Investigation and analysis of ship to platform collision incidents on the UK Continental Shelf: highlighting trends between the enforcement of offshore regulations and the occurrence of vessel to platform collision incidents

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ABSTRACT: An offshore installation is exposed to ship collision risk from in-field and passing vessels. Both categories of collision have occurred on the United Kingdom Continental Shelf (UKCS), and both have the potential to result in catastrophic damage to the installation, although to date only significant consequences have been observed in UK waters. World-wide, catastrophic collisions with installations have occurred resulting in severe damage to vessels and installations, leading to loss of life and environmental damage. This led to the authors investigate the occurrence and reporting of ship to platform collisions on the UKCS 1971 to 2017. It was found that there were periodic fluctuations in the occurrence of collision accidents. This research analyses the accident trends in order to determine the whether the fluctuations were a regular occurrence and, if so, what was the cause. 511 ship to platform collision incidents between 1971 and 2017 were subject to analysis, in terms of damage classification, the vessel type, month of occurrence and a comparison of the release of regulations with the fluctuation of incidents. Subsequently, this analysis has identified a key trend between the reporting of offshore collision incidents and the release and enforcement of offshore Safety Case regulations.

Keywords: Offshore safety, vessel/platform collisions, Safety Case, offshore regulations, collision management.

1 Introduction and Background

Following the public inquiry into the Piper Alpha disaster, the responsibilities for offshore safety regulations were transferred from the Department of Energy to the Health and Safety Commission (HSC) through the Health and Safety Executive (HSE) as the singular regulatory body for safety in the offshore industry (The Stationary Office, 1974) (Wang, 2002) (Department of Energy, 1990). In response to this, the HSE launched a review of all safety legislation and subsequently implemented changes. The propositions sought to replace the legislations that were seen as prescriptive to a more “goal setting” approach. Several regulations were produced, with the mainstay being the Health and Safety at Work Act. Under this, a draft of the offshore installations Safety Case (SC) regulations was produced. The regulations required operational SCs to be prepared for all offshore installations. A SC is to be submitted by the “operator” for fixed installations and by the “owner” for mobile installations. Within this, all new production installations require a design SC and for mobile installations, the duty holder is the owner (The Stationary Office, 1974) (Wang, 2002) (Department of Energy, 1990) (Inge, 2007) (HSE, 2005) (HSE, 2015a) (HSE, 1992).

This paper is structured as follows. Section 1 provides an introduction and background to the research, as well as an outline of some collision prevention measures. Section 2 contains the methodology for the scope of the research and the data collection. Section 3 presents the analysis of the collision incidents in terms of vessel type, damage classification *etc.* Section 4 outlines a timeline of key offshore regulations and demonstrates the correlation of collision incidents with offshore regulations and events. Section 5 provides a discussion and Section 6 presents some brief conclusions.

1.1 The Cullen Inquiry and offshore safety

The key driver in the development of the modern SC was the Piper Alpha disaster and the subsequent Cullen inquiry. Lord Cullen chaired the official Public Inquiry into the disaster in two parts. The first was to establish the causes of the disaster, and the second made recommendations for changes to the safety regime. The inquiry began in November 1988, with Lord Cullen’s report being published in November 1990. The oil and gas production companies’ trade association (now Oil & Gas UK) was represented throughout but did not participate in in the first part of the inquiry. The first part served to establish the cause of the disaster. However, the trade association did participate in part two of the inquiry, which considered measures to prevent future major accidents, and provided 34 expert witnesses (Department of Energy, 1990) (Inge, 2007). Following Piper Alpha and recommendations in the Cullen Report, the HSE developed and implemented Lord Cullen's key recommendation: the introduction of safety regulations requiring the operator/owner of every fixed and mobile installation operating in UK waters to submit to the HSE, for their acceptance, a safety case (Department of Energy, 1990) (Inge, 2007) (HSE, 1992).

After many years of employing the SC approach in the UK offshore industry, the regulations were expanded in 1996 to include verification of Safety Critical Elements (SCE). In addition, the offshore installations and wells regulations were introduced to deal with various stages of the life cycle of the installation. SCEs are parts of an installation and its plant, including computer programs or any part of the system that can contribute to or cause a major accident. Similarly, systems whose purpose is to prevent or limit the effect of a major accident are also included (Wang, 2002) (HSE, 2005) (HSE, 2015a) (HSE, 1996). However, it is felt that an expansion of SCs is necessary, especially in the offshore and marine industry. They are static documents that are produced at the inception of offshore installations and contain a structured argument demonstrating that the evidence contained therein is sufficient to show that the system is safe. This is the full extent of SCs, as they involve very little updating unless an operational or facility change is made. It can be difficult to navigate through a SC, as they can be difficult for project teams and regulators to understand, as well as often being monolithic (Eleye-Datubo, et al., 2006) (Auld, 2013) (Loughney & Wang, 2017).

Over more recent times, there has been an emphasis on research conducted regarding ship to platform collisions. This is evident on the UKCS where the HSE have updated their books relating to ship to platform collisions, their detection and the risk management of collisions. This emphasis on ship to platform collisions can be seen in the HSE’s three new publications: “Collision Detection on the UKCS (2018)” which is an expansion of the previous document from 2006; “Effective Collision Risk Management for Offshore Installations” which replaces the document OTO 1999 052; and “Ship/Platform Collision incident Database (2015)” which expand upon the previous database from 2001 (HSE Research Report 053). The latter of the three provided the basis for the research presented in this paper (Loughney, et al., 2018) (Pemberton, et al., 2018) (Wall, et al., 2018).

1.1.1 Relevance of ship to platform collision research in other areas

However, the emphasis on collision research is not solely located on the UKCS, in recent years a number of publications have been produced relating to ship to platform collision management on the Norwegian Continental Shelf. For example, Oltedal (2012) identified two groups of direct causes common to a series of collision incidents on the NCS. One was the unmonitored approach related to inadequate transfer of command and the second was human deficiency to detect or interpret a technical state or error. The authors concluded that the underlying factors related to violations of procedure, that caused ship to platform collisions had been incorporated into the normal behaviour of the crew (Oltedal, 2012). This finding serves to strengthen part of the hypothesis in this research whereby the release of new or updated procedures initially causes an increase in the level of incident reporting. Then, after a certain time period, this normalised behaviour of procedural violation drifts into normal operations and the level of reporting decreases. This theory cannot be completely responsible for the fluctuations of incidents on the UKCS, but it serves to strengthen the argument that procedural changes can affect the recording of incidents. When this supposed normalised behaviour of procedural violations may have some further merit is in the incomplete recording of collision incidents. More often than not many offshore collision incident reports have gaps or a complete absence of information.

Further analysis of ship to platform collisions was conducted by Hassel *et al.* (2017) on the NCS. In this research the authors compared the vessel traffic patterns for seven installations on the NCS, comparing the vessel installation passing distance using AISdata before and after the installations were placed in their locations. Hassel *et al.* (2017) showed that the current methodology of calculating collision risk leads to overly conservative estimates of collision risk from passing vessels. They noted that vessel will alter their sailing routes when new installations are commissioned. It was found that vessels will alter course to achieve a passing distance of more than 1 nautical mile (1852m). This is more than 3 times the safety zone allocated around offshore installations (500m) (Hassel, et al., 2017).

1.2 In-field and passing vessel collisions on the UKCS

There are a large variety of in-field vessels which are used to support offshore exploration and production. The different types of vessels and units, which could be operating either within the 500m safety zone or in close proximity to an installation, include:

- ERRVs.
- Multi-purpose vessels (including WTW/W2W).
- Platform Supply Vessels (PSVs).
- Mobile Offshore Drilling Units (MODUs).
- Mobile accommodation units (Flotels).
- Shuttle tankers.
- Heavy lift vessels (HLVs).
- Anchor handling tugs.
- Tugs.
- Barges (e.g. pipelay barges).
- Diving support vessels (DSVs).
- Survey vessels.
- Well stimulation vessels etc.

Each of the above listed vessel types of present risk of collision to the installation (HSE, 1999) (Pemberton, et al., 2018). Historical data has indicated that there are two distinct collision scenarios involving in-field vessels, which are:

- Powered vessel collisions.
- Drifting vessel collisions.

