note a substantial decrease in the number of vessels on collision course after 2002. The introduction of AIS on all larger ships is assumed to be the main reason for this decline. With AIS is it easier to identify a vessel and to avert collisions by taking precautionary measures such as calling them (35).

3 Methodology

In order to evaluate scenarios that could lead to a passing vessel-platform collision, recent collisions have been reviewed. The main technological advances considered by this paper are introduced in this section, but are discussed further in section 4.

3.1 Literature

Throughout this evaluation process, literature has played a key role. The goal of initial searches was to achieve a greater understanding of topic in order to formulate the research questions. Keywords included: AIS, GPS, electronic charts, vessel-platform collisions, causal factors, and human error.

The main driver for this thesis is the improvements in technology and what this means for the current models. The review began by learning about the current models. It was also important to review the causal factors behind accidents and near misses for recent passing vessel collisions. One challenge was finding enough documentation. Such collisions are infrequent and due to the guarded nature of the maritime industry, it is believed that near miss incidents are under reported. This is reflected in Figure 3-1.

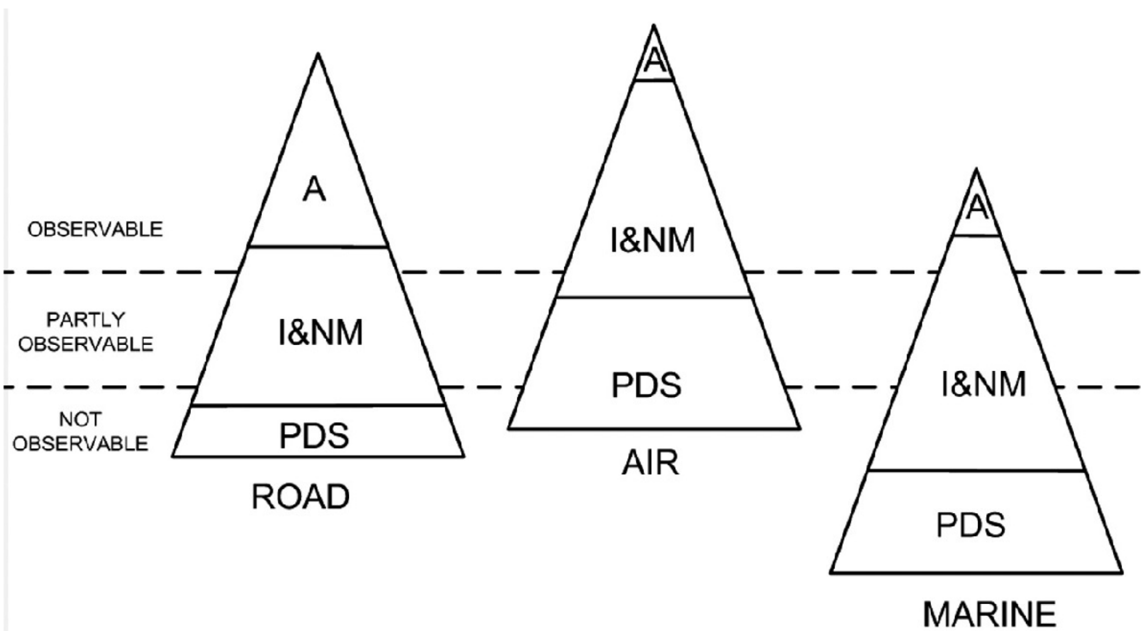


Figure 3-1: Observation of incidents for three different branches of transportation (A-Accidents; I&NM-Incidents and near misses; PDS-Potentially dangerous situation) (10)

3.2 Interviews

While undertaking this thesis, interviews were carried out with ConocoPhillips, Det Norske Veritas, SafeTec and Simon Møkster Shipping. Chief objectives of these interviews were to learn more about:

- Collisions which have occurred to determine what went wrong (human/mechanical/weather)
- Any other factors which could lead to a collision
- Why the barriers failed
- Consequences
- Improvements in safe work practices

- How technological advances impact collision risk

3.3 Review of Recent Collisions

Vessel navigators are under pressure to be on time, produce at the desired level, keep the clients happy, and not to incur any unnecessary cost. Obviously, they do not set out to collide with platforms, but safety may be compromised to achieve efficiency. For collision barriers to be effective, a safety environment must be created at all levels of the industry (8).

When analyzing the failures, ideally, the whole system should be evaluated. But too often the focus often lies on the people who were directly involved with the accident. But, the shipowner also influences the opportunity for an accident by putting constraints and pressures on the captain. The cargo holder also influences the manner in which the vessel will operate. They decide what they're willing to pay and they select the ship, but if an accident occurs, they have virtually no liability (26).

It is important to understand why the decisions that lead to an accident made sense to the navigator, otherwise the history will probably repeat itself. For example, in 2004, *M/V Far Symphony* collided with West Venture Platform because the captain was unaware that autopilot was engaged when he attempted to maneuver the vessel manually. Five years later, the duty officer on the *Big Orange XVIII* bridge activated the vessel's autopilot in order to answer a telephone call in an adjacent room on the bridge. He failed to deactivate it upon returning to the steering position. Because the vessel was in the 500 m safety zone the autopilot should not have been engaged (33).

According to Kristiansen (26), maritime accidents have some common characteristics:

1. Routine
    - Accidents are often associated with normal activities
2. Gradual escalation
    - Accidents rarely happen instantaneously
    - Usually due to the inability to handle situations as they emerge
3. Multiple causes
    - An accident usually occurs due to several causal factors related to technology, humans and organization which interact with each other.
4. Human error
    - Accidents often involve human errors which should be viewed in a wider scope
5. Situational factors
    - There are usually situational characteristics (i.e. external conditions, competence, workload, work environment, mental state, etc.)

A review of accidents which have occurred in recent years revealed some similarities. Table 3-1 provides an overview of the causal factors. Most of the information is based on accident investigation reports acquired from the NPD. A more in depth discussion of the casual factors and the barrier failures is given in section 4.

Table 3-1 Causal Factors of Recent Collisions

Year	Vessel/ Installation involved	Causal Factors
06.03.1988	Submarine *U27* – collision with Oseberg B Jacket	Platform on navigational charts, but no signal received from the sonar (53)
30.09.1995	*M/S Reint* - collision with H-7	Ship on Autopilot and captain was absent from the bridge (53)
05.03.2000	"*Knock Sallie*"- collision with Norne FPSO"	Error in the DP software causing erroneous movements to be made. The captain had experience, but reacted to late. The residual crew was inexperienced and had little training in operating systems. (44)
08.05.2002	*Marbella* (factory vessel) – collision with BD platform of the Bravo installation	A number of causal factors led to this collision, including the lack of a satisfactory voyage plan and proper position plotting in relation to the installation, and an unexplained alteration of course to starboard some 6 minutes before the collision. (51)
07.03.2004	*Far Symphony* - collision with West Venture	On autopilot trying to maneuver the vessel manually. Manual maneuvering of the vessel is not possible when the autopilot is engaged. (53)
02.06.2005	*Ocean Carrier* - collision with bridge between EKOP and EKOT	• Miscommunication during crew change • Not following governing documents • Lack of communication on the bridge (6)
13.11.2006	*Navion Hispania* - Incident with Njord Bravo	DP in autopos mode with only port main propeller and rudder active as a result of bad fuel and loss of thrust (46)
04.08.2007	*M/V Jork* - collision with Viking Echo Gas Platform	• Distracted while doing admin work on the computer. • Possibly intoxicated (50)
09.07.07	*Bourbon Surf* – collision with Grane Platform	Navigators on the bridge with a focus on navigation • Both the captain and first officer were absent from the control console, leaving the ship unsupervised on autopilot. • Incorrect judgment of the ships speed and distance to the platform. • The ship set the platform as the way-point. • 500 m Pre-enty checklist not completed • Clearance for passage of the 500-meter zone (22)
06.10.2008	*Federal Kivalina* grounding	The pilot turned his attention away from

		the navigation during the last 15 minutes before the ship ran aground. (1)
08.06.2009	*Big Orange XVIII* - collision with Ekofisk 2/4-W	Autopilot engaged in 500 m safety zone. Tried to maneuver the vessel manually, but it was not possible with the autopilot is engaged. (33)

3.4 Modern Technology

The review of accidents in the previous section indicates that a majority of the passing vessel-collisions on the NCS are accidents are due to human factors. A platform has no control over the actions of passing vessels and when a vessel is traveling at full speed time can be a critical factor to successfully carrying out the platform's emergency response plans. With new technology it may be possible to identify a collision scenario sooner and to contact the vessel earlier, enabling the collision to be averted.

3.4.1 Introduction of GPS

Before GPS, the navigational standard was DECCA, a low-frequency radio navigation system. The maximum daylight range was around 400 nautical miles, but at night the accuracy was reduced to 200-250 nautical miles depending on propagation conditions (49). This system was primarily used for navigation in coastal waters (29). With GPS, the range has increased to the entire planet, as the navigator can zoom in/out and pan (42). GPS has revolutionized the way many vessels navigate by quickly and accurately determining the vessels position, velocity, and heading in the open sea.

More information on GPS is found in Section 4.2.1.1.

3.4.2 Introduction of Electronic Charts

GPS positioning information has enabled a computer based alternative to paper charts. The main advantage of electronic charts if that they can be automatically corrected, with very little effort on the part of the navigator. With Navigation systems, such as GNSS (Global Navigation Satellite Systems), the ships position will be continuously plotted, eliminating the possibility of human plotting error. Furthermore, with the advent of electronic transmission, the ship can receive chart corrections immediately (5).

More information on Electronic Chart Display and Information System (ECDIS) is found in Section 4.2.1.2

3.4.3 Introduction of AIS

According to SOLAS, all vessels larger than 300 GRT were required to be fitted with Automatic Information Systems (AIS) by December 31, 2004. AIS is used as a complement to radar to improve the safety and efficiency of navigation. AIS uses a transponder system to transmit real-time information such as the vessel's name and GPS position. This information can be received by other vessels or onshore locations (i.e. VTS) and automatically uploaded onto electronic charts.

Many vessel- platform collisions are due to poor watchkeeping, ignorance of the platforms existence or using the platform as a waypoint. Having the AIS linked to the ECDIS enables the officer on the SBV and or VTS to call the vessel on collision course by its name, which increases the probability of successfully attracting the attention of the vessel by VHF radio (52).

More information on AIS is found in Section 4.2.1.3.

3.5 Basis for New Model

Although there is no clear reduction in passing vessel-platform collisions, an update of the model should be made to reflect the technological advances. A collision is an undesirable event for both the maritime and petroleum industries. Consequently, regulations and technology will continually improve in order to prevent collisions from happening.

Technological standards for the maritime industry are not the only thing that has improved over the last 20 years. Modeling theories have evolved as well to keep up with the intricacies of socio-technical systems (18). These theories will be discussed in section 5.

Regardless of whether a new model is developed of the current models are updated, it is important to understand the causal factors and barrier failures which can lead to a collision. These are discussed in section 4.

4 Model for Vessel-Platform Collision

In the previous section, recent accident events were discussed. But because of the infrequency of such events and the limitations of the accident reports, these accidents only provide a small indication of what can lead to a vessel-platform collision. In this section, a deeper look is taken at the causes of collisions and the barriers in place to prevent them. The main source of information for this section was literature review and conversations with maritime professionals.

An accurate definition of the system is needed before a ship-platform collision model can be developed. A "bow-tie diagram" will be used to aid in the development of the risk picture. The subsections in this chapter follow the activities shown in Figure 4-1. The first step is to identify the causal factors which could lead to a vessel on collision course (top event). This step is the most important because only causes which have been identified may be addressed. There are obvious scenarios that might lead to a collision (such as being absent from the bridge); but, they are usually the result of several causal factors which unfold gradually. These factors can represent equipment failures, human error, or external factors (i.e. weather).

The second step is to define the barriers which should prevent the vessel from going on a collision course. These can range from the ship-owners policies to IMO regulations.

Finally, if the first set of barriers should fail and lead to the vessel on collision course with the platform, there is a second group of barriers to prevent the catastrophic consequences from occurring.

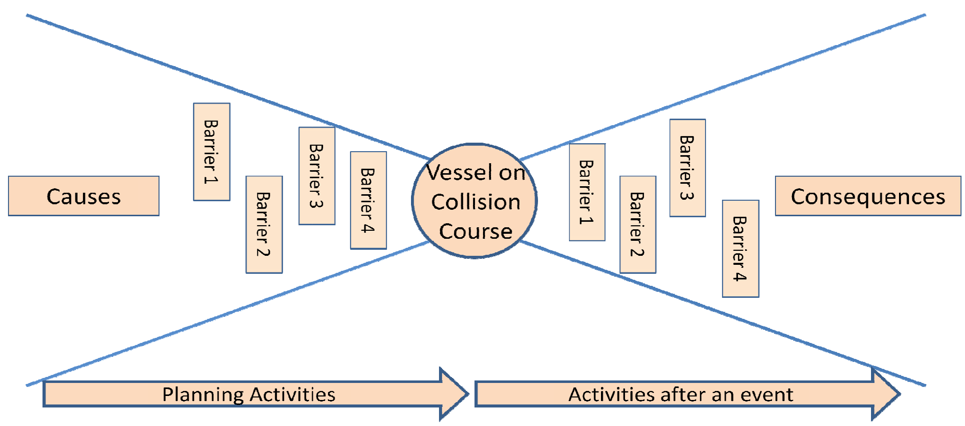


Figure 4-1: Bow-tie diagram

4.1 Causal Factors leading to Collision

Causal factors are the conditions or actions that put the vessel at risk of a collision. These factors take place before to the casualty, and are not directly associated with the accident event. Causal factors are shaped by the following two decision levels (26):

1. Sharp end: the daily vessel operating conditions
2. Blunt end: management decisions made onshore

To understand the cause of an accident, the whole system must be evaluated. Accidents are caused by a combination of operator, technology, work conditions, and organizational factors. There is a tendency for people to focus on the consequences rather than the root causes, which is why it is easy to focus on the sharp end, as it envelops the people who were closest to causing the collision. In daily operations the navigator faces difficulties varying from communication problems to high workloads. On the blunt end, the business climate may shape the safety and maintenance policies. It is the management side which can create opportunities for error through time constraints and lack of resources.