In the powered scenario the in-field vessel tends to impact with the installation at speed and, therefore, there is the potential for significant damage. Under a drifting scenario, the vessel has either lost power through engine failure or is not under command and drifts into the installation (Hassel, et al., 2017) (Travanca & Hao, 2015) (Advanced Mechanics and Engineering Ltd, 1985) (Storheim & Amdahl, 2014). In-field collision risks tend to be considered as a relatively high frequency, but low consequence events, however experience has shown that they do have the potential to result in severe damage and tend to amount to a high proportion of an installation's repair costs (Pemberton, et al., 2018).

1.2.1 Passing vessel collisions

The passing vessel category can include all vessels proceeding on the high seas and not visiting or working in the vicinity of, and in connection with, a particular offshore installation. For example, a supply vessel or ERRV is likely to pass a number of other offshore installations enroute to a specific installation. For these installations, this vessel represents a passing vessel hazard, whilst for the installation it is visiting it will represent an in-field vessel hazard.

As with in-field vessels, the hazards presented by passing vessels can be sub-divided into two distinct categories:

- Powered Vessel Collisions.
- Drifting Vessel Collisions

1.2.2 Powered Collisions

This type of collision can be defined as a collision which occurs when the vessel collides with the installation whilst moving under power. Such collisions could occur if a vessel had set a course using an installation as a way point or set a course between two points and failed to consider the presence of an offshore installation. This would also have to coincide with personnel on the bridge of the vessel failing to notice the installation and take corrective action to avert a collision (Pemberton, et al., 2018) (Oltedal, 2012) (Travanca & Hao, 2015). Powered passing vessel collisions are potentially the worst type of collision, as the colliding vessel can be large and travelling at a speed which could result in very large collision energies.

Table 1 presents examples of typical passing vessels encountered in UK waters. The Table also presents typical sizes and speeds of vessels and the impact energy if a collision occurred with an installation. The examples presented are based on a large number of traffic surveys carried out on the UKCS (Pemberton, et al., 2018) (Travanca & Hao, 2015).

Table 1: Typical Passing Vessel Which Could Collide with an Offshore Installation

Vessel Type	Displacement Tonnes	Speed Knots	Impact Energy (Megajoules - MJ)	Impact Energy (Kilonewton Meter - kNm)
Tanker	120,000	13	2952	2952000
Ferry	8,500	16	317	317000
Merchant Container Ship	22,500	11	396	396000
Offshore Supply Vessel	5000	10	73	73000
Offshore ERRV	3,500	10	51	51000
Large Fishing Vessel	1,000	8 (Transit)	9	9000
Small Fishing Vessel	400	8 (Transit)	4	4000

Whilst this list does not attempt to define every type of vessel that can collide with an offshore installation, it gives an indication of the magnitude of the hazard should a collision occur. It can be seen from Table 1 that, in the event of any of these vessels (with the exception of smaller fishing vessels) colliding with an offshore installation, whilst travelling at typical operating speeds, such a vessel would present a threat to the integrity of the vast majority of installations on the UKCS. It is noted that certain types of installations, such as FPSOs and some mobile units, may, due to their inherent strength and flexible mooring, be able to withstand much higher impact energies than 11-14MJ without their overall integrity being threatened, however, this should be assessed on a case by case basis (HSE, 2000).

1.2.3 Drifting Collisions

This type of collision can occur when a vessel has lost propulsion and cannot maintain a course or sufficient steerage. In the event of the vessel being unable to re-establish power in time and with no effective measures available to control the course of the vessel, the possibility exists that it could collide with an installation (Pemberton, et al., 2018) (Storheim & Amdahl, 2014).

The main difference between this type of collision and a powered vessel collision is that as the vessel is not under power (i.e., it is under the influence of environmental conditions such as wind, waves, current), the velocities involved tend to be much lower, in the region of 1-4 knots. In a drifting vessel scenario, given the lower drift speeds involved, there is more time available to recover the vessel from the collision course either through use of its secondary propulsion units (self-recovery) or through towage (external recovery). In addition, it is noted that the greater time assists in the decision-making process on the installation in terms of identifying the optimal mitigation procedure. A number of drifting vessel scenarios have occurred in the North Sea to date with a significant proportion resulting in precautionary down manning (Pemberton, et al., 2018).

1.3 Brief outline of collision prevention measures on the UKCS

It is most likely that any collision is caused by vessels, which are associated with the offshore installation. However, it is also possible for a passing vessel to enter the 500m zone or even collide with an offshore installation. Collisions involving passing vessels have the potential for much larger consequences than those involving attendant vessels. This is because passing vessels have a larger displacement than attendant vessels, and when coupled with the fact that in previous passing vessel collisions, they travel and impact at much higher speeds, they can hit platforms with a large amount of energy. Furthermore, the larger displacement and speed of passing vessels, combined with the oil and gas industry's inability to control events beyond the 500m zone, has meant that attentions have been more focused on the activities of authorised vessels and simply providing as early a warning as possible when the installation may be at risk (HSE, 2003) (Brown & Williams, 2005) (Bole, et al., 2013).

Following the development of an Automatic Identification System (AIS), there is a mandatory requirement for all sized commercial vessels to be fitted with AIS and the system can be used to monitor static and dynamic information regarding their vessel. The introduction of AIS increases the probability of detection of merchant vessels and has had a significant impact on collision risk management for all marine traffic on the UKCS (Bole, et al., 2013).

1.3.1 Civil Marine Radar

Commercial shipborne radar has been commonplace for many years and their installation is mandatory on vessels under the provisions of the International Convention for the Safety of Life at Sea (SOLAS). Throughout the various resolutions of the International Maritime Organizations (IMO) minimum performance standards for the equipment on vessels, the aim of the radar equipment has endured. However, this poses a potential problem when using shipborne radar for providing collision risk warning for an installation or any other third party. Specifically, the performance standards relate to the minimum expectation for range/bearing accuracy and discrimination of targets detected by the shipborne unit in the vicinity of itself rather than being able to predict their movement in relation to another location, such as, the installation it guards (Bole, et al., 2013) (Brown & Williams, 2005) (Alenia Marconi Systems Ltd., 2002) (IMO, 2002) (Transas, 2017).

Figure 1 depicts an offshore field with seven installations and the radar coverage area of a hybrid radar system (Radar Early Warning System – REWS) with a 25 nautical mile range, fitted at installation 'B'. Similarly, an ERRV using the 12 miles range to the south of installation 'G' is also represented. The early warning provided by the ERRV of vessels approaching the field from the west is likely to be impaired and will require an extra degree of vigilance from those involved (HSE, 2006) (Bole, et al., 2013) (Alenia Marconi Systems Ltd., 2002) (IMO, 2002).