The causal factors listed in this section originated as an outcome of the literature review and interviews. It was found that accidents are the result of a combination of the following:

- The Navigator
- Natural Phenomena
- The Ship
- The Route
- Traffic Congestion

4.1.1 The Navigator

It must be assumed that the navigator comes to work with intentions of performing his job safely and without impacting the environment. However safety is not the navigator's only objective. He must provide a service in a timely manner and avoid incurring any unnecessary costs for the owner. One reason the navigator is selected for the job is his ability to balance all of the operational demands in parallel with the company's safety objectives (8).

The primary role of the watch-keeper is to assure safe navigation of the vessel. As a result of the demanding environment, there are various challenges associated with this performing this task. On one hand, there are work overloads which occur as a result of various factors, such as minimum manning levels, the required documentation for each port, short transit times and/or poor levels of visibility which demand a higher level of concentration. On the other hand, work underloads exist due to the passive nature of the task in uncongested waters (24).

One of the first studies on human error in ship operation included the following factors (26):

- Distraction
- Fatigue
- Alcohol
- Vague pilot-master relationship
- High Turnover
- Poor bridge design
- Inadequate operational procedures
- Unclear use of sounds and signals

Many of these factors still apply today. An additional factor which can appear during 'boom' times is the increased use of foreign workers, which leads to communication problems due to language and cultural barriers. A 2007 study performed for the Norwegian Labor and Welfare Administration revealed that one out of three Norwegian companies use foreign workers from EU countries. About half of these workers were hired on a contract basis. These workers, mostly Polish and Swedish, provide much needed labor, but language barriers create challenges in relation to occupational accidents. Language problems can result in verbal instructions being incorrectly understood. With globalization, it is important to understand how these challenges are addressed by safety management and how they will affect the accident models (21).

The ISM code states that the company who is responsible for ship operation, presumably the owner, should ensure that the master (navigator) is properly qualified, familiar with the safety management system and given the necessary support. Yet, it is estimated that 75-90% of accidents are rooted in human error. By definition, the navigator will be associated with the accident events. Human error occurs when the procedures are disregarded or carried out in a less than adequate manner. These discrepancies are usually related to omission, commission, wrong timing or sequence. Negligence also falls under this grouping (26).

Because offshore platforms are visible from long distances and their position is accurately plotted on navigational maps they are attractive navigational aids for many mariners. Although the navigator will take action to avoid colliding with the platform, any inaccuracies in the navigational equipment could lead to a collision. Often the passing vessel will violate the 500 m safety zone to approach the platform and confirm its identity (27).

As new technologies are introduced the navigator must recognize the new opportunities for error. For example, the introduction of ARPA has been suggested to reduce the prudence of the navigator (26). It would be useful to investigate further how navigational practices have evolved over time with the introduction of GPS, ECDIS, and AIS. On one hand, AIS could potentially reduce the likelihood of a collision by eliminating the need for a close inspection. But alternatively, it could result in more vessels using the platform as a waypoint, since the location will be marked on the ECDIS.

4.1.2 Natural Phenomena

The radar performance can be noticeably affected by certain meteorological conditions without warning. Some natural phenomena, such as heavy wind or rain, can affect the radar display which will be obvious to the observer. But there are other meteorological conditions which can affect the propagation of radar wave through the atmosphere and cause degradation in the performance without being obvious to the radar observer (17).

Precipitation

The radar energy may be scattered by all types of precipitation, (i.e. rain, hail, sleet and snow) which weakens the pulse and reduces the detection ranges. 'Rain clutter' occurs when the precipitation reflects back enough energy to the radar that it is displayed. This impacts the ability of the vessel to detect targets, as there will be a lack of contrast between the echo and the background in precipitation areas. Because of its greater water content, rain tends to have more of an effect on radar clutter.

Sea Conditions

The height of the waves can significantly affect the range at which the vessel on collision course can be detected and consequently the efficiency of the platform's collision avoidance strategy. 'Sea clutter' will be displayed when sufficient energy from the water is reflected back to the radar display. It can occur in any sea condition other than smooth water and, like rain clutter, the resulting contract between the echo and the background it can make it difficult to detect small targets in the area. The ARPA system may register a larger number of ghost targets in sea states where the significant wave height is in excess of 5 meters or there is a large swell.

Furthermore, the vessel's movement, and consequently the radar performance, will be effected by the sea state. As the waves cause the vessel to roll and/or pitch, the center of the radar beam may fluctuate from the sea to above the horizon. The vessel size and stability will determine its susceptibility to sea induced movement.

Fog and mist
Although fog and mist generally do not produce echoes, dense fog can slightly reduce the detection range. The impact of fog on the visibility is mentioned in section 4.1.4.

Propagation
Under normal atmospheric conditions (1atm and 15°C at sea level with a constant 60% relative humidity), the radar horizon is approximately 15% further than the visible horizon. With variations in the prevailing atmospheric conditions, anomalous propagation can occur, but it is nearly impossible to predict the extent to which these irregularities occur.

- Sub-refraction – Radar detection ranges may be reduced if the lapse rate is greater than normal or if there is an increase in relative humidity with height, e.g. areas where cold air moves over a warm sea surface.
- Super-refraction - Radar detection ranges may increase if the lapse rate is greater than normal or if there is a decrease in relative humidity with height, e.g. warm air moving over a cold sea surface.
- Radar Ducting – At certain heights, it is possible for the temperature to rise with greater altitudes. A duct can occur which leads to 'second trace returns', by trapping the radar pulses and allowing them to travel increased distances over the Earth's surface.

AIS is considered to be a complement to radar. Should natural phenomenon effect the radar, ECDIS and AIS the can reduce the risk of collision. Platforms equipped with an AIS transponder will benefit with a risk reduction of 10% (9). Electronic charts can also offer an advantage over paper charts, as notes from a previous voyage in the area, which could be beneficial to the navigator may be retrieved. To obtain a clearer picture of the benefit, survey of the level of detail and how frequently navigators store notes on the electronic charts could be useful.

4.1.3 The Ship

Stability & Maneuverability
As mentioned earlier, the size and stability of the ship will determine is susceptibility to sea induced movement. Larger vessels will generally be more stable, but as size increases the maneuverability decreases. For both large and small vessels, the velocity of the passing vessel on collision course will affect the time to until the potential collision, which will influence the effectiveness of the platform's collision avoidance plan. Good communications and effective promulgation are important for reducing the risk of an incident.

Technical Standard
Substandard ships and ship owners pose a safety hazard, which is difficult to control due to the international nature of the maritime industry. More than half of the collisions in the North Sea are due to old and/or flags of convenience (FOC) vessels (27). Although FOC are associated with substandard shipping and poorer work conditions, there has been a steady growth in flagging out. Some flag states, known as Flags of Convenience FOC, lack both the drive and competence to enforce the safety standards set by the IMO (26).

Due to the shortcomings of Flag state control, there was a need for Port States to challenge certificates of foreign vessels. In 1982 a Memorandum of Understanding on Port State

Control (MOU PSC) was signed by 19 European states and Canada. This gives Port States the authority to control shipping in their own waters through inspections of foreign vessels. If several deficiencies are found during the inspection, the vessel will be detained. As shown in Figure 4-2, several Flag States have a detention rate much higher than average. Typical areas for deficiencies are shown in Table 4-1.

The average detention percentage was 4.9% in 2008. Figure 4-2 only includes flags with 20 and more port State control inspections with detention percentage exceeding the average. High risk flags such as Bolivia and Libyan Arab Jamahiriya also had high detention rates, 83.33% and 90.91% respectively, but do not appear on the figure because there were less than 20 inspections of these flags.

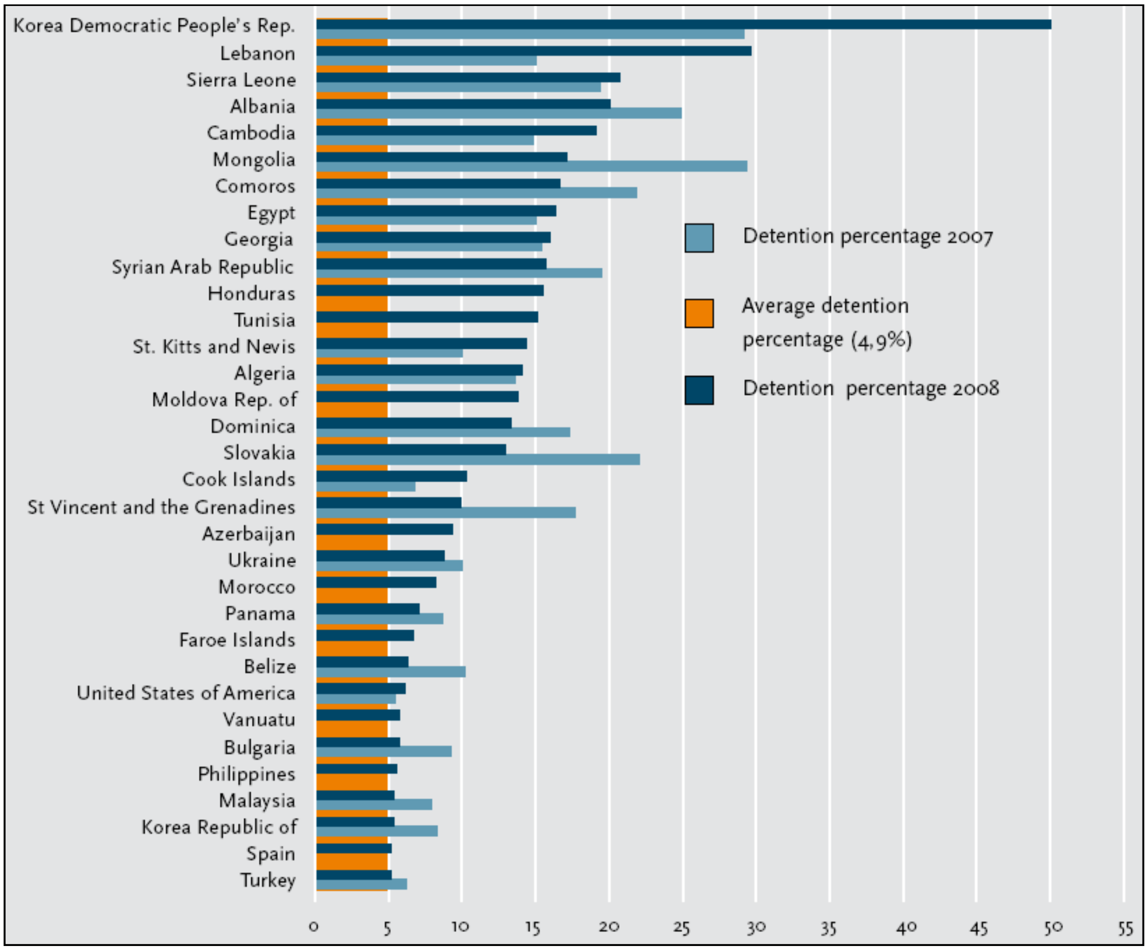


Figure 4-2: Detention Rate in % forFlag States exceeding the average rate (32)

Nearly 25% of the deficiencies found during the State control inspections relate to the equipment and machinery, with 12% of the total deficiencies pertaining to navigational equipment.

Table 4-1: Detention rate in % for inspection areas (32)

		2006		2007		2008	
Def. Main Group	**Category of deficiencies**	Def	Def%	Def	Def%	Def	Def%
Certificates	Crew certificates	2684	4,1%	3098	4,1%	3341	3,99%
	Ship's certificates and documents	4198	6,3%	5152	6,9%	5458	6,55%
Total Certificates		6882	10,4%	8250	11,0%	8826	10,54%
Equipment and Machinery	Mooring arrangements	936	1,4%	1122	1,5%	1343	1,6%
	Propulsion and auxiliary mach.	5077	7,7%	5379	7,2%	6283	7,5%
	Radio communications	2724	4,1%	3040	4,1%	3009	3,59%
	Safety of navigation	7570	11,4%	7875	10,5%	10174	12,14%
Total Equipment and Machinery		16307	24,7%	17416	23,3%	20809	24,83%
Management	ISM related deficiencies	3087	4,7%	4657	6,2%	4641	5,54%
Total Management		3087	4,7%	4657	6,2%	4641	5,54%
Safety and Fire Appliances	Alarm signals	488	0,7%	532	0,7%	608	0,73%
	Fire safety measures	8511	12,9%	9319	12,5%	10039	11,98%
	Life saving appliances	6017	9,1%	6147	8,2%	6465	7,71%
Total Safety and Fire Appliances		15016	22,7%	15998	21,4%	17112	20,42%
Security	Maritime security	735	1,1%	775	1,0%	951	1,13%
Total Security		735	1,1%	775	1,0%	951	1,13%
Ship and Cargo Operations	Cargoes	567	0,9%	593	0,8%	689	0,82%
	Gas and chemical carriers	192	0,3%	226	0,3%	291	0,35%
	MARPOL - annex I	4601	7,0%	5097	6,8%	5034	6,01%
	MARPOL - annex II	68	0,1%	162	0,2%	98	0,12%
	MARPOL - annex III	13	0,0%	11	0,0%	0	0,0%
	MARPOL - annex IV	39	0,1%	46	0,1%	149	0,18%
	MARPOL - annex V	640	1,0%	743	1,0%	790	0,94%
	MARPOL - annex VI	92	0,1%	163	0,2%	176	0,21%
	MARPOL related operational deficiencies	121	0,2%	125	0,2%	192	0,23%
	Operational deficiencies	2135	3,2%	2544	3,4%	2756	3,29%
Total Ship and Cargo Operations		8468	12,8%	9710	13,0%	10175	12,15%
Stability and Structure	Bulks carriers	171	0,3%	270	0,4%	328	0,39%
	Load lines	3118	4,7%	3414	4,6%	4204	5,02%
	Structural safety	5183	7,8%	5875	7,9%	6882	8,21%
Total Stability and Structure		8472	12,8%	9559	12,8%	11414	13,62%
Working and Living Conditions	Accident prevention (IL O147)	1369	2,1%	1559	2,1%	1829	2,18%
	Accommodation	1684	2,5%	1943	2,6%	2366	2,82%
	Food and catering	1673	2,5%	1886	2,5%	1989	2,37%
	Working spaces	2449	3,7%	2960	4,0%	3639	4,34%
Total Working and Living Conditions		7175	10,8%	8348	11,2%	9823	11,71%
End Total		66142		74713		83751	

Submarine traffic is typically excluded from collision models since the probability for collision with this vessel type is negligible compared to the probabilities for collision with other vessel types. But there have been a few collisions between platforms and submerged submarines. It should be noted that in areas where submarines operate, it may be necessary to install submarine beacons and additional promulgation may be required (48).

4.1.4 The Route

Obstacles

In areas where there are a large numbers of vessels and platforms, it could be reasoned that the watchkeeper will be more vigilant than in areas where obstacles are sparse. However, data for passing vessel collisions does not support this. Areas where platforms are more numerous are at greater risk; probably because the watchkeeper's heightened awareness is unable to compensate for the increased risk in congested areas (13).

Visibility
When visual observation is not possible, the navigator must depend on electronic aids. Even though the vessel should be traveling at reduced speeds and it is assumed that the navigator will be more vigilant, accident statistics indicate that a large proportion of collisions occur when visibility is poor. If a SBV is utilized as part of a platform's collision avoidance strategy, low visibility will impact the ability of the watchkeeper on the bridge to visually identify a collision scenario. Furthermore, the platform's Emergency Response Plan (ERP) is likely to require the SBV to approach the vessel and to use maritime light and sound signals. Poor visibility will impede the effectiveness of these methods.

In the late 1970's the effect of visibility was studied in the Dover Strait. Three visibility classes were applied in this study:

- Clear: Greater than 4km
- Mist/fog: 200m-4km
- Thick/dense: Less than 200m

For the Dover Strait, the probability of collision was found to be 300 times higher for the 'Thick/dense' visibility; however, because such conditions occur less that 1% of time, this class was found to contribute to 68% of collisions (26).

To better understand the affect that technological advances have had, a similar study can be carried out in the North Sea for platforms to determine how visibility affects the collision risk. The observed data can be used to find the Fog Collision Risk Index (FCRI).

$$FCRI = \sum_{i=1}^{n} P_i \times V_i \ \ (collisions/encounter)$$

Where
P_i = Probability of collision per million encounters
V_i = Fraction of time that the visibility is in the range i
i = Visibility ranges: from clear (1) to zero visibility (n)

Past and present data for the visibility ranges for weather stations in the North Sea can be found using a climate database. Norwegian meteorological institute implemented a free data policy in September 2007 and consequently all climate data is available for free (28).

The constant, k, corresponds to the failure frequency for 100% clear visibility It may be found using the FCRI and historical collision frequency, μ.

$$k = {}^{\mu}/_{FCRI}$$

Now it is possible to find the collision frequency in terms of the visibility.

$$\mu = k\left(\sum_{i=1}^{n} P_i \times V_i\right) \ (collisions/nm)$$

4.1.5 Traffic Congestion

In the North Sea, the risk of a collision for a platform located near a busy shipping lane is comparable to that of a major fire on a platform. Whereas, the likelihood of a collision for an platform in a more isolated location away from shipping lanes is relatively insignificant (27). All 8 of the passing vessel–platform collisions observed in the UKCS database occurred in the Southern area of the North Sea, which is more densely populated with shipping traffic (13). Clearly, there is an opportunity to influence the probability of a passing vessel collision in the design phase, when the platform's location is determined.

Factors which influence the probability of collision include (17):

- Traffic density and proximity to the target location
- Proximity to traffic separation schemes, vessel routes and/or constricted navigational channels
- Other types of shipping passing in the area
- Size, speed and habits of passing traffic.
- Fishing routes and activity in the area.
- Estimates competency of the regular traffic crews

These factors will need to be assessed before locating a platform. By applying the appropriate vessel traffic data and vessel-platform collision models, the likelihood of experiencing a collision can be estimated. The assessment of traffic density may be carried out using COAST database. This data comprises numerous sources including port log data provided by LMIS (Lloyds Maritime Information Services), radar data from offshore and onshore radar stations, manual vessel traffic surveys, operator information etc (39).

In the UK sector, the densities are defined as (48):

Low:	<1,000 passing vessels per year
Low to Medium:	1,000 to 5,000 passing vessels per year
Medium to High:	5,000 to 20,000 passing vessels per year
High:	> 20,000 passing vessels per year

The degree of concentration should also be considered as there are some areas, such as the southern North Sea and Irish Sea, where the routes funnel down resulting in vessels passing in close proximity to platforms (17). It is also essential to identify regular passing traffic (e.g. ferry operators, fishing organizations and regular shipping lines) and to consult with their representatives. The local users should also be notified of the developments which follow. For busy areas, it may be required to assess how potential traffic route modifications due to the platform will impact the likelihood of vessel-vessel collisions (48).

Data from Vessel Traffic Services (VTS) can be used to identify any changes in traffic patterns.

4.2 Barriers (to prevent a collision course)

A review of past collision incidents reveals that mechanical failure or inadequate watchkeeping on the vessel are the primary factors which can lead to a collision capable of causing catastrophic collapse of the platform. Other than selecting the platform's location during the design phase, the duty holder has little control over the likelihood of a collision. Because of the serious consequences of a collision to the platform and the workers on it, the offshore industry understands that it cannot depend solely on vessels to perform their responsibility of keeping out of the way. As part of the platform's overall collision risk management strategy, the Duty Holder will have systems in place to provide early collision risk warnings (17).

Barriers are risk control measures which reduce the collision risk by either decreasing the frequency or reducing the severity of a collision. The barriers may be implemented on the vessel, the platform or the sea area. However, the barriers on vessels are only effective if enforced by IMO (38). The barriers in this section are the result of literature survey and interviews with mariners and a specialist in collision risk management.

4.2.1 Detection and Communication

In the design phase, the requirements for detection of and communication with passing vessels should be addressed. Depending upon the risk level of the platform, this could include high visibility paint, additional lighting, RACONS and/or AIS (48).

Advances in technology have improved the detection for both the platform and the vessel watchkeepers and communications between the two. For vessels that appropriately plan their voyage, GPS improves safety by allowing the vessel to quickly and accurately determine their position, velocity and heading in the open sea. GPS also laid the foundation for electronic charts. Updates such as the location of new platforms can automatically be made. Situational awareness has been improved even further with AIS, which averts problems like target swapping and provides the name of the vessel.

4.2.1.1 GPS

The first experimental GPS satellite was launched in 1978; however it wasn't until 1994 that the system was declared operational with 18 satellites. Today there are 24 satellites. New satellites have been launched to replace those which have reached the end or their life or malfunctioned (5).

Before GPS, Loran-C (LOng RAnge Navigation) was the primary aid for vessel navigation. This system worked using a Loran-C receiver to pick up electronic pulses which were sent from onshore stations of a known location. The latitude and longitude would automatically be calculated based on the time it took the signals to travel from the station to the vessel. The disadvantage of this system was that operations were limited to coastal areas.

The introduction of GPS revolutionized the way vessels navigated, by improving both the safety and efficiency levels for mariners. It was now possible for mariners to quickly and accurately determine their position, speed, and heading in the open sea. GPS can also be used to ensure compliance with regulations, such as the 500m safety zone around platforms. This information can be used to aid the navigator in reaching his destination safely and in a timely manner (52). However, smaller vessels with a lower standard of seamanship may have not installed GPS. These types of ships are more likely to pose a collision risk (53).

Differential GPS (DGPS) is an enhancement to the basic GPS signal which provides much higher level of precision. Many countries utilize the increased safety of DGPS for maritime operations such as locating and mapping out buoys and navigational hazards. GPS and DGPS have laid the foundation for other technological advancements such as electronic charts and AIS. Two additional civilian signals are planned in the future, which will improve the accuracy, availability and integrity (52).

4.2.1.2 Electronic Charts

For centuries, paper nautical charts have been utilized by navigators. Only recently has GPS positioning information enabled a computer based alternative. The main advantage of electronic charts is that they can be automatically corrected with very little effort on the part of the navigator. During a typical year, it is estimated that 10,000-15,000 manual corrections must be made by a navigator with a worldwide paper portfolio of 2,000-3000 charts.

With electronic charts, the human error factor is also reduced since the alterations are inserted exactly as specified by the marine cartographer. Furthermore, with the advent of electronic transmission the ship can receive the updated immediately. The electronic system also allows for completely new charts to be transmitted to the ship. It should be noted that this technology also allows for small corrections to be printed out onboard, thus making it quicker to update paper charts. However, when collision models were developed, the system was paper based and it often took months for the corrections to reach a ship by post.

Additional information, such as routes, notes and links to extra material can be overlaid on top of the electronic chart. This information can be saved and retrieved when the vessel plans another route in the same area. With paper charts, the information is erased after each use, making them subject to wear from general use. With Navigation systems, such as GNSS (Global Navigation Satellite Systems), the ships position will be continuously plotted. This eliminates the possibility of human plotting error (5).

The main disadvantage of electronic charts is the screen size. For an ECDIS system, the minimum approved size is 21 inches, which is one-sixth the size of a paper chart. This problem can be overcome zooming and panning. Also, display sizes over 40 inches are becoming more affordable. A second disadvantage is the dependence on electronic equipment and the need for a power supply. For this reason, a backup chart system and emergency power supply are required (5).

4.2.1.3 Automatic Identification System

Traditionally, navigators use visual observation, audio exchanges, and radar to detect and avoid potential collisions. However, in busy waters and in situations with limited visibility, it was a challenge to positively identify targets on the display. But with the advent of transponders and advances in the maritime industries regulatory regime, automatic identification system (AIS) was introduces and vessels fitted with the appropriate equipment could be identified.

As of December 31, 2004, all vessels larger than 300 GRT are obligated to be fitted with AIS. It is unlikely that AIS will ever replace radar, as there are some gaps where the type or size of a vessel falls outside of the SOLAS requirements. AIS information includes vessel identification, geographic location, vessel type, and cargo information which should be used as a complement to radar. AIS improves the safety and efficiency of vessel navigation by fulfilling the following functional requirements (23):

- Providing a clear warning of land and other fixed hazards
- Enhancing traffic images and improving situation awareness
- Aiding in collision avoidance by detecting floating and fixed hazards
- Detecting floating and fixed navigational aids

AIS provides and alternate way to obtain information for both navigation and collision avoidance strategies. AIS stations may be installed on a vessel, an offshore platform or on land. AIS operates on dedicated VHF frequencies using a transponder system that transmits and receives information from all other AIS stations within its coverage area in real-time. The vessels position, velocity and are automatically fed from the ship's sensors to the AIS system. (17).

The typical range at which a platform can be viewed either visually of with radar is 12 nm. AIS offers a huge improvement in detection. Although the horizontal range of Shipboard AIS transponders is highly variable, it is typically about 40 nm. This allows significantly more time to asses if the vessel could be a threat to the platform and for earlier intervention (5). When used on platforms, it can reduce the collision risk by 10% (9).

In order to keep the amount of information to a minimum, the different information types, "static", "dynamic" or "voyage related" are updated at different rates. The static and voyage related data are updated every 6 minutes, unless there is an outside request. The dynamic data is updated more frequently based on the ship's maneuvering condition. The safety related messages are updated as needed. The information included for each of the various message types is (3):

Static:

- Maritime Mobile Service Identification (MMSI) number
- IMO number (where available)
- Call Sign and name
- Length and beam
- Type of ship (container, tanker, etc.)
- Location of position fixing antenna (aft of bow, port or starboard of centerline)

Dynamic information: Dependant on speed and course alteration

- Ship's position with accuracy indication and integrity status;
- Position time stamp (in UTC);
- Course over ground (COG);
- Speed over ground (SOG);
- Heading;
- Navigational status (e.g. NUC, at anchor, underway, aground etc. - this is input manually); and
- Rate of turn (where available).
- Angle of heel (optional and where available)
- Pitch and roll (optional and where available)

Voyage related information: Every 6 minutes, when is data amended, or on request

- Ship's draught;
- Hazardous cargo type (if any);
- Destination and ETA (at masters discretion); and
- Route plan (waypoints).

Short safety-related messages:

- Free format text message - sent as required.

MMSI is a unique number for each vessel that can be used to contact the specific vessel using Digital Selective Calling (DSC).

Target swapping can occur with VTS radar plotting, which is when a two targets plotted by ARPA/ATA pass too close and each loses its tag to the other moving or static radar target.