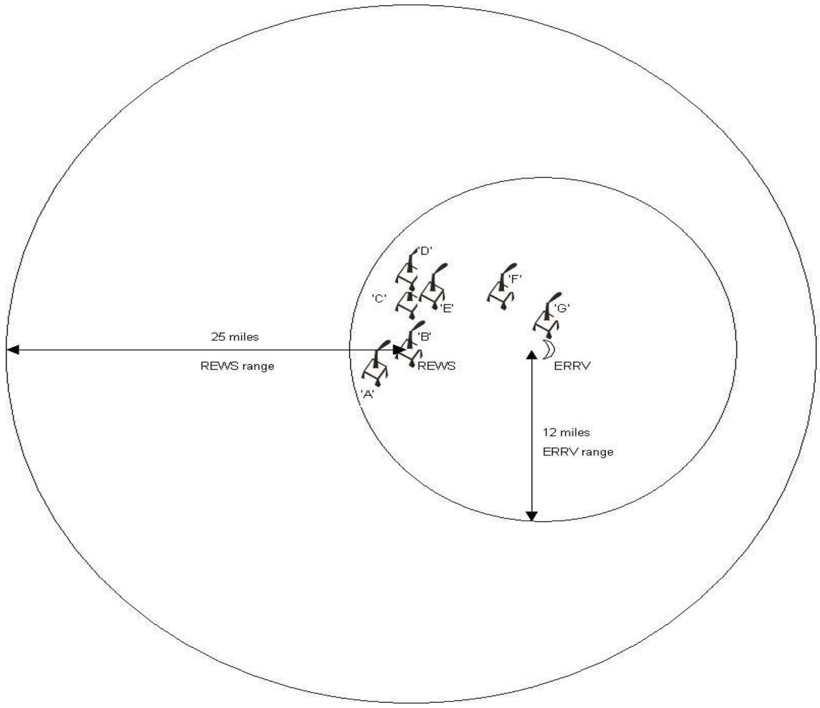

Figure 1: Radar coverage provided by hybrid radar system and ERRV

1.3.2 Automatic Identification System

AIS was first introduced in 2002 for the marine industry and in theory, provides the potential to increase maritime safety by providing a means for ships to autonomously exchange information on their identity, position, course, speed and other data with other nearby ships, close-orbit satellites and shore stations. Subsequently, the situational awareness of OOWs on board vessels fitted with the equipment should be increased. Initially the first system was introduced in 2002 for vessels covered by the IMO SOLAS convention, which covers merchant vessels of 300 gross tonnage trading internationally. Later it was introduced to non-SOLAS vessels in a simplified form in 2006 (Brown & Williams, 2005) (Bole, et al., 2013) (Transas, 2017) (HSE, 2006).

AIS is designed to operate in the following modes:

- In a ship-to-ship mode for collision avoidance.
- As a means for coastal states to obtain information about a ship and its cargo.
- As a traffic management tool when integrated with a Vessel Traffic System (VTS) or hybrid radar system of the type used on some offshore installation on the UKCS.
- As a transmission node that can be used to deliver emergency or binary short messages.

- As a personal distress device that can be used to broadcast positions to the vessels nearby and local maritime search and rescue centres.

1.4 Research Justification and Gap

While the authors were conducting research regarding dynamic risk assessment techniques and methods for offshore installations and Safety Critical Elements (SCEs), more specifically data gathering regarding offshore ship to platform collisions, a periodic pattern emerged between the release of SC regulations and the number of collision incidents on the UKCS. An attempt to identify trends with safety case regulation and incidents regarding offshore SCEs, was conducted. However, due to possible under reporting or the availability of data, it is difficult to demonstrate the trend of some SCEs, with the updating of offshore regulations. On the other hand, it is possible to demonstrate the effect of a number of possible influences, (slow updating or enforcement of regulations, and under reporting or improper recording of incidents), and the effects they may have on incidents on-board offshore platforms. A key area that can be assessed is the issue of ship to platform collisions. As demonstrated by the research conducted in other geographical areas, along with the UKCS, an understanding of how and why collision incidents and accidents occur. Thus, research endeavours to fill the knowledge gap related to the periodic trend of ship to platform collision incidents by asking the following questions: what can cause a regular periodic fluctuation in collision accidents year by year? Are there isolated events in time where collisions are more or less likely to occur? what effect have new or amended regulations had on this periodic trend and is there precedent o suspect causation over correlation?

The aim of this research is to analyse ship to platform collision incidents on the United Kingdom Continental Shelf (UKCS) between 1971 and 2017. This analysis shall consist of determining the operating experience of the offshore installations on the UKCS for the time period of the study as well as determine the number of reported incidents that have occurred each year. Given that the operating experience and the number of incidents is outlined, a frequency of incident occurrence is presented, both per year and cumulatively. This will clearly demonstrate the trend of ship to platform collision incidents. A further objective is to develop a timeline of the release of key offshore regulations and events that have been intended to mitigate and affect collision incidents. This timeline is to be potted along with the collision incidents in order to determine if the fluctuations in the reporting of collision incidents correlates to the release of regulations and the occurrence of key offshore events.

2 Methodology

2.1 Determining the scope of the analysis

It is known that SCs are subject to review and updating as often as is required to keep them up to date. The process of change to the SC may be slow and gives a monolithic appearance to the SC document. A SC is a relatively high-level document, which identifies the operator/owner, describes the installation and its layout, its environmental limits, the types of operation to be undertaken and how the health and safety aspects will be managed, and the maximum number of persons expected to be on the installation at any one time. Similarly, there also needs to be a description for the arrangements for detecting toxic or flammable gas, as well as descriptions for the detection, prevention and mitigation of fires, and the arrangements for protecting people from the hazards of explosion, fire, heat and smoke. This is usually in the form of a temporary refuge, egress routes, means of evacuation and means of monitoring and control for an incident. There should also be a demonstration by suitable risk assessment that the risks have been mitigated to a level that is ALARP and a description of the verification scheme (Wang, 2002) (Loughney, et al., 2018) (HSE, 2014).

A number of areas were looked at in order to attempt to demonstrate some patterns with offshore incidents and offshore regulation. One of these areas was that of gas turbine fuel release and ignition incidents, however, the information gathered was not sufficient to produce a coherent comparison (HSE, 2014). However, due to possible under reporting or the availability of data, it is difficult to demonstrate the trend of some SCEs, with the updating of offshore safety regulations. On the other hand, it is possible to demonstrate the effect that slow updating and enforcement of regulations, as well as under reporting, has on incidents on-board offshore platforms. A key area that can be assessed is the issue of ship to platform collisions. The current database of ship to platform collisions provided by the HSE is out dated as it was last published in 2001; similarly, the Oil and Gas Producers (OGP) produced a document in 2010 of worldwide collision statistics (HSE, 2003) (OGP, 2010). However, the OGP document provides only the frequency of collisions of incidents over key offshore and shipping areas around the world. Neither is sufficient to demonstrate the trend between offshore collision incidents and offshore regulations. Therefore, a statistical analysis is conducted for ship to platform collisions from 1971 – 2017 across the UKCS. Information is provided by the HSE's RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrence Regulations 2013) database, the World Offshore Accident Databank (WOAD) from DNV GL and the Marine Accident Investigation Branch (MAIB) (HSE, 2013) (DNV GL, 2017) (Gov.UK, 2017). The aim of this analysis is to demonstrate that there is a trend between key offshore regulations and ship to platform collision incidents.

2.2 Data Collection

2.2.1 Collision Incidents

In terms of this research, an incident has been defined as a reported impact or contact between a vessel and a fixed or mobile installation in terms of the RIDDOR 2013 database, which utilises reported incident information from the OIR/9b and F2508A forms. The analysis presented is the culmination and continuation of research regarding the compilation of the HSE's Ship/Platform collision incident database (2015) (Loughney, et al., 2018), as well as analysis of the previous collision incident databases (HSE, 2003).

The original 1985 collision incident database was compiled from studies performed by the National Maritime Institute Ltd. (NMI) (National Marine Institute, 1985) (National Marine Institute, 1985) and the International Association of Drilling Contractors (IADC) (International Association of Drilling Contractors (IADC), 1984). An update in 1991 by Advanced Mechanics and Engineering Limited (AME) (Advanced Mechanics and Engineering Ltd, 1985) used incident records taken from the HSE Energy Division (ED) OIR/9A files (ED was known as the Offshore Safety division at the inception of the previous database). A further database was developed in 2003 (Ship/platform collision incident database (2001)) (HSE, 2003) which extended and cross-checked the Collision Incident Database produced under MaTSU reports MaTR0321 (1995) and MaTR0447 (1997) (Marine Technology Support Unit, 1995) (Marine Technology Support Unit, 1997). The 2003 database included 557 incidents of vessels colliding with offshore oil and gas installations have been recorded in the period from 1 January 1975 to 31 October 2001.

As stated previously the HSE, OGP and Oil & Gas UK have produced ship to platform collision statistics, however, these documents are not sufficient to demonstrate the trend between offshore collision incidents and offshore regulations. Therefore, a statistical analysis is conducted for ship to platform collisions from 1971 – 2017 across the UKCS.