AIS can provides unambiguous identification of the targets and gives a warning when target swapping occurs. The range of VHF transmissions is much longer than radar. VHF also has a limited ability to transmit around corners, which means that AIS transmissions can be received in areas which are blind to radar as shown in Figure 4-3 (5).

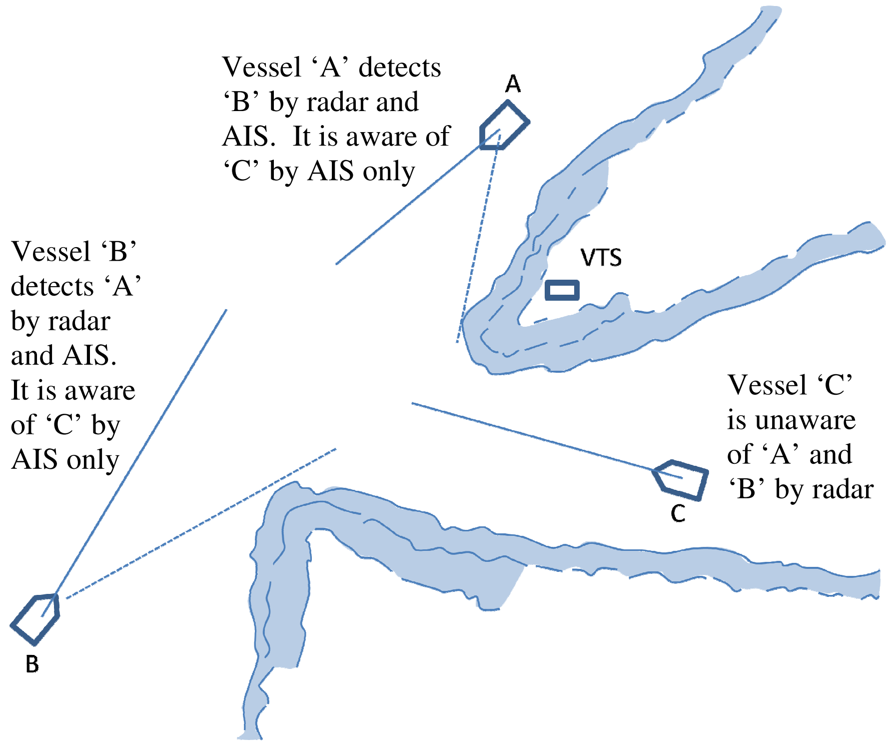


Figure 4-3:Fjord effect (Based on (5))

AIS can also be used to positively identify buoys. If the buoy should move, an alarm will be sent to the onshore authorities. Furthermore, with AIS, the bouy doesn't physically need to be in the location to be viewed by vessels. Virtual AIS allows for dangerous areas, such as a new wreck, to be marked on a vessel's AIS display before the real wreck marking buoy is installed.

AIS information relies completely on GPS, which means that ground-based information does not depend on sensors for processing. For larger vessels equipped with AIS, course changes will be indicated at least 5 minutes sooner than with traditional ARPA/ATA (5).

AIS does not replace radar and is used as a complement to radar, by providing additional information. AIS can be used in conjunction with radar to ensure that the two information sources match up. AIS allows for vessel traffic areas which are currently not feasible by radar, due to geographical and/or cost reasons, to be monitored by onshore authorities.
AIS is not just for shore-based purposed and has a lot to offer the navigator.

Initial problems with AIS:

- Poor bridge installation
- Incorrect information being programmed
- Missing information
- Lack of user training

Problems with AIS are similar to those which lead to 'radar assisted collisions'. However the AIS specifications in the IMO standards only intend to provide a device for the benefit of onshore purposes. If it is not used as a navigational aid, then the navigator does not need to be trained in the benefits and limitations of the equipment. Newer vessels, from 2008, benefit from an integrated AIS and radar display. AIS provided more in depth information which assists in detecting and avoiding collisions (5). A comparison on the anti-collision purposes of AIS and radar is given in Table 4-2.

Table 4-2: Anti-Collision Purposes of AIS and Radar (taken from (5))

	AIS/VHF derived data	**ARPA/ATA radio derived data**
Overall accuracy	Positional errors 10-30 meters	Similar to AIR at close range, but accuracy reduces linearly with range, due mainly to bearing accuracy
Framework for calculations	Ground based	Relative to ship
Derivation of aspect	Obtained directly from compass of target ship (when available	Derived by calculation and depends on accurate knowledge of own ship's course and speed through water
Detection of changes in target course and speed	Immediate (when compass available), as soon as gyro starts to change, Otherwise will be apparent when ground track changes	Takes several minutes
Identification of target size	Good if static data is transmitted	Can be misleading Changes with range and aspect
Reliance on other equipment	GPS system Sensors on other vessels Programming on other vessels	All necessary equipment on ship Requires compass and log
Reliability of detecting other vessels in the vicinity	Only if fitted with AIS Not significantly weather dependant	Dependent on echo strength and weather conditions
Target swap	No	Possible
Interference and false echoes	Unlikely	A possibility
Reduced coverage due to own-ship obstructions	Unlikely	Can occur depending on aerial position
Reduced coverage due to land mass	Unlikely	Yes, line of sight only
Range	Typically 20-40 miles depending on aerial heights and environmental factors	Typically 10-20 miles depending on aerial heights and environmental factors
Transmission and target response density causing overload	A possibility	Unlikely

AIS is a relatively new development and it does have its limitations. The AIS location accuracy depends on the accuracy of the underlying subsystem (i.e. GPS). The AIS information must be manually updated periodically by the navigator, otherwise, erroneous information will be transmitted and there is no way for the recipient to verify the integrity of the information, other than calling up the vessel in question. There are a limited number of slots for transmitting messages, which could be a problem in busy areas. Around the UK, monitoring of early AIS use indicated that many targets either did not transmit an AIS signature or transmitted incorrect and/or missing data. Port and cargo information generally experienced a high error rate. In a 2007 study, 94 vessels were inspected and the vessel type was entered incorrectly in 74%, the ship length was incorrect in 47%, the navigational status was wrong in 30%, and the ship beam value was incorrect in 18% of the vessels (30).

AIS must be used as a complement to radar. As mentioned earlier, AIS is a ‘cooperative’ system and not all vessels are required to be fitted with AIS. Radar does not require any action by the vessel in order for it to be detected. Furthermore debris and other floating objects will not appear to the AIS. But if the radar is being operated in ‘sea stabilized’ relative motion, which is a preferred display and operating mode for many mariners, there is the potential for radar and AIS information to be mismatched (17).

At this point, the extent to which AIS technology will be utilized for collision risk warning and management remains to be fully proven. It is a corporative system and it is dependent on the captain to input the correct data. There is the possibility that erroneous data could lead to further problems. It would be interesting to survey navigators to determine how reliance on new technology has changed navigational practices (17).

4.2.1.4 Radar

Radar assists in collision avoidance by providing an indication of the position of passing vessels in relation to the platform. Radar operation can be a very demanding task in congested waters where the operator has may targets to monitor. Conversely, in waters with little traffic, maintaining vigilance is also a challenge. Detection of targets can fail due to weak signal, signal noise, no warning, boredom or lack of breaks. But with improvements in technology, the task of monitoring radar had been substantially eased (5).

In recent years, radar has become enhanced with increasing digital information. Automatic Radar Plotting Aid (ARPA) provides target tracking information, speed and Closest Point of Approach (CPA), and the time of the closest point of approach (TCPA) alerting the platform of a danger of collision with a passing ship. When GPS was linked to radar a target’s true course over ground (COG) and speed over ground (SOG) could be calculated and displayed. With the advent of digital charts, radar images could be enhanced by overlaying them on an electronic chart. As mentioned earlier, AIS is also used as an enhancement to marine radar (5).

4.2.1.5 VTS

Collision risks can be reduced by Vessel Traffic Service (VTS), which provides active monitoring and navigational advice for vessels. VTS is an integrated part of StatoilHydro’s emergency response center. In Norway, the StatoilHydro Marin provides ocean monitoring services for 51 StatoilHydro installations. They are able to monitor 80% of the NCS petroleum activity by radar. AIS transponders are used in the identification of vessels from a distance of 40 nm. VTS is able to alert installations of a vessel on collision course within an hour estimated impact. Their objective is to identify and warn ships on a course towards an installation. VTS coordinates all offshore SV, ERRV and guard vessels.

Many VTS stations have radars, and the addition of AIS offers a number of positive benefits. The Statoil Hydro Marine surveillance consists of 50 integrated radars, 10 AIS transponders, and 19 VHF stations. As shown in Figure 4-4, there is a significant overlap of the radar coverage, which offers optimal target detection.

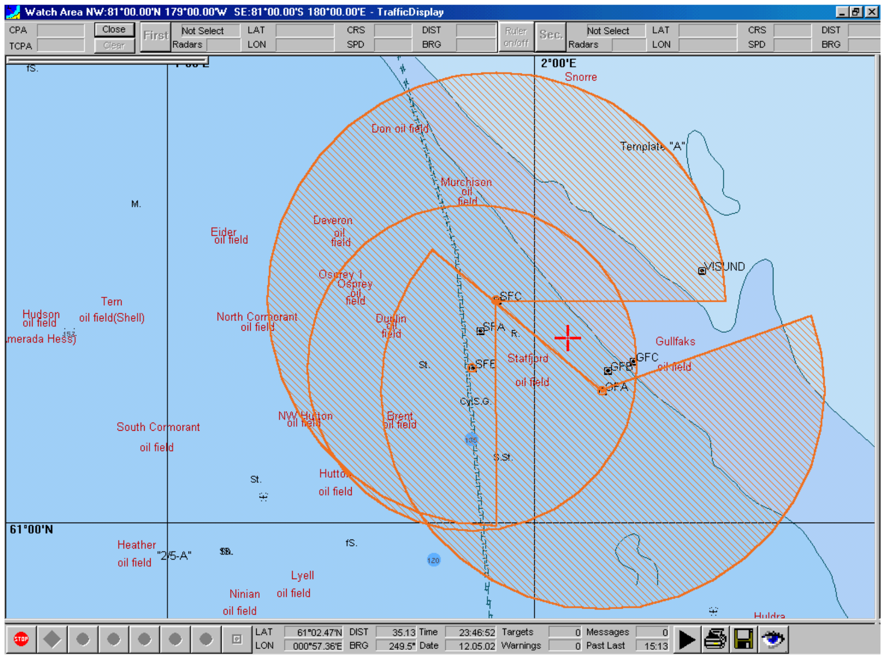


Figure 4-4: StatoilHydro Marin Radar Coverage (20)

VTS data may also be used during accident investigations. For example, the captain of the Grane told the investigation team that the ships speed was 1.5-2 knots just before impact; however, records from Statoil Marin indicate that the boat's speed at the collision ranged from 2 -7 knots, and was probably a few less than 7 knots (34).

VTS can also assist with data collection. Monitoring by VTS plays a main role in Norway's RNNP project. As shown in Figure 4-5, collision trends such as "major accident DFU vessel on a collision course" can be measured with more accuracy.

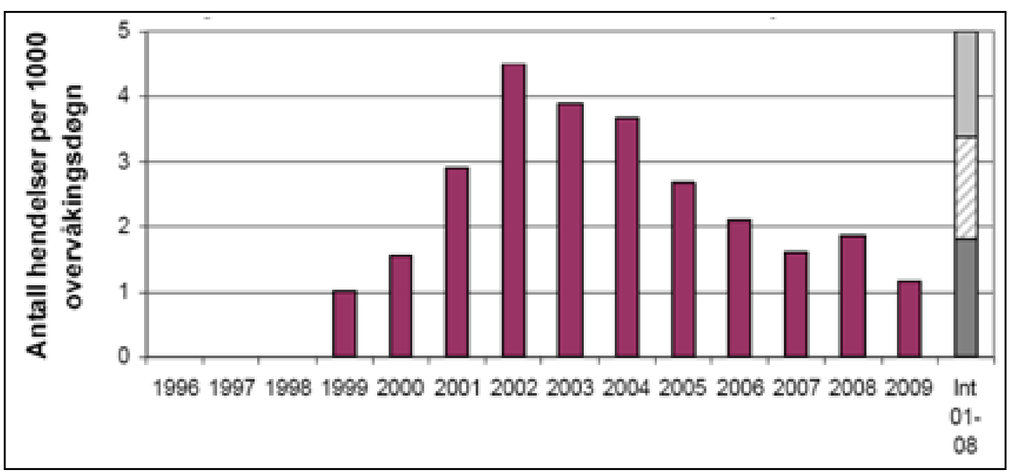


Figure 4-5: Number of ships on a collision course in relation to the number of facilities monitored by Sandsli VTS (36)

4.2.2 Platform Barriers

Passing vessels could cause immediate catastrophic damage, but other than location, an platform has very little control over the risk posed by passing vessels. In the North Sea, platforms are equipped with foghorns and strobe lights (48).

4.2.2.1 Design

In the North Sea, the material and welding standards for platforms have improved over the years. Often the platforms are ranked based on the year they were designed and constructed. The main differences in the various generations are (16):

- First generation: Standard Charpy tests, but few material properties requirements
- Second generation: Higher fatigue life requirements for joints
- Third generation: CTOD requirements for steel and welding procedures

Without reserve buoyancy a rig would be expected to fail with an impact energy of 20 to 25 MJ. The RABL project showed that upper-deck reserve buoyancy could enable a rig to survive an impact energy of 60 to 70 MJ. Although this is significantly higher, this additional protection would only be effective for smaller passing vessels. At this time it is not possible to protect a platform from a collision with a larger merchant vessel (15).

4.2.2.2 Promulgation & Safety Zone

The existence of a platform must be broadcast to the marine industry both in advance of and continuously after emplacement. Early warnings should include consulting with regular local traffic. Navigational warnings may also be broadcast by radio as well as fortnightly bulletins for the fishing industry via Kingfisher Information Services (KIS). In the case of mobile platforms, rig move warnings should be given.

After emplacement, the location of the platform should be marked on paper and electronic navigational charts. AIS or RACON will aid in warning vessels. The navigational warnings should be repeated regularly and additional notices should be given to mariners. FishSafe or a similar fish plotter database should be used to warn the fisherman of underwater structures. Advances in technology have also improved promulgation. Digital Selective Calling (DSC) may be used to send safety messages from the platform or the support vessel followed Very High Frequency (VHF) radio messages. It may also be necessary to have dedicated guard vessels on location.

All platforms are protected by safety zones, which is 500m radius around each platform. Masters of the passing vessel are responsible for remaining outside of the safety zone, but the dutyholders have only a limited ability to enforce this requirement (48). There are numerous accounts of vessels illegally entering the safety zone for various reasons:

- Some vessels use the platform as a waypoint
- Unaware of platform
- Curious about the platform

The current models consider vessels which use the platform as a navigational mark or which approach out of curiosity to be under full control. Unless they experience a power or steering failure and start to drift towards the platform, they are not considered to be a collision hazard (9). Although this barrier may provide some protection if the platform is known, in the case of passing vessels that have not successfully completed the voyage planning, the safety zone is assumed to offer no protection.

4.2.2.3 EERV

Traditionally, the primary source of monitoring passing vessels and appraising the collision risks is the ERRV or its predecessor, the SBV. For many platforms, the EERVs are still utilized to detect approaching vessels. As discussed in previous sections, AIS can compensate for many radars shortcomings, but the enhanced capabilities are only effective if the approaching vessel is also equipped with AIS (17).

Because safe navigation can be interpreted as a threat, many SBV are reluctant to warn the platform is a passing vessel is more than 30 minutes away. However, the platforms emergency response plans are time critical (19). With AIS, the SBV can contact the passing vessel by name to better assess the threat. It would be useful to survey ERRVs to determine how their approach to contacting passing vessels has changed with the introduction of AIS

4.2.3 Vessel Specific Barriers

In addition to the aforementioned technical barriers, there have been changes in company attitudes and policies in response to accidents. For example, 20 years ago, it would have been acceptable for a captain to enjoy a few alcoholic drinks ashore before commencing on a voyage. Today, there is a zero tolerance policy for alcohol use. Some companies offer counseling and treatment options (42).

To confirm the presence of the captain on the bridge, some newer vessels have an alarm that sounds every 12 minutes and if the captain does not acknowledge it, an alarm will sound on the entire vessel after 3 minutes (42). As this type of alarm becomes more common, it must be taken into account by the models, which include an absence from the bridge of 20 minutes or more to be a factor in collision risk.

Fatigue is also recognized as a problem. The common rotation pattern is 6 hours on, 6 hours off. But 8-8-4-4 rotation plans are also being tried out. Reductions in the vibration levels aboard newer vessels will also improve the quality of the crews rest periods. Although checklists only take a few minutes to complete, some captains neglect them. But attitudes are changing and more captains are starting to see their value (42).

A shipping company must be careful to perform background checks. As long as the captain holds a license, he can find a job, even if his safety record is flawed. Another potential problem area is the amount of paperwork that a captain is expected to complete (42). This was one of the causal factors which lead to MV Jork colliding with Viking Echo Delta facility in 2007 (50).

4.2.3.1 Ship Class

Classification Societies are independent bodies which issue a class certificate verifying that the vessel meets a standard for design, maintenance and repair. It is used as a quality check for insurance companies and is the basis for negotiating insurance rates. The owner can select from 40 societies for the class and associated services. Because the owner is paying, there can be a trade-off between cost and safety. Figure 4-6 shows the variation of detention rates for different classification societies.

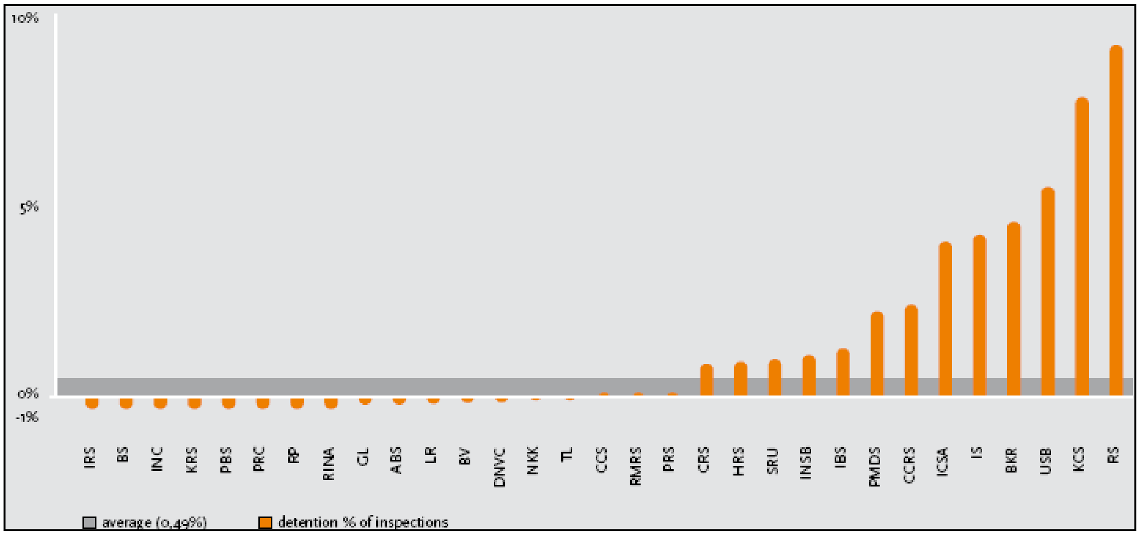


Figure 4-6: Detention Rate in % for classification societies compared to the average rate (32)

4.3 Top Event

For purposes of organizing the barriers that must fail in order for the collision to occur, the top event is a vessel on collision course. Once the threat of a potential collision has been identified, the OIM will have a short time to assess many concerns including the following (48):

- Options available to establish communications with the vessel
- If the vessel is under power or drifting
  - If under power, is the vessel's route normal or has been affected by marine traffic?
  - If drifting, is the drift controlled?
- Other vessels in the area that could assist
- Velocity of vessel and estimated time to collision
- When the platform must take action
- Size of the vessel and its potential impact energy
- How weather conditions effect the vessel and the impact on evacuation
- Vulnerability of the likely point of impact
- When operations should be shut down
- When evacuation should commence

4.4 Barriers (after collision course is identified)

Although the platform operator and its attendant vessel have little control the collision potential for a passing vessel, if the errant vessel can be warned in sufficient time, it may be possible it influence the outcome of the event.

4.4.1 Emergency Response Plans

Each platform should have a concise emergency procedure in place for when a passing vessel poses a collision risk to the platform. The parameters for activating the emergency response plans are determined as part of the Safety Case risk assessment. The parameters may include:

- Distance until the CPA
- Expected time until vessel passes through safety zone
- Failed communications

- Expected time until impact

The plan should distinguish between drifting and powered vessel threats, as this will significantly affect the time available before expected impact. In addition to the considerations listed in section 4.3, the contingency plan should include (48):

- Responsibilities for detection, communication and assessment of the hazard
- When to alert the platform of the threat
- In the case of a drifting vessel, the decision points for carrying out a controlled shutdown and evacuation
- Actions of the SBV(s) in the event of an imminent threat
- How the predicted impact point and weather conditions will affect the evacuation plan

Modern technology improves the accuracy of the time estimates. It can take several minutes for changes in the targets course and velocity to be detected by radar, but with AIS the changes are detected instantaneously (26). In almost all ship on collision course situations evacuation will be executed. This will of course be more often than actual collisions. The frequency of evacuation is assumed to be twice as large as the frequency of collision. It is assumed that in 5% of the ship on collision course situations that the platform is not evacuated, which may be due to (9):

- The vessel not being detected
- Bad weather conditions
- Misjudgment of the situation, etc.

4.4.2 Dedicated Standby Vessels

Every ERRV must be able to participate in the platform's collision avoidance strategy as required by the duty holder, such as monitoring the 500m safety zone, warning approaching vessels and platforms of collision risk, and preventing them when possible (31).

When AIS is linked to the ECDIS, the probability of the watchkeeper on the ERRV successfully identifying and contacting an errant vessel by VHF radio is increased. Furthermore, as the SBV is able to approach an incoming vessel applying maritime light and sound signals. This should reduce the effects of failure modes, such as "distraction by a non-routine event", "absorbed in secondary tasks", "incompetent", "asleep on bridge", "incapacitated" and "impaired". Further explanation of these failure modes is found in section 4.6.

4.4.3 Digital selective calling (DSC)

The platform OIM and/or VTS will want to establish contact with the vessel once it has been identified as being on a collision course. In the past this could have been a problem if the navigator was absent from the bridge, or the calls may have been ignored if the navigator did not consider it to be important. But AIS has eased the difficulty of contacting an errant vessel.

One of the safety related pieces of information transmitted in AIS is the Maritime Mobile Service Identities (MMSI). This unique nine digit number can be used to contact the specific vessel using Digital Selective Calling (DSC). By using a VHF DSC controller, a GMDSS alarm will go off and the warning will be broadcast on a working frequency. The captain on the errant vessel must return to the bridge to silence the alarm and at that point, he will also hear the warning. If the navigator has disabled the alarm or does not respond to it, there are still other options. AIS should list the name of the navigator's supervisor. This piece of information can be used to look up and call the supervisors INMARSAT-B (satellite communications) number. Usually there is an INMARSAT-B extension in the captains office and if the captain is in his office he will most likely answer the phone and redirect the vessel to avoid the collision (25).

4.5 Range of consequences

An assessment of the consequences of a vessel-platform collision is outside of the scope of this paper, but for continuity, a brief list of the possible consequences is given below. These consequences should be used to evaluate the need for additional safety measures.

- Fatalities and injuries
- Total collapse of the platform
- Ignition
- Environmental damage due to released hydrocarbons
- Lost production
- Damaged reputation
- Glancing blow
- Collision averted

When investigating an incident, the Voyage Data Recorder (VDR) will be retrieved and played back. This box contains a record of the 24 hours prior to collision. It is possible for AIS data to be logged in the VDR which could be useful for the analysis (17).

4.6 Implications for Existing Models

As technology is improved, it is important that the fault trees and underlying assumptions for the vessel- platform collision scenarios are updated. Human errors may play a significant role in collisions today, but with advances in technology it may be possible to design out human error. This section is largely inspired by *A Guide to Practical Human Reliability Assessment* (24). In the fault tree shown in Figure 4-7, the top event is ‘inadequate watchkeeping’, which is a common failure models for most models. The impact of modern technology on the basic event which could lead to a watch-keeping failure is discussed below.

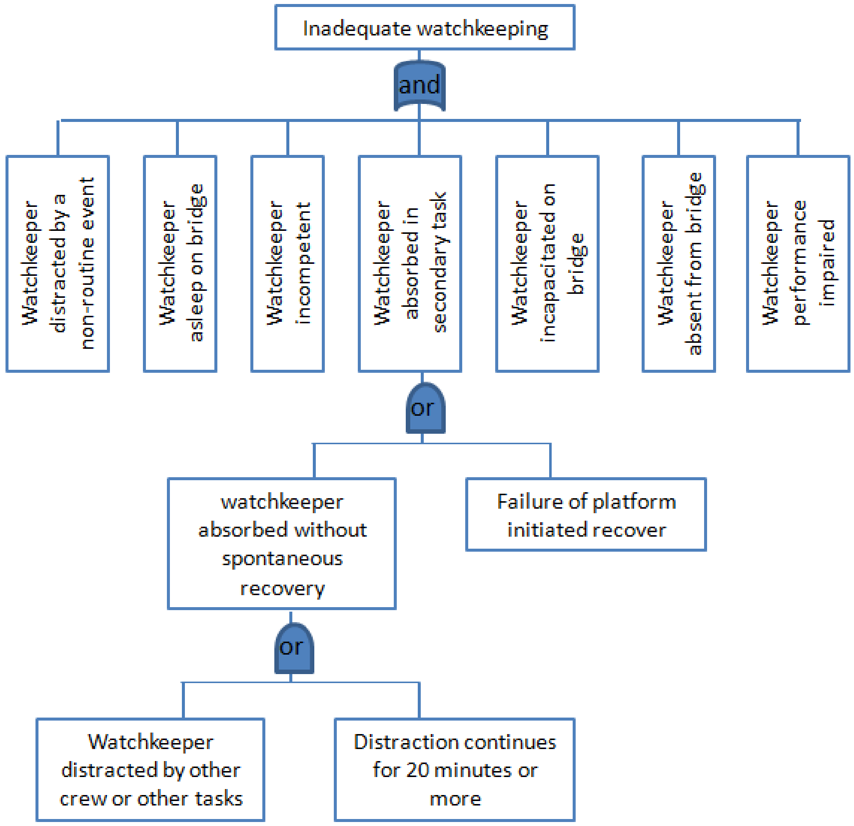


Figure 4-7: Fault Tree for Inadequate Watchkeeping (24)

Watch-keeper distracted by a non-routine event

This description is used for a minor emergency which causes the watch-keeper to become distracted on the bridge. If the vessel is equipped with AIS, it is possible for the platform or VTS to positively identify the vessel and to contact the watch-keeper well in advance of the collision. With GPS, the watchkeeper has a better awareness of the vessels location, velocity and heading.