The 2001 ship/platform collision incident database has been further cross-checked and extended. A ship/platform collision database ranging from 1st January 1996 to 31st December 2015 has been produced and awaiting publication (Loughney, et al., 2018), where a total of 176 incidents of vessels impacting or contacting both fixed and floating offshore structures have been recorded. The incident data has been recorded from a number of sources. In many cases, the data is supplemented or confirmed from additional sources. Incident data across the whole study has been compiled from previous accident databases up to 1996. However, the following sources have been utilised to compile a new and updated incident database from 1996 to 2017:

- Reporting of Injuries, Diseases and Dangerous Occurrence Regulations 2013 (RIDDOR), utilising search criteria "Collisions, or potential collisions", between "vessels and offshore installations" (HSE, 2013).
- World Offshore Accident Databank (WOAD) using the search criteria "Collision, Offshore Units" and "Europe North Sea" (DNV GL, 2017).
- Marine Accident Investigation Branch (MAIB) using the search criteria "Offshore installation", "collision" and "contact" (Gov.UK, 2017).
- Global Integrated Shipping Information System (GISIS) using search criteria "Collisions" and "North Sea" (IMO, 2017).
- World Energy Related Casualties (WREC) using search criteria "offshore installations", "collisions" and "North Sea" (DNV GL, 2017).

2.2.2 Operating Experience

In order to clearly analyse the volume of reported collision incidents, incident frequencies are required. These incident frequencies are calculated utilising the operating experience, *i.e.* the number of installations operating per year, and the number of incidents reported per year.

Initially, the operating experience of platforms operating on the UKCS per year is required. The operating experience is divided given the type of platform, in this case, fixed, floating and jack-up. For the purpose of this research, a fixed installation is defined as any platform or group of platforms linked by bridges or walkways and may be of either steel or concrete construction. The operating experience is presented as the number of installations operating in the UKCS within a given year. This includes the progression of new platforms that come into service and platforms that have been decommissioned.

Operating experience of fixed installations has been determined from the Oil & Gas Authority, OSPAR and the individual operators where known (Oil and Gas Authority, 2017) (OSPAR, 2017). Mobile installations (floating and jack-up) operating experience on the UKCS has been determined form OSPAR, the Oil & Gas Authority, MarineTraffic, Rig Zone and Infield (Oil and Gas Authority, 2017) (OSPAR, 2017) (RigZone, 2017) (InfieldRigs, 2017) (MarineTraffic, 2017). A mobile or floating installation is referred to in this study as semi-submersibles and monohulls, such as, Floating Production, Storage and Offloading (FPSO) units, Floating Storage Units (FSUs) and drillships. The operating experience of jack-up installations has been analysed separately to the rest of the floating installations. Furthermore, sources (Broughton, et al., 2000) (Oil & Gas UK,, 2016) (Tullow Oil SK Ltd.,, 2015) (HESS, 2015) (Maersk, 2015) (BP, 2011) (Nexen, 2012) (BP, 2005) (Centrica, 2015) (Centrica Energy, 2015) (BP, 2012) (Perenco, 2015) (Centrica Energy, 2016) (Oil & Gas UK, 2012) (Ithaca Energy UK Ltd., 2017) (ConocoPhillips, 2016) (Scottish Enterprise, 2005) were utilised to obtain additional information regarding installations that are still in operation, have ceased operation and have been decommissioned. A key issue with the jack-up operating data compared to fixed and floating data is that the number of platforms that have been decommissioned or taken out of service since 1996 was not known accurately. Hence, the number of jack-up installations operating on the UKCS steadily increases, and potentially devalues the data presented following 1996.

3 Vessel/platform collision incident analysis

3.1 Trend of incident frequencies

Table 2 and Figure 2 demonstrate the operating experience of fixed, floating and jack-up installations from 1975 to 2017.

Following the acquisition of the operating experience of platforms on the UKCS, the number of incidents reported between 1975 and 2017 must be determined. As stated in paragraph 4 of Section 3, the number of incidents has been determined from previous databases up to 1996. From 1996, a new collision incident list, for the UKCS, has been compiled using the previously outlined incident databases (RIDDOR, WOAD, GISIS, MAIB and WREC). In order to demonstrate a coherent analysis, an incident frequency and a cumulative incident frequency has been calculated based upon the approximate level of operating experience per year. Table 2 and Figure 3 demonstrate the operating experience, the number of incidents that have been reported and the frequency of these incidents. It can be seen that four incidents were recorded from 1971 to 1974 however; they are not part of the overall frequency analysis as there is limited data regarding operating experience. Similarly, these numbers are only confirmed from WOAD, as the HSE did not begin recording incidents until 1975. This subsequently provides the collision incident frequency per year and the cumulative incident frequency from 1975 to 2017.

Table 2: Operating experience per year of fixed and mobile installations on the UKCS

Year	Fixed	Floating	Jack-up	Total (N)	Cumulative (N_1)	Year	Fixed	Floating	Jack-up	Total (N)	Cumulative (N_1)
1975	61	26	2	89	89	1997	218	39	14	271	4,276
1976	71	20	3	94	183	1998	223	40	15	278	4,554
1977	77	23	2	102	285	1999	230	44	17	291	4,845
1978	84	18	1	103	388	2000	234	45	21	300	5,145
1979	89	16	2	107	495	2001	241	44	22	307	5,452
1980	91	20	2	113	608	2002	243	43	22	308	5,760
1981	94	24	3	121	729	2003	246	43	22	311	6,071
1982	100	28	4	132	861	2004	248	43	22	313	6,384
1983	104	30	8	142	1,003	2005	249	43	22	314	6,698
1984	113	36	16	165	1,168	2006	250	43	22	315	7,013
1985	121	38	18	177	1,345	2007	264	45	22	331	7,344
1986	127	27	15	169	1,514	2008	267	48	22	337	7,681
1987	136	24	14	174	1,688	2009	267	47	24	338	8,019
1988	143	32	20	195	1,883	2010	260	46	26	332	8,351
1989	155	32	23	210	2,093	2011	261	45	26	332	8,683
1990	160	53	49	262	2,355	2012	261	47	27	335	9,018
1991	180	57	44	281	2,636	2013	266	44	27	337	9,355
1992	185	44	42	271	2,907	2014	267	43	30	340	9,695
1993	194	40	37	271	3,178	2015	256	42	33	331	10,026
1994	213	30	33	276	3,454	2016	264	43	35	342	10,368
1995	221	35	33	289	3,743	2017	264	46	36	346	10,714
1996	214	34	14	262	4,005						

In Table 3 the frequency, λ, is calculated by dividing the number of incidents by the number of operating installations per year (r/n). The case is the same for the cumulative frequency, λ_1 which is calculated by r_1/n_1.

Table 3: List of all reported collision incidents on the UKCS, as well as operating experience and incident frequencies

Year	Total Exp. (N)	Cumu. Exp. (N_1)	All Inc. (r)	Cumu. Inc. (r_1)	Freq. (λ)	Cumu. Freq. (λ_1)	Year	Total Exp.(N)	Cumu. Exp. (N_1)	All Inc.(r)	Cumu. Inc. (r_1)	Freq. (λ)	Cumu. Freq. (λ_1)
1971		-	1	-	-	-	1996	262	4,005	8	356	0.031	0.089
1972	-	-	0	-	-	-	1997	271	4,276	16	372	0.059	0.087
1973	-	-	1	-	-	-	1998	278	4,554	16	388	0.058	0.085
1974	-	-	2	-	-	-	1999	291	4,845	14	402	0.048	0.083
1975	89	89	12	12	0.135	0.135	2000	300	5,145	13	415	0.043	0.081
1976	94	183	12	24	0.129	0.132	2001	307	5,452	10	425	0.033	0.078
1977	102	285	20	44	0.196	0.155	2002	308	5,760	7	432	0.023	0.075
1978	103	388	19	63	0.184	0.163	2003	311	6,071	5	437	0.016	0.072
1979	107	495	25	88	0.234	0.178	2004	313	6,384	4	441	0.013	0.069
1980	113	608	17	105	0.150	0.173	2005	314	6,698	7	448	0.022	0.067
1981	121	729	29	134	0.240	0.184	2006	315	7,013	6	454	0.019	0.065
1982	132	861	23	157	0.174	0.183	2007	331	7,344	11	465	0.033	0.063
1983	142	1,003	20	177	0.141	0.177	2008	337	7,681	8	473	0.024	0.062
1984	165	1,168	12	189	0.073	0.162	2009	338	8,019	4	477	0.012	0.059
1985	177	1,345	18	207	0.102	0.154	2010	332	8,351	5	482	0.015	0.058
1986	169	1,514	13	220	0.077	0.145	2011	332	8,683	6	488	0.018	0.056
1987	174	1,688	6	226	0.034	0.134	2012	335	9,018	3	491	0.009	0.054
1988	195	1,883	7	233	0.036	0.124	2013	337	9,355	7	498	0.021	0.053
1989	210	2,093	18	251	0.086	0.120	2014	340	9,695	3	501	0.009	0.052
1990	262	2,355	24	275	0.092	0.117	2015	331	10,026	4	505	0.009	0.050
1991	281	2,636	19	294	0.068	0.112	2016	342	10,368	1	506	0.009	0.050
1992	271	2,907	25	319	0.092	0.110	2017	346	10,714	1	507	0.009	0.050
1993	271	3,178	14	333	0.052	0.105							
1994	276	3,454	12	345	0.043	0.100							
1995	289	3,743	3	348	0.010	0.093							