Watch-keeper absorbed in secondary task

In this case, the watch-keeper may become absorbed in a secondary task, such as preparing documentation for each port, and fail to realize the amount of time that has passed by. More modern vessels include an alarm which will go off on the bridge every 12 minutes to confirm the presence of the navigator. Should the watch-keeper be distracted by other tasks, this alarm will remind him of how much time has passed.

If the watchkeeper should still be so absorbed that he fails to survey his surroundings every 12 minutes, AIS makes it easier for the platform of VTS to contact the vessel.

Watch-keeper incompetent:

This event includes inadequate watch-keeping performance which may be due to lack of experience or manning problems. Certain advances in technology such as ECDIS, should make it easier for the watchkeeper to perform his tasks; however, AIS may still be used to contact the watchkeeper if he is unaware of a collision course.

Watch-keeper asleep on bridge
The watch-keeper may fall asleep on the bridge due to prolonged watch-keeping duties and excessive fatigue. As mentioned earlier, modern vessels include an alarm which will go off on the bridge every 12 minutes to confirm the presence of the navigator. Although this alarm may alert the navigator, depending on the level of fatigue, he may immediately fall back asleep.

Watch-keeper incapacitated by accident or illness
The watch-keeper may become injured on the job and it may go undiscovered until the next watch-keeper comes on duty.

Watch-keeper incapacitated by alcohol
Attitudes about alcohol have changed in the last 20 years. Many shipping companies have zero tolerance policies regarding alcohol use and make counseling available to crew with problems.

Watch-keeper absent from bridge:
The watch-keeper leaves the bridge for a short time either to eat, go to the toilet, shift change.

Watch-keeper performance impaired
Excessive fatigue resulting in reduced effectiveness of the watch-keeper. Different working rotation schedules, such as 8 on-8 off-4on-4off may improve the performance of the watch-keeper. Lower vibration levels in newer vessels will also improve the quality of the watch-keeper's rest.

5 Accident Models

If the decision is made to undertake a new model to estimate the passing vessel-platform collision frequency, there are different modeling theories to consider:

- The sequence of events model
- The epidemiological model
- The systemic model

The model is selected based upon how the accidents are believed to have occurred. The sequence of events model views the accident as a chain of events, where one event causes the next, and so on, until the failure occurs. The epidemiological model takes the view that there are factors which trigger the unknown failures in management decisions, procedures, equipment design, etc. The systemic model views an accident as a normal part of the system, which occurs as a result of imperfect knowledge and resource constraints (8).

5.1 Sequence-of-events model

The sequence-of-events model, also referred to as the domino model, tells a simple story of what is needed to cause an accident. It is based on one problem leading to the next and that all events in the sequence are needed for the failure to occur. The assumption is that the events occur in a specific order and by removing one of the events in the series the accident will be averted. But, this is hardly ever the case. The pathway is easy to represent graphically as shown in Figure 5-1.

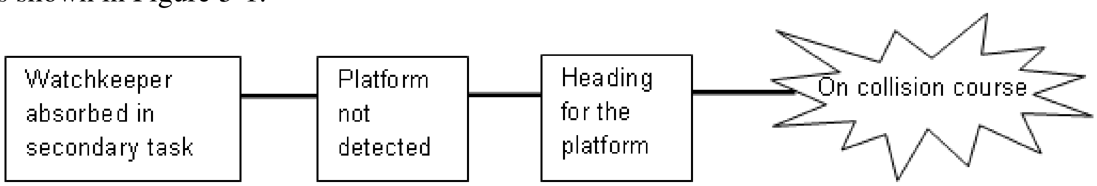


Figure 5-1: sequence of event leading to collision course (based on (8))

For sequence of events models, it is believed that placing a barrier will prevent the accident from occurring as shown in Figure 5-2.

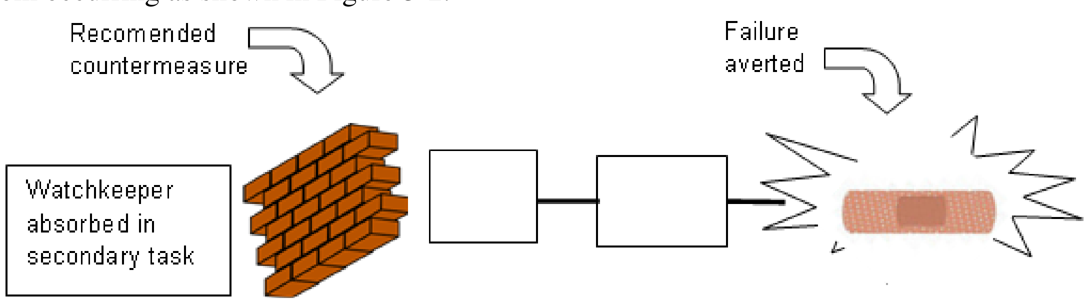


Figure 5-2: Blocking pathway to prevent collision course (based on (8))

But the collision course may have several patterns of causes, and putting one countermeasure in place somewhere along the pathway to failure may not be enough as shown in Figure 5-3.

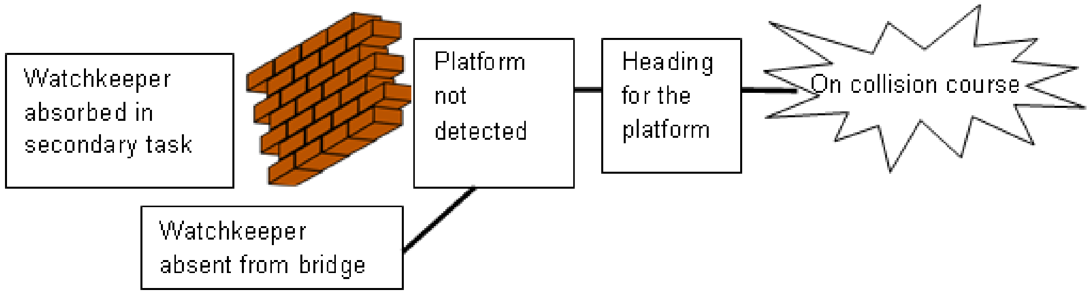


Figure 5-3: Subtle vulnerabilities leave opportunities for the failure to occur (based on (8))

When developing barriers, it is crucial to understand all of the weaknesses in the system (management, resources, etc) that could contribute to the collision course. This model type is not ideal because the chain is subjective and as further improvements in technology are made the pathways will continue to change.

The sequence-of-events model does not assist in the understanding of the organizational factors. When backtracking through the series of events, humans are often identified as the root cause or weak link in the chain. Current collision models are sequence-of-events accident models. They are based on fault trees and event trees, which may not account adequately for the complexity of modern socio-technical systems.

5.2 Epidemiological model

The epidemiological model views accidents as a combination of hidden errors within the blunt end that are activated by unsafe acts committed by the sharp end. This model views human error as an indication of a deeper problem. The accidents are believed to be prevented by identifying and removing the latent error or ensuring that they do not get activated. It offers the possibility of more complex connections between the various factors, but the signature image of the model, shown in Figure 5-4, is similar to the sequence-of-events model.

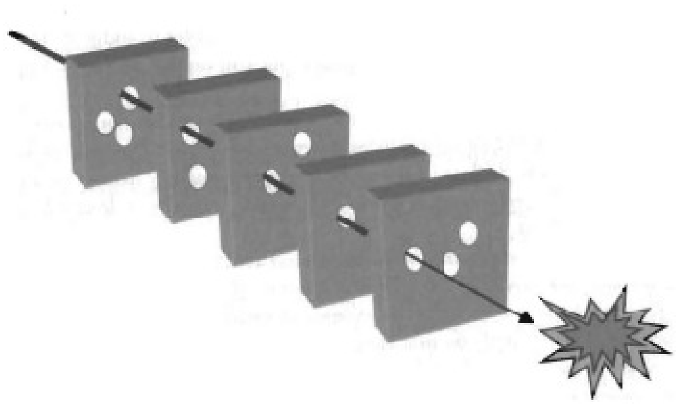


Figure 5-4: Epidemical Model – Accidents Occur When Latent and Active Failures Align (8)

Epidemiological models help with identifying the organizational factors, but there is little evidence that failures occur in this way. This type of model does not explain the interaction between the active and latent failures, or how and why the holes align. When identifying hidden failures, creativity can lead to everything within the organization being interpreted as a potential error. Although the model could be useful during accident investigations, it is less meaningful for making predictions.

5.3 Systemic Accident Model

The systemic accident model is based on the point of view that if the individuals had foreseen the failure, they would have reacted differently. Rather than just focus on human or mechanical error, this model takes into account the socio-technical system that shaped the conditions for the people and equipment performance. The systemic approach focuses on the performance of the system as a whole, not just the parts as the previous two models discussed. Rather than look for holes, this view attempts to understand why the actions made sense to the people involved in the accident at all levels of the organization.

Systemic models build on two primary principles: emergence and control. Safety is considered to be an emergent property that can only be determined by evaluating how the system components interact within the larger system. The control or constraints on the system are based on prior ideas (probably incorrect) of how the components interact. Because systems are dynamic, as time passes, the margins allotted for the initial controls or constraints become narrower. Accidents are seen as the byproduct of a normal system, which occur when the control or enforcement of safety related constraints become inadequate.

Because they do not rely on cause and effect relationships to explain the interactions behind the failure, systemic models better represent the complexity behind the system. Of course, the models are also more complex.

5.3.1 Application of Systemic Accident Model for Vessel-Platform Collision

As a result of the increasing intricacy of socio-technical systems and the variability of human performance to accommodate the complexity, collisions should be considered a normal occurrence. Systemic models might be better suited for the dynamic nature of marine operations. There are Monte Carlo simulation tools available which are flexible enough to achieve realistic behavior of the vessel traffic passing by the platform.

It is outside of the scope of this thesis to develop a new model; however, this section presents an example of how a systemic accident model could be developed to measure the risk of a passing vessel collision. The methodology presented below is based upon the TOPAZ (Traffic Organization and Perturbation AnalyZer) method which was developed by researchers at NLR. TOPAZ is normally applied to aircraft traffic management, which like the maritime industry involves multiple interactions between the operators and the technical systems.

The steps in the TOPAZ safety risk assessment cycle include (45):

- Step 0: Defining the scope, level of detail, safety context and objective of the of the assessment
- Step 1: Construct a complete outline of the process
- Step 2: Identifying the associated hazards
- Step 3: Develop relevant safety scenarios
- Step 4: Rank the severity of each scenario
- Step 5: Determine the frequency of each scenario
- Step 6: Asses the risk tolerances for each scenario
- Step 7: Identify the primary sources of unacceptable risk for each scenario

Step 0:
The objectives are to be identified. This should be done in close cooperation with both the safety agencies and the maritime industry. For the example presented in this section, the scope was only to identify collision risk for a specific platform.

Step 1:
A concise outline of the system must be developed. As shown in Figure 5-5, the vessel-platform collision model can be viewed as a system composed of the following four elements: vessel, platform, external conditions, and VTS. With the exception of external conditions, the operating policies for each element will define how they interrelate.

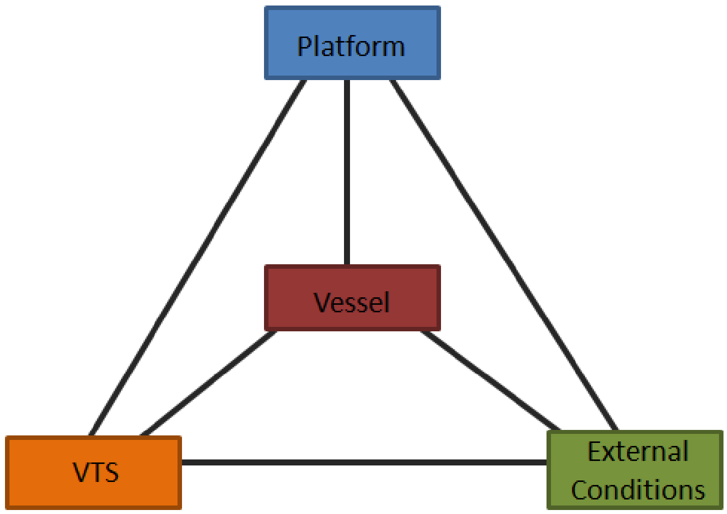


Figure 5-5: Four main elements of vessel-platform model

Step 2:
Hazards scenarios for each element are identified, such as: avoidance planning is not used, navigator is not effectively keeping watch, navigator is not tuned to VTS frequency, etc.

Step 3:
The intricacies of each hazard and resulting interactions between elements are to be defined. The subsections that follow describe the logic behind a possible structure for the new model. The starting point for the model is the location of the platform, which will determine the number of vessels per year that are expected to pass. Another significant factor is the number of years the platform will be present

Steps 4 and 5:
Identifying the severities and assess the frequencies for each element. For example, the frequency experiencing rain and sea clutter will be dependent on the external condition. Radar clutter will affect the ability of the vessel to detect a platform, but the severity of clutter will be lessened if the platform and vessel are equipped with an AIS transponder.

At this point, a systemic accident model could be constructed using a Monte Carlo simulation tool. Essentially, an infinite number of passing vessel scenarios would be generated, as shown in Figure 5-6. The values of the initial conditions are assigned randomly for each run based on their probability of occurrence. Each scenario would be unique, but all could potentially happen.

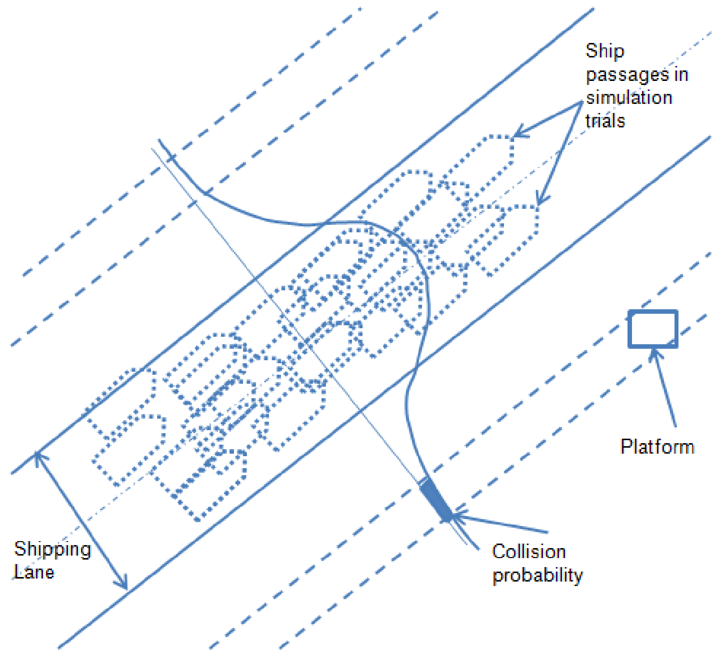


Figure 5-6: Monte Carlo ship-collision model

The model should allow the user to filter the specifics of any simulated accident based upon all input and output criteria. This will include the location of the platform, meteorological and hydraulic conditions, the velocity and size of the vessel, and the geometry of the impact. The output of the model should reflect the range of outcomes:

- collision is averted
- vessel crosses the safety zone
- glancing blow
- passing vessel colliding at full speed

Steps 6 and 7:
Assess the risk tolerance and identify the safety bottlenecks. An example of this is shown in Figure 5-7. The collision scenarios must be sorted from lowest to highest impact energy. The blue line represents the frequency of which the impact energy either occurs or is exceeded. The cut-off criterion of 10^{-4} may be used to establish the annual frequency limit (53).

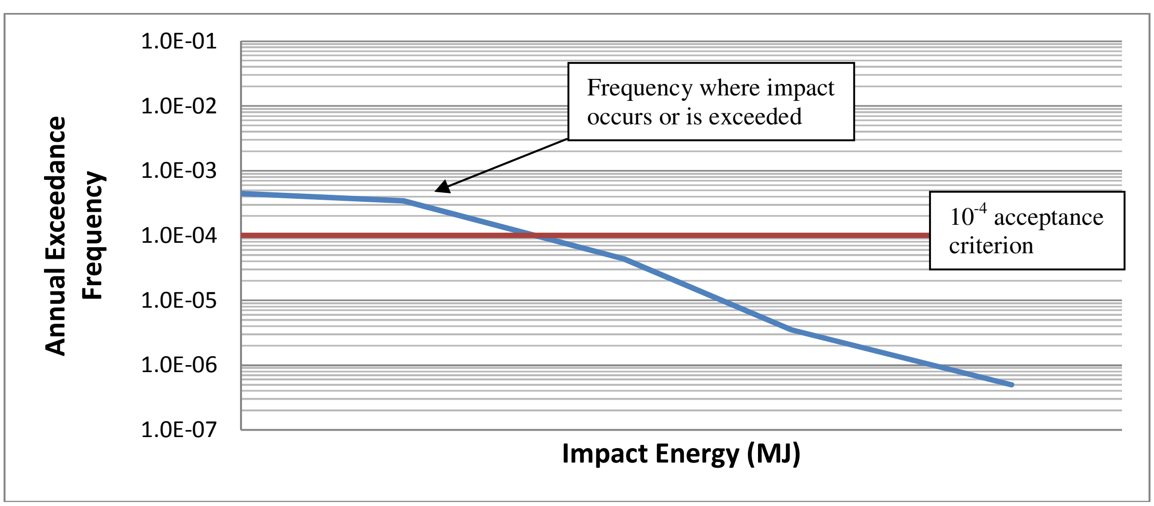


Figure 5-7: Example, Exceedance Frequency for Passing Vessel Collision Risk

5.3.1.1 External Conditions

The external conditions are not considered to be a direct cause for a vessel-platform collision; however, they will influence the ability to detect a potential collision. For example, in poor visibility situations, the detection will be completely dependent upon surveillance equipment. The subsystem for external conditions is shown in Figure 5-8.

In this example, only natural phenomena are included in the external conditions. Another factor that could be considered is the impact of other platforms in the area. Depending upon the platform's location, other platforms could increase the likelihood of a collision or provide a shielding effect.

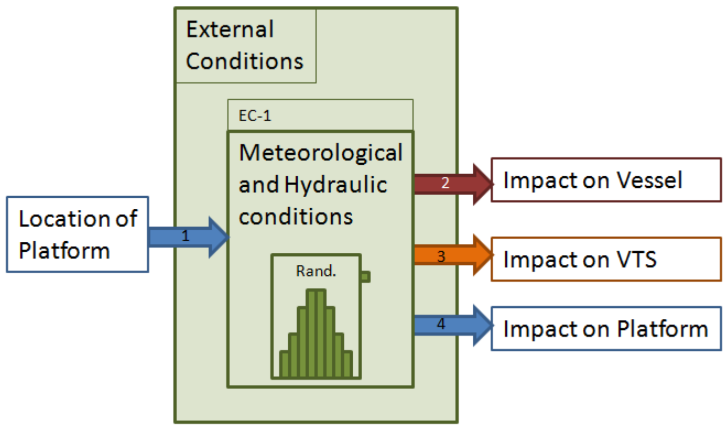


Figure 5-8: External Conditions subsystem

Tag	Description
1	It is important to have the accurate meteorological and hydraulic data for each platform if the model is used to capture collision risk for more than one asset or if a generic model is developed.
EC-1	Past and present data from weather stations in the North Sea can be found using a climate database. As mentioned earlier, Norwegian meteorological institute implemented a free data policy in September 2007 and consequently weather and ocean data are available for free (28). The model will use this data to randomly generate the external conditions for each simulation. Based upon these conditions, the visibility, traffic density, stability and maneuverability of the vessel would be affected. These conditions would be used as an input for the other systems.
2	The external conditions may impact the ability of vessel to detect the platform. The motion and maneuverability of the vessel is affected by the external conditions. The watchkeeper and crew's behavior may also be affected and crew members could become sick.
3	The external conditions may impact the ability of VTS to monitor the platform.
4	The external conditions may impact the ability of platform to detect the vessel. The watchkeeper and crews behavior may also be affected.

5.3.1.2 Platform

The location of the platform will be decided in the design phase. This will be the first opportunity to influence the risk of collision, as the volume of passing traffic will be determined by the location. The availability of VTS is also based on the location. The subsystem for platform is shown in Figure 5-9.

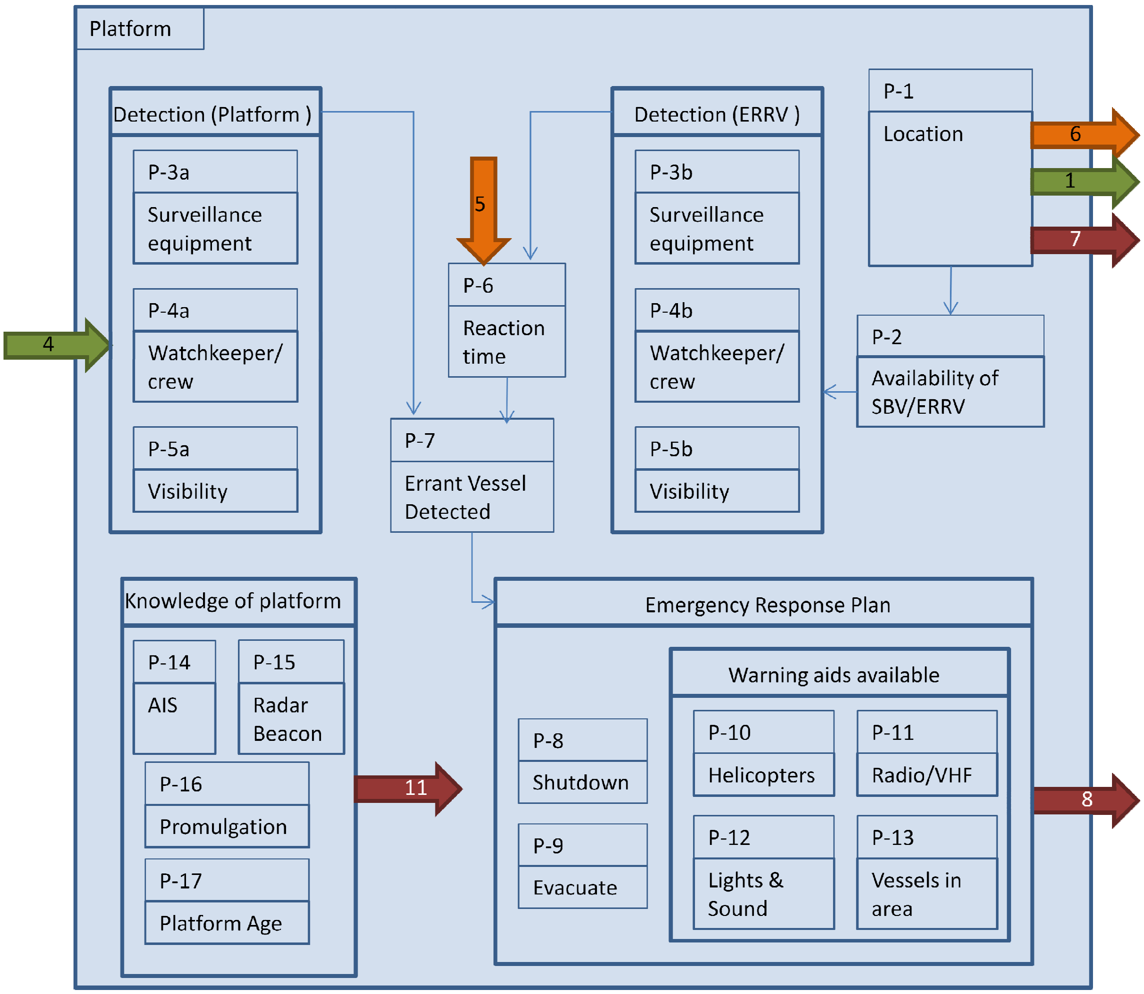


Figure 5-9: Platform subsystem

Tag	Description
1	The location of the platform will be determined during the design phase. For each platform evaluated by the model, the external conditions, VTS monitoring, and vessel traffic will be influenced by the location.
4	The external conditions will influence blocks P-3, P-4 and P-5.
5	In addition to the platform and/or the ERRV, VTS may be monitoring the area. This arrow indicates VTS alerting the platform of a vessel on collision course.
6	The availability of VTS to monitor the platform depends on location.
7	The location will influence the types of vessels that will pass this location.

Tag	Description
8	This arrow represents the affect that the warning aids will have on the vessel when the emergency response plan is initiated.
11	If the navigator has failed to plan the voyage sufficiently, there are various ways that the platform can make itself known to passing traffic: radar beacons, AIS transponder, promulgation, and/or age. This arrow represents the vessels knowledge of the platform based upon the aids used.
P-1	The location of the platform is selected in the design phase. The operator has the greatest ability to influence the platform's collision risk when selecting a location.
P-2	The model for the performance of the ERRV accounts for visual monitoring, communication with passing vessels and platform, and conflict detection and reaction. In clear visibility conditions, monitoring may include visual observation. In dense fog conditions, radar and AIS will be the primary means of detection. If a collision course is detected the ERRV/SBV must notify the platform and be prepared to assist with carrying out the emergency response plan. The ERRV/SBV's availability to participate in the emergency response plan may depend on if it is being shared with other platforms in the area.
P-3 a/b	Radar / AIS monitoring is perhaps done on the platform, by a SBV, and/or by VTS. The SBV is considered to be part of the platform system. Once the vessel is identified as a possible threat and the platform is informed, the Emergency Response Plan begins.
P-4 a/b	The external conditions may influence the habits of the watchkeeper and crew. For example, in warm, sunny weather the crew may choose to spend their free time outside or on the deck. But, for the observations of the crew to have any impact on reducing collision risk, they must feel comfortable reporting any unusual vessels to the OIM/watchkeeper. Hence, a safety culture must exist within the organization at every level.
P-5 a/b	Visibility Conditions must be defined for the model. For example: • Visibility Condition 1: Greater than 4km • Visibility Condition 2: 200m-4km • Visibility Condition 3: Less than 200m
P-6/ P-7	The emergency response plan will only be initiated if the platform detects the errant vessel or if the ERRV or VTS informs the platform of the risk posed by a passing vessel. There may be a time delay as the ERRV or VTS will try to contact the vessel before contacting the platform.
P-8/ P-9	The platform will need to be shutdown and evacuate if it is under threat from a vessel on a collision course. The success of these actions will depend upon the time available.
P-10/ P-11/ P-12/	Once the emergency response plan is initiated, there are warning aids integrated into the platform, such as Radio/VHF and Light & Sound. Depending upon the time available and location, other resources, such as helicopters and stand-by vessels in the

Tag	Description
P-13	area may be identified and asked for assistance. The likelihood of averting the collision will be improved each available aid.
P-14/ P-15/ P-16/ P-17	The likelihood of a collision course will be reduced if the vessel is aware of the platforms existence. If the voyage planning was insufficient, this can be achieved by a combination of promulgation, AIS transponder and/or radar beacon. For regular vessel traffic, the age of the platform will also influence the navigator's awareness of it.

5.3.1.3 VTS

The model of the VTS system provides position, velocity, and heading estimates for the vessel.