By applying the use of a calculated incident frequency and cumulative frequency, based upon the operating experience on the UKCS from 1975 to 2017, it can be seen that the number of incidents has drastically decreased over the 42-year period. This is demonstrated by Figure 2, which highlights the trend of incidents frequencies per year as well as the cumulative incidents frequency per year. What can be seen in Figure 3 is that the average frequency of incidents has

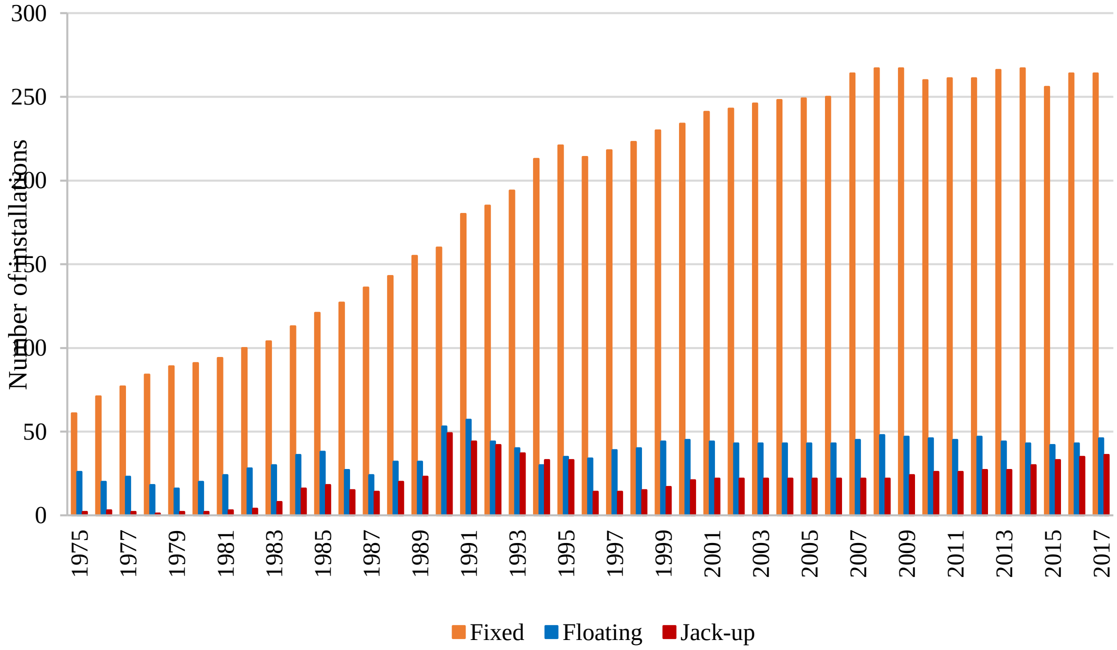

Figure 2: Number of fixed and mobile installations operating on the UKCS per year

generally decreased since 1981. This clearly demonstrates that over the 40-year period from the introduction of the HSWA to the current amended SC regulations, the enforced regulations have had a huge impact on installation safety in terms of collision incidents. Similarly, as the number of reported incidents has decreased, the approximate number of operating installations has increased.

While this brief incident frequency analysis does demonstrate that the number of reported incidents has gradually decreased since 1981, it also shows that the individual frequencies per year fluctuate as they decrease. There are many reasons why these incidents may fluctuate, however what can be observed is the relationship between the number of incidents per year and the implementation of key SC regulations. Section 4 shall outline this trend and further analyse the ship to platform collision incidents.

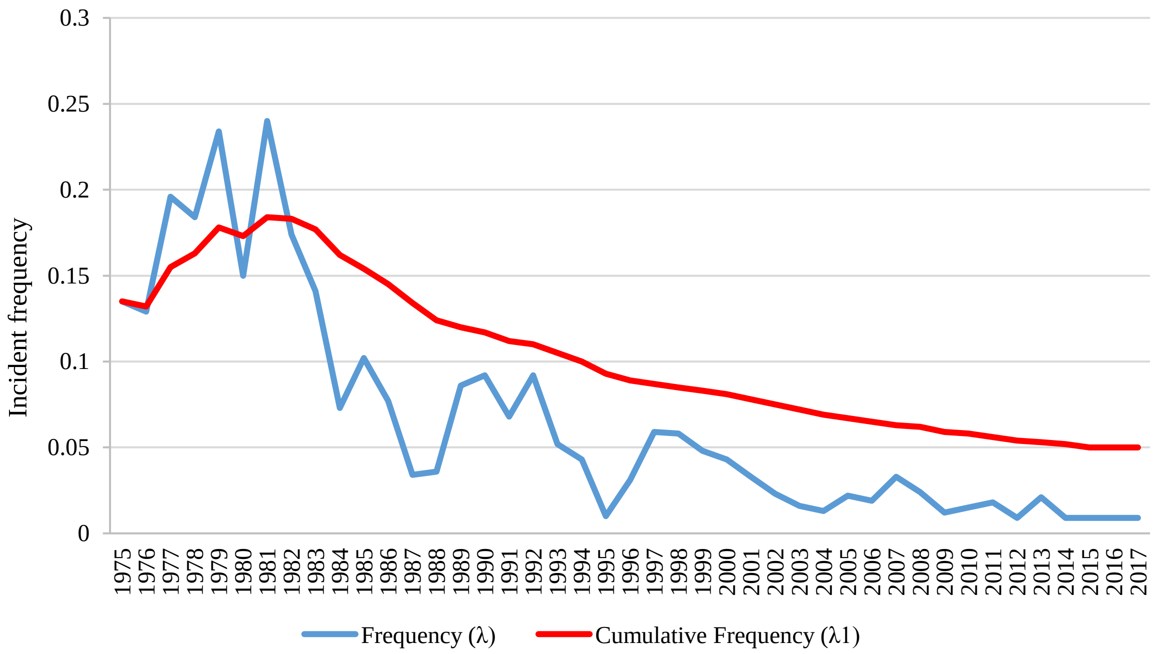

Figure 3: Frequency and cumulative frequency of all reported incidents to all installations per year

3.1.1 Vessel Types (1996 – 2017)

Between 1996 and 2017, the majority of incidents were caused by attendant vessels. Focus is made on this time period as this is the time frame for the updated HSE ship to platform collision database and represents a brief analysis of the updated data. A breakdown of the attendant vessels shows that 23 incidents were caused by “Stand-by” vessels, 93 by “Supply” vessels, 34 were “Other Attendant” vessels, with the rest being “Unspecified” (26). It can also be seen that

2 incidents occurred due to “Passing” vessels (a merchant container and a trawler). The category of “Other Attendant” includes the following vessel types:

• Anchor handler	6 incidents
• Diving support	5 incidents
• Inspection vessel	1 incident
• ISP (Insulation, Scaffolding and Painting)	1 incident
• Merchant tanker	5 incidents
• Other support vessels	3 incidents
• Tug	7 incidents
• Other unspecified attendant vessels	6 incidents

Figure 4 demonstrates the trend of incidents given the type of vessel and the month of occurrence. Given the data presented, most incidents have occurred in the 6-month period of October to March when compared to April to September. This can be attributed to an increase in the number of incidents involving supply vessels between October and March. In this period, weather conditions are likely to be more adverse and hence increases the risks during cargo transfer. Similarly, there is a large spike of incidents in the month of July. This can also be attributed to the weather in the sense that the weather is generally better between May to September and therefore increased maintenance and close support work is carried out. This can be seen by the cumulative number of incidents between May to September where the majority of incidents involving standby vessels occur, as well as other attendant vessels. This is backed up further by the fact that the number of incidents related to other attendant vessels increases, due to the fact that the period between May to October is usually when annual inspections and repairs take place. This can be seen also by the number of diving support vessel incidents, where 4 of the 5 incidents occur between the period of May to August.

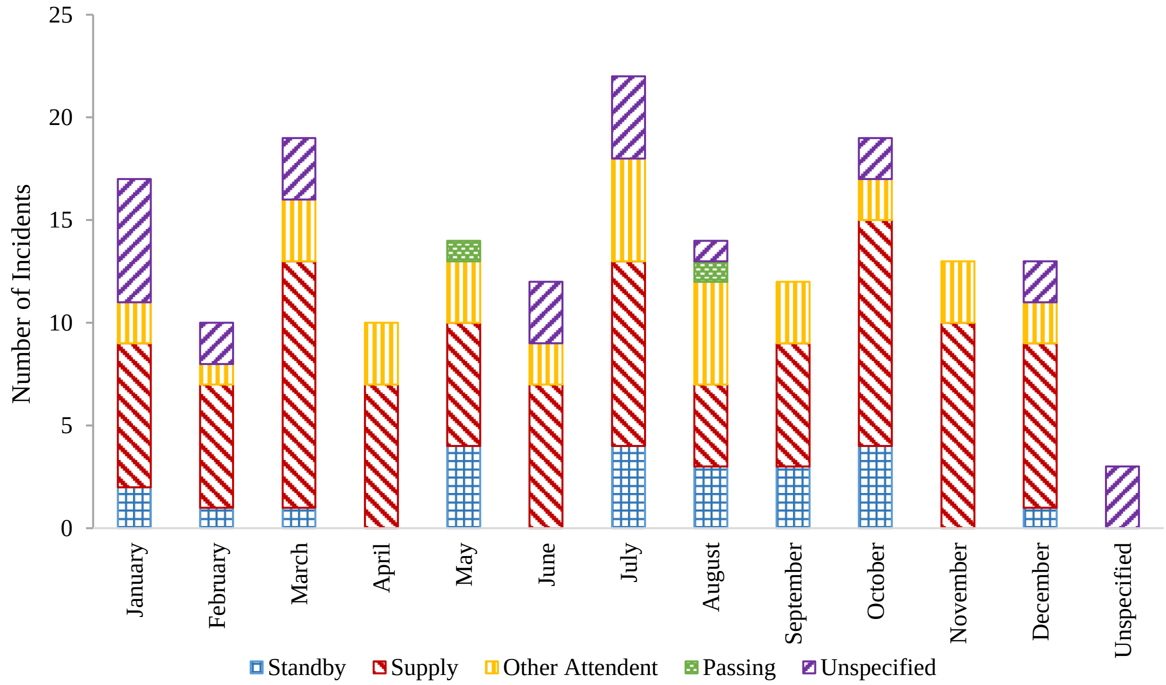

Figure 4: Number of incidents by vessel type per month

Standby and supply vessels caused the highest proportion of damage requiring repair on installations on the UKCS. The main reasons for this are primarily a combination of:

- the requirement for the vessel to come close to the installation during cargo transfer operations,
- the relatively high number of supply vessels visits per year, and
- the requirement for the supply vessel to maintain position for extended periods usually by use of engines and thrusters to counteract the effects of environmental forces.

All of the reported impacts with shuttle tankers prior to 1997 resulted in only minor damage to the installation. However, since 1997 there was a period where a number of collisions between FPSOs and attendant shuttle tankers caused significant damage to the stern of the FPSO and some damage to process and utility systems on board the FPSO. It would appear that this period has not continued according to current data. On most conventional, tanker-shaped FPSOs, the most probable locations for ship-to-ship collision impacts will be:

- The bow for drifting vessels.
- The stern of the FPSO/FSU for the offloading tanker.
- The side for supply vessels and passing powered vessels.

For collisions to the bow or stern of a conventionally shaped FPSO there should be a significant element of structural protection against damage occurring to the process equipment which is usually mounted amidships. For collisions against the side of the FPSO, the combination of the height of the FPSO's side, the side ballast tanks, and the strength of the longitudinal structural members, should offer significant impact resistance and energy absorption, again minimising damage to process equipment. Also due to the requirement of having a double hull the ballast tanks afford a considerable amount of protection. (HSE, 2000) can provide greater guidance on the matter.

Having an effective "crumple zone" around the process systems, in most circumstances, prevents installation collision damage from being exacerbated, or escalated, by adding process damage (with the resultant hazards of hydrocarbon loss of containment, possible fire, and so forth). Collision damage to the FPSO may be severe, but in the event of an offloading tanker collision (a predictable/relatively frequent, potentially high energy visiting vessel) it is unlikely to be catastrophic in most instances, as the speed, and hence impact energy, is most likely to be modest, as a result of in-field manoeuvring being done at a lower velocity than open water passage making (Pemberton, et al., 2018).

3.1.2 Damage Classification

Figure 5 demonstrates the damage class of and incidents resulting in minor, moderate or significant damage to all installations per year respectively. For the period of 1996 to 2017, 2 incidents were reported as “significant”, 6 were deemed to be “moderate” and 65 resulted in “minor” damage. The remaining incidents resulted in either no damage to the installation or the damage was unspecified. It is key to address the fact that the two significant damage cases were due to collisions with passing vessels, and this issue was iterated in Section 1. It is possible in the unspecified classification that there may be passing vessels, however, it is unlikely as a passing vessel collision is a more high-profile incident due to the unauthorised access to the 500m zone. Therefore, these incidents are much more likely to have more complete incident reports than attendant vessel collisions.

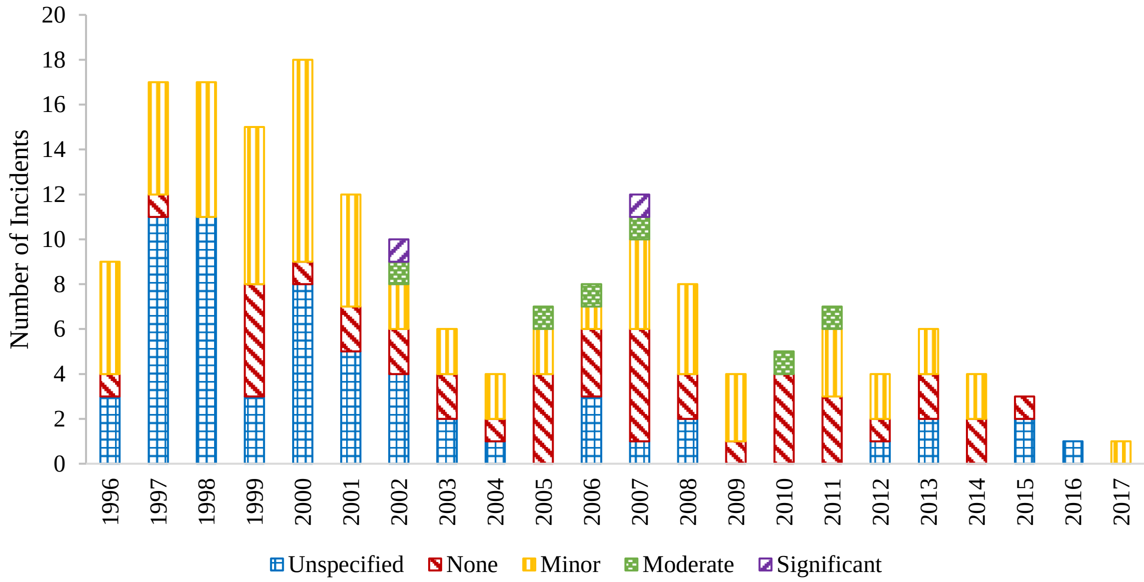

Figure 5: Damage classification of all reported incidents to all installations per year (1996-2017)

What is clear from the data is that there is a significant number of reports where incidents have not been fully reported, *i.e.*, an unspecified damage classification. This under-reporting has appeared numerous times throughout the data records from 1996 to 2017 for other categories in the accident reports, such as vessel type, installation type, installation name and field location. This makes compiling a comprehensive database exceptionally difficult as many gaps are left and many questions regarding the incident are left unanswered. Furthermore, the responsibilities of the reporting are divided, for example, if an offshore installation, on the UKCS, is impacted by a passing vessel, it is the duty of the operator (fixed) or owner (floating) of the offshore installation to report the incident to the authorities in the UK, in this case the HSE. However, the vessel must report the incident to the flag state, and this could be almost any sea faring nation in the world. This process undoubtedly leads to conflicts in reporting as both key crews involved (vessel and installations) may have different perceptions on the incident. On the other hand, in the event the two reports are combined, they may provide a more complete report. What is apparent from the under reporting is that having multiple incident reporting bodies leads to misinformation and incomplete reports. What may be more prudent is to have all parties involved in an incident report to the governing body of the sea or ocean where the incident has occurred.