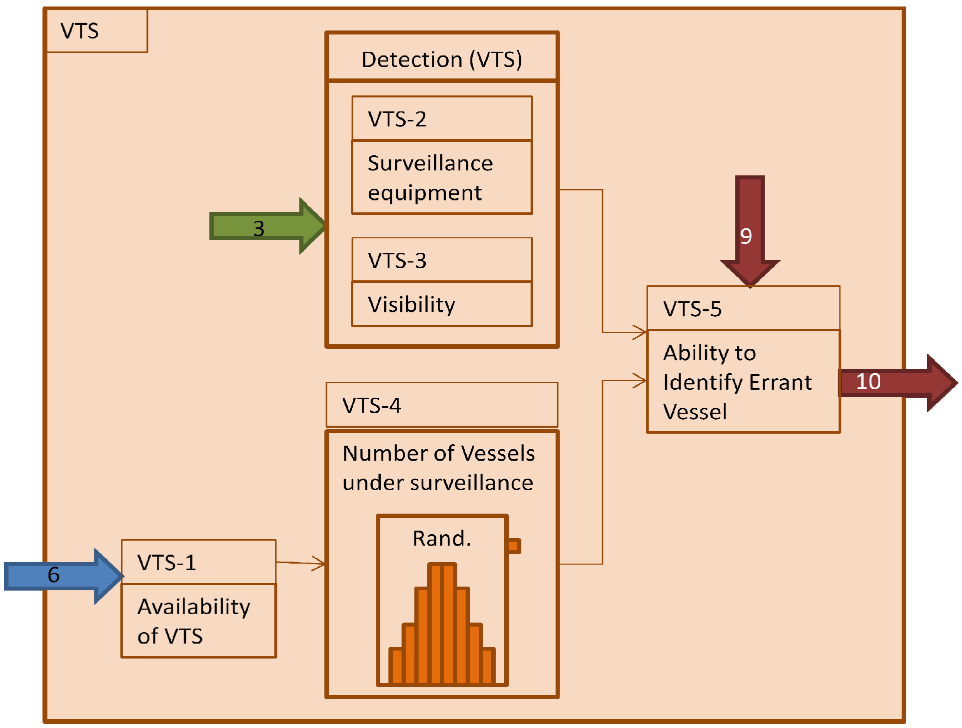


Figure 5-10: VTS subsystem

Tag	Description
3	External Conditions can impact the performance of the surveillance equipment.
6	The location of the platform will determine if VTS monitoring is available.
9	The technical state of the vessel will impact its ability to be detected and contacted.
10	If an errant vessel is detected, VTS will attempt to contact the captain.
VTS-1	The location of the platform will determine if the platform will be under the surveillance of VTS. If VTS is not available, this subsystem will not be included.
VTS-2/3	Surveillance equipment is similar to the description for P-3. Visibility is considered relevant if the area is monitored by CCTV.

VTS-4 The number of vessels under surveillance may impact the ability of VTS to detect an errant vessel. Perhaps a new model could be used to understand how the optimum number of operators needed to monitor the area.

VTS-5 The ability to identify the errant vessel is based on the technical standard of the vessel and if the surveillance equipment is functioning properly.

5.3.1.4 Vessel

The vessel's navigator is responsible for planning and executing the voyage safely. The subsystem for the vessel should include the elements that could lead to a collision course.

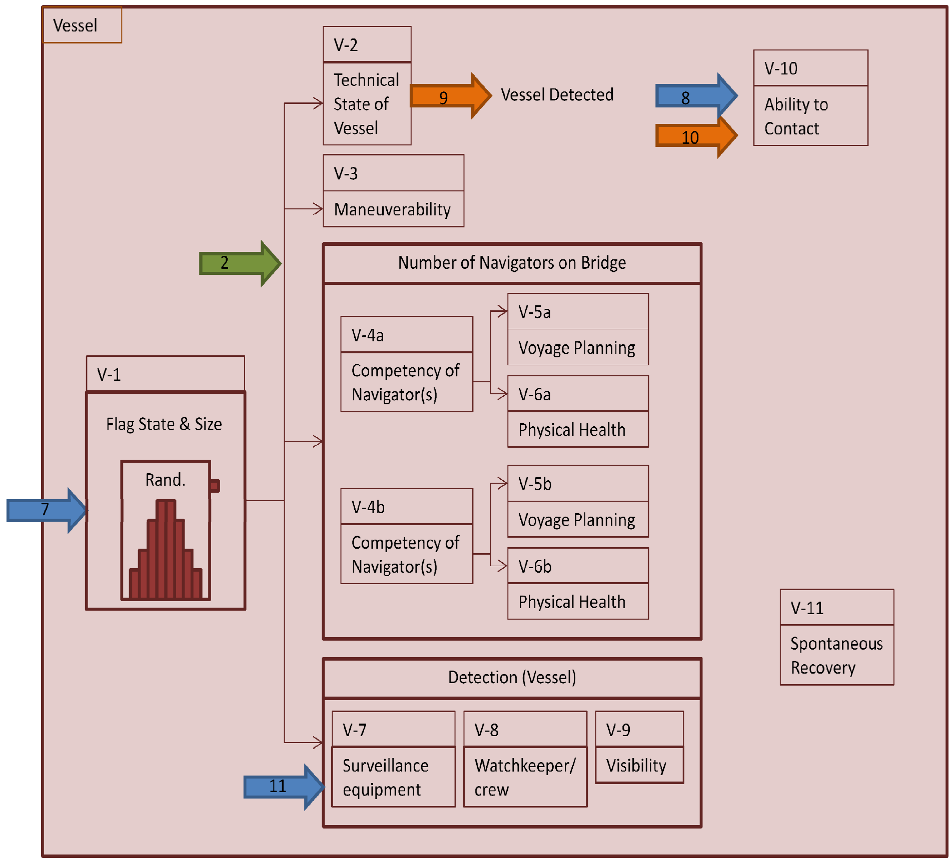


Figure 5-11: Vessel subsystem

Tag	Description
2	The impact of external conditions on the vessel. Sea and weather conditions could affect the accuracy of radar equipment, stability of vessel, watchkeeping behavior, and cause sea sickness. Problems such as sea clutter could affect the vessels ability to detect the platform. Rough external conditions could affect the maneuverability of the vessel. Perhaps VTS data might show a seasonal variance in the number of vessels due to 'waiting on weather'. Under ideal weather conditions, the crew may be more likely to be on the deck. But, for this to translate to a reduction of collision risk, the crew must be in an environment where they feel like they could question the navigator's actions.

7 If data from VTS is available, the probability distribution of (Black/Gray/White) list flags and the (small/medium/large) size category should be included. Otherwise, these variables should be estimated.

9 The technical state of the vessel will impact its ability to be detected and contacted.

8/10 The model for the communications system between the passing vessel and the VTS/ERRV. Communication attempts are assumed to immediately follow the detection of the collision course. The model should account for delay or failure of the DCS.

11 If the navigator is aware of the platform, either through familiarity or promulgation, he will generally plan to avoid a collision.

V-1 The volume and type of traffic passing by the platform will be based on the location. The vessel flag/size/age/etc. would be selected at random based upon VTS data, or other available data. If the external conditions for the simulation run are poor weather/visibility, then the vessel should be traveling at lower speeds. But if the traffic density is low or if there are pressures from the ship owner, the vessel could be navigating at unsafe speeds. The percentage of vessels operating irresponsibly in poor weather may be acquired from surveys or assumed.

The model of the passing vessel represents the vessel movements (acceleration, constant speed, deceleration, turning) during transit. Size categories for the vessels must be defined for the model e.g.:

- 0-1500 dwt
- 1500-5000 dwt
- 5000 - 15000 dwt
- 15000 – 40000 dwt
- > 40000 dwt

Because flags of convenience are more likely to have lower standards and higher accident rates, it is important to take the model takes the flag state into account. The Paris MoU ranks the quality Flag States on a "Black, Grey and White list".

- Black List: Poor performers that are considered high risk
- Gray List: Average Performers
- White List: quality flags with low detention records

V-2 The technical state of vessel will be based on the size and flag state.

V-3 The vessel's maneuverability is related to its size.

V-4 a/b The model for the performance of the navigator(s) during the voyage includes tasks such as auditory monitoring, visual monitoring, vessel control, and collision course detection and reaction. The model should include dynamic representations of the captain's situation awareness and the competence of the pilot.

V-5 The competency of the navigator will correspond to appropriate voyage planning.

a/b

V-6 Physical Health

a/b The physical health of the navigator will affect his ability to perform. Poor eyesight may lead to oversight of obstacles. More serious conditions could leave the navigator incapacitated and without a lookout until the next shift comes to relieve him.

Perhaps if the ship owner requires the navigator to have a physical exam, deficiencies in health could be identified and treated.

V-7/ V-8/ V-9 Similar to P-3, P-4 and P-5.

V-10 VTS, ERRV and/or the platform will attempt to contact the errant vessel once it is detected. But communications may not be achieved for a number of reasons such as a technical error or the navigator may be absent or incapacitated. If the navigator is on the bridge, he may disregard the warnings if he fails to understand the severity of the situation.

V-11 In some instances, the collision course may not be detected or the vessel may not be respond to communication attempts. But, the vessel could still recover spontaneously.

6 Discussion

Accurately quantifying the risks of ship-platform collision has been a goal of the petroleum industry for many years, but technological advances have been made which are not reflected by the current models. New modeling theories have been developed which are better suited to capture the complexities of modern socio-technical systems.

This thesis set out to answer the following questions:

Have improvements in technology reduced the frequency of passing vessel-platform collisions?

Although the chance of a Passing vessel hitting a platform is extremely low (≈ 0.0001%) (19), the consequences are catastrophic. With the introduction of modern navigational technology, the overall trend for collision risk has been reduced; however, the reduction has not been as apparent for passing vessels. Arguments can be made both ways as to whether or not technological improvements have actually reduced the risk of collision by a passing vessel.

It could be reasoned that a majority of the collisions are caused by irresponsible navigators. But, in scenarios where the navigator is distracted and unaware that the vessel is on a collision course, AIS has made it possible for the vessel to be identified and contacted by name. Although there are no discernable trends (36), it is assumed that technological advances can reduce the likelihood of passing vessel-platform collisions if VTS, the platform, and/or ERRV are monitoring the area and the navigator is present to receive the warnings.

What are the causal factors of vessel-platform collision and the barriers are in place to prevent such an event?

An accident is often the result of multiple factors. If the only factors to be identified are those which immediately precede the collision, it could result in development of barriers which treat the symptoms and have little impact on reducing collision risk. While the causal factors addressed in the existing models are still relevant today, technological advances reduce the likelihood of their occurrence. Concurrently, new factors, such as reduced navigator prudence, have emerged. Similarly, barriers have been enhanced by technology. Because an errant vessel can be detected at a range of 40 nautical miles with AIS, compared to the 12 nautical mile range achieved be radar, a vessel on a collision course can be detected and contacted earlier. If judged necessary, emergency response plans can be initiated more rapidly.

As technology improves, some factors may become less relevant and others could surface.

Should newer modeling theories be used to capture the socio-technical relationships?

Different modeling theories present different views of the process and the conditions necessary for a collision to occur. Many of the current collision models are based on fault trees and event trees. These sequential accident models may not account adequately for the complexity of modern socio-technical systems. In systemic models, the idea of causality is replaced with emergence. Models based on Monte Carlo simulation are limited, in that the ranking of frequency and severity is largely influenced by human judgment.

In order to identify potential trends, vessels and platforms should report all collisions, safety zone infringements and near miss incidents. Unfortunately, most accident databases fail to include near-miss reporting primarily because there is little motivation for personnel to report them. It is important that the causes leading up to a near-miss incident be identified in order to capture them properly in the model (13). If a new model is developed, more efforts should be made to improve surveillance and accident/incident reporting. Passing vessel-platform collisions are infrequent, but it is incorrect to assume that only a low standard navigator will be involved. In collisions involving field related traffic, the OIM has a say in the quality of the navigator, and yet the accidents still occur.

Both the petroleum and the international maritime industries are affected by passing vessel collisions and accordingly, both are committed to reducing the risk further. Generally, averting a collision by reducing the initiating causes will be less costly than the consequences.

Modern simulation packages can give a more complete and realistic picture of collision risk. This presents an opportunity for both parties to better understand the root causes and to decide the best way to allocate resources to reduce collision risk. Additionally, cross-industry dialog may reiterate the importance of avoiding conflicts between sailing routes and petroleum activities.

7 Conclusions

During the last two decades, the situational awareness for large vessels has greatly improved as a result of GPS, AIS, and electronic charts. Advances will continue to be made and the factors leading to a passing vessel colliding with an platform will continue to evolve. With this progression, socio-technical systems have become more complex and the current models and methodology shall become outdated.

Updating the existing models or simply applying correction factors to reflect changes in technology is not an adequate solution. The current collision models are based on fault trees and event trees, which focus primarily on human errors or equipment failure. A systemic modeling approach would take into account the socio-technical system that shaped the human and equipment performance. This offers a better understanding of what could cause a passing a vessel collision, and more importantly the opportunity to learn how such collisions could be averted.

Developing a passing vessel-platform collision risk model using a Monte Carlo simulation tool is achievable and would provide the most realistic representation of the system. The most significant challenge would be obtaining good statistical data for the input variables due to the low number of large scale accidents. However, with proper planning data collection could be carried out in conjunction with model development.

In conclusion, the current models are based on the modeling approaches and assumptions from the late 1980's. At this time, they offered the best available estimate of collision risk and are still adequate today. But, just as it would be irresponsible for merchant vessels not to incorporate the technological improvements, it would be imprudent not to develop a new collision model to reflect advances in theories and simulation.

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