3.1.2.1 Consequences from *in-field vessels*

From Figure 6, it is clear that the majority of in-field vessel impacts cause little or no significant structural damage to the installation. However, even though the structural integrity of the installation is not compromised in the majority of in-field impacts, the impact area will normally still require to be inspected and the protective coatings on structural members repaired, if damaged. Whilst such repair should be straightforward, the location of the damage near sea level can increase the costs of repairs several fold.

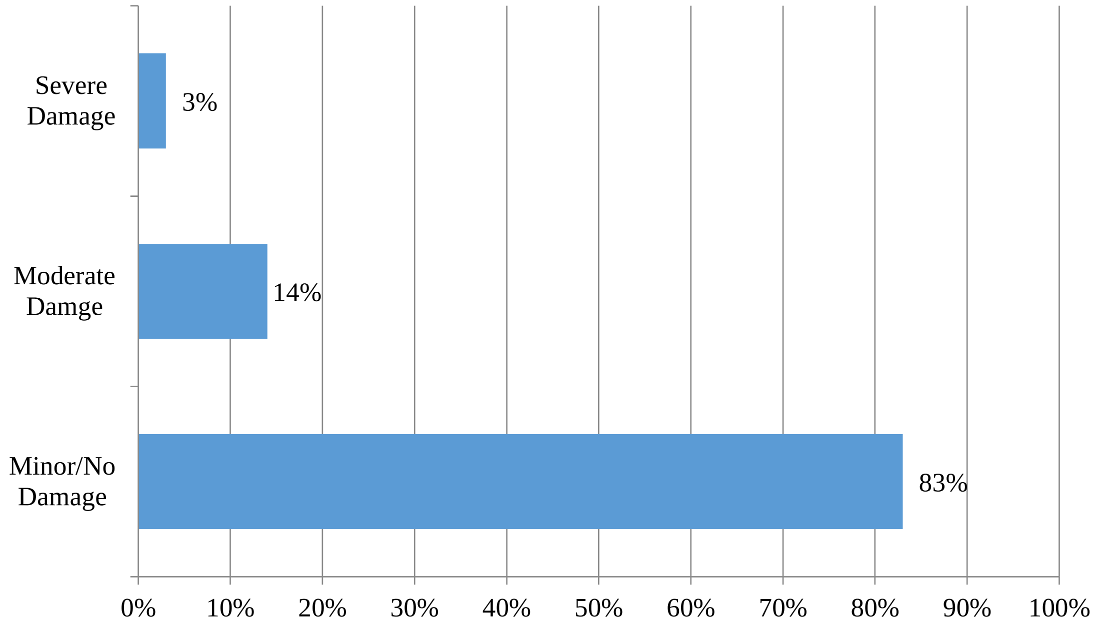

Figure 6: Damage classification of in-field vessel impacts.

3.1.2.2 Consequences from passing vessels.

In terms of the consequences of passing vessel impacts, normally a higher percentage of passing vessel collisions result in severe damage to the installation, with the remainder causing only minor or no damage. The majority of passing vessel collisions have involved fishing vessels.

These statistics may be read as indicating that the consequences of a passing vessel impact with an installation will probably not be catastrophic and will most likely result in minimal damage. However, one of the severe damage incidents, which occurred in 1988 involved the 6616 gross tonne cargo vessel Irving Forest and the Jack-up Glomar Labrador I, and, reportedly, came close to causing collapse of the installation. In another passing vessel impact, which occurred in the Southern North Sea between a port bound supply vessel and a British Aerospace radar tracking platform, the platform sustained approximately £6m worth of damage and was out of full operation for 15 months. In addition, a review of the World Offshore Accident Database (WOAD) showed that of the 40 offshore related vessel collision incidents, within WOAD, which occurred during the period 1971-95, 5 collisions resulted in the total loss of the installation.

It should also be noted that the magnitude of costs incurred should an installation suffer total loss (or any damage where there is significant loss of life and/or environmental damage), whether it is as a result of a fire or ship collision, will be extremely high. Insurance underwriters would probably cover some of the resulting losses, but past experience shows that the uninsured losses to the installation's and also to the offshore oil and gas industry as a whole, would be very significant.

4 Analysis of collision incidents and offshore regulations (1975 – 2017)

1.1 Key Offshore Regulations and Events 1974 – 2017

Before any data is presented, it is important to understand the timeline of key offshore regulations and incidents that have shaped the modern-day SC regulations. Table 4 identifies the key timeline of incidents that have built the current SC regulations. These regulations and their times of implementation are vital for the analysis and discussion included later in this study.

Table 4: Timeline of key regulations and events that have shaped the modern offshore safety case

Year	Name	Description
1974	Health & Safety at Work Act (HSWA)	The HSWA adopted a holistic approach to the health, safety and welfare of workers. The Act focuses on the concept that any situations that may give rise to harm need to be recognised and suitable measures put in place to eliminate or reduce the potential for harm. It set up two new organisations to oversee its implementation: The Health and Safety Commission (HSC) and the Health and Safety Executive (HSE). The HSE is the executive organisation that enforces the provisions of the HSWA. However, in April 2008 the HSC was dissolved and merged with the HSE. The HSC used to protect health and safety at work in the UK by conducting research, training and providing advice and information. The Commission also used to propose new regulations and approved codes of practice under the authority of the Act. This is all now conducted by the HSE (The Stationary Office, 1974) (Inge, 2007).
1988	Piper Alpha Disaster	Piper Alpha was an oil production platform in the North Sea off the coast of Aberdeen, Scotland. The platform began production

		in 1976, initially as an oil platform but was later converted to accommodate gas production. Oil & Gas fires and explosions destroyed Piper Alpha on 6 July 1988, killing 167 people, including two crewmen of a rescue vessel and 61 workers aboard survived. Thirty bodies were never recovered. The total insured loss was about £1.7 billion ($3.4 billion), making it one of the costliest manmade catastrophes ever. At the time of the disaster, the platform accounted for approximately ten per cent of North Sea oil and gas production. The Cullen Inquiry was set up in November 1988 to establish the cause of the disaster, chaired by Judge William Cullen. After 180 days of proceedings, the "Public Inquiry into the Piper Alpha Disaster" or "Cullen Report" was released in November 1990. It concluded that the initial condensate leak was the result of maintenance work being carried out simultaneously on a pump and related safety valve. The report was critical of Piper Alpha's operator, which was found guilty of having inadequate maintenance and safety procedures (Inge, 2007) (Oil & Gas UK, 2008) .
1989	Offshore Installations (Safety Representatives & Safety Committee) Regulations	The document provides information on interpretation and enforcement of the Offshore Installations (Safety Representatives and Safety Committees) Regulations 1989. These regulations were made under the Mineral Workings (Offshore Installations) Act 1971. They allow the workforce on an offshore installation to elect safety representatives from among themselves and confers on those functions and powers in relation to the health and safety of the workforce. They also provide for time off with pay for safety representatives so they can perform these functions and undergo relevant training (The Stationery Office, 1989).
1990	The Cullen Report	The Cullen Inquiry was set up in November 1988 to establish the cause of the disaster, chaired by Judge William Cullen. After 180 days of proceedings, the "Public Inquiry into the Piper Alpha Disaster" or "Cullen Report" was released in November 1990. It concluded that the initial condensate leak was the result of maintenance work being carried out simultaneously on a pump and related safety valve. The report critical of Piper Alpha's operator, which was found guilty of having inadequate maintenance and safety procedures. 106 recommendations were made calling for, amongst many matters, the requirement of a SCs, the transference of the discharge of offshore regulation from the Department of Energy to a discrete division of the HSE. The responsibility of implementing the recommendations was spread across the regulators and the industry with, the HSE overseeing 57, the operators were responsible for 40, the offshore industry were given 8 to progress and the final one was for the Standby Ship Owners Association. The industry acted urgently to carry out the 48 recommendations that operators were directly responsible for. The HSE developed and implemented Lord Cullen's key recommendation: the introduction of safety regulations requiring the operator/owner of every fixed and mobile installation operating in UK waters to submit to the HSE, for their acceptance, a SC (Inge, 2007).

1992	Safety Case Regulations	The Offshore Installations (Safety Case) Regulations came into force in 1992. By November 1993 a safety case for every installation had been submitted to the HSE and by November 1995 all had had their safety case accepted by the HSE. The Safety Case Regulations require the owner/operator/duty holder of every fixed and mobile installation operating in UK waters to submit to the HSE, for their acceptance, a safety case. The safety case must give full details of the arrangements for managing health and safety and controlling major accident hazards on the installation. It must demonstrate, for example, that the company has safety management systems in place, has identified risks and reduced them to as low as reasonably practicable, has introduced management controls, provided a temporary safe refuge on the installation and has made provisions for safe evacuation and rescue (Inge, 2007) (HSE, 2005).
1995	Offshore Installations Prevention of Fire and Explosion, and Emergency Response (PFEER)	PFEER deals primarily with fire and explosion events, but it also deals with any event which may require emergency response and includes systems that may rely on radar on a standby vessel or responsible staff on the installation monitoring incoming vessels. The Regulations, ACOP and guidance deal with: (a) preventing fires and explosions, and protecting people from the effects of any which do occur; (b) securing effective response to emergencies affecting people on the installation or engaged in activities in connection with it, and which have the potential to require evacuation, escape and rescue (Amended in 2005 and 2015) (HSE, 2015b).
1996	Offshore Installation (Design & Construction) Regulations	DCR Requires the installation to possess integrity at all times, as is reasonably practicable. It requires the design of the installation to withstand such forces that are reasonably foreseeable and in the event of foreseeable damage it will retain sufficient integrity to enable action to be taken to safeguard the health and safety of persons on or near it. The duty holder also has to record the appropriate limits within which it is to be operated. Further duties can be found in the Offshore Installations and Wells (Design and Construction, *etc*.) Regulations 1996. (HSE, 2008b).
2005	Offshore Installations (Safety Case) Regulations (April 2006)	The Offshore Installations (Safety Case) Regulations 2005 came into force on 6 April 2006. They replace the previous 1992 Regulations. The primary aim of the Regulations is to reduce the risks from major accident hazards to the health and safety of the workforce employed on offshore installations or in connected activities. The Regulations implement the central recommendation of Lord Cullen's report on the public inquiry into the Piper Alpha disaster. This was that the operator or owner of every offshore installation should be required to prepare a safety case and submit it to HSE for acceptance (HSE, 2005). These SC regulations have been replaced by the 2015 regulations.
2008	Safety Zones around Oil & Gas Installations in	While this document is not a regulation, it explains the purpose and significance of safety zones around offshore oil and gas installations and their effect on marine activities, particularly relating to fishing vessels. A safety zone is an area extending 500

	Waters around the UK (HSE)	m from any part of offshore oil and gas installations and is established automatically around all installations which project above the sea at any state of the tide. Subsea installations may also have safety zones, created by statutory instrument, to protect them. These safety zones are a 500m radius from a central point. Vessels of all nations are required to respect them. It is an offence (under section 23 of the Petroleum Act 1987) to enter a safety zone except under the special circumstances. (HSE, 2008a).
2013	Guidelines for Offshore Marine Operations (G-OMO)	The International Guidelines for Offshore Marine Operations (G-OMO) document was officially launched in the UK on the 11th November 2013 and in Norway on the 1st June 2014. It was the product of the G-OMO work group – details of which are contained within the document. G-OMO supersedes and replaces the June 2009 update publication "Guidelines for the Safe Management of Offshore Supply and Rig Move Operations (NW European Area)", often referred to as the 'NWEA Guidelines'. G-OMO is designed to offer a standard global approach to and encourage good practice in safe vessel operations for the offshore oil and gas industry (Norwegian ship Owners Association, 2013a). In terms of this research, particular attention is focused on Chapter 8 of G-OMO "Collision Risk Management". This states that most offshore facilities, in theory, will be protected by the establishment of a 500m safety zone around the structure, unit or vessel. The best practices described in G-OMO have been developed on the presumption that such a safety zone exists. However, it should be noted that some offshore facilities, particularly vessels, may not be protected by such a zone. Despite this, it is strongly recommended that when attendant vessels are approaching any offshore facility the practices, described in Chapter 8 of G-OMO, should be observed, irrespective of whether a safety zone has been established around the facility (Norwegian Ship Owners Association, 2013b).
2015	Offshore Installations (Offshore Safety Directive) (Safety Cases *etc.*) regulations (July 2015)	The Offshore Installations (Offshore Safety Directive) (Safety Case *etc.*) Regulations 2015 came into force on 19 July 2015. They apply to oil and gas operations in external waters, that is, the territorial sea adjacent to Great Britain and any designated area within the United Kingdom Continental Shelf (UKCS). They replace the Offshore Installations (Safety Case) Regulations 2005 in these waters, subject to certain transitional arrangements (HSE, 2015a).

4.1 Trend of collision incidents

Figure 7 demonstrates the number of vessel to platform collision incidents from 1971 to 2017 as well as the key regulations and events as outlined in Table 4. It can be seen from Figure 6 that the number of vessel to platform collision incidents from 1971 to 2017 is very turbulent, as more clearly demonstrated by the average incident trend line. At first glance, this trend seems to be rather erratic, following no logical pattern. However, when the milestones in the offshore safety regulation and events timeline are taken into consideration, patterns begin to emerge.

Initially, from 1971 to 1973 the number of incidents is very low at one per year. A possible reason for this is that the data entries for 1971 to 1973 are from WOAD only, as the HSE began their ship to platform collision recordings from 1975. However, from 1975 onwards, the number of incidents per year greatly increased until 1981 from 12 to 32 respectively and there are a number of potential factors that can cause this rapid increase. Firstly, the HSWA was enforced from 1974 hence; the recognition of dangerous incidents that can cause harm to personnel increased. Secondly, as more and more dangerous incidents were being recognised, the need to report said incidents also increased. Therefore, it is safe to say that an increased awareness of dangerous situations coupled with the need to report these incidents gives rise to a dramatic increase in the number of collision incidents. Thirdly, according to the HSE, the average number of installations operating in the UKCS alone increases from 88 in 1975 to 120 in 1981. The increase in the number of operating platforms would statistically increase the number of collisions at that time. Finally, along with the HSWA 1974, the regulations for preventing collisions at sea (1972) were enforced from 1977. It is possible that these regulations in 1977 contributed to the increase of reported incidents up to the peak in 1981. However, it is also valid to state that the decrease in the number of reported incidents post 1981 was affected by the 1977 regulations. The initial increase immediately following the enforcement of the regulations can be attributed to an acclimatisation period. This is the period where operators were becoming used to the new procedures, and the older procedures, now deemed unsafe and out of date, were phased out.

From 1981, however, the number of incidents per year begins to decrease until 1987, from 32 to 7. This decrease is much greater that the increase in incidents from 1975 to 1981. It is possible that the enforcement of the HSWA had a large effect on the safety procedures on offshore platforms in the North Sea. This hypothesis would also be consistent with the average number of platforms operating in the UKCS, which increases from 120 in 1981 to 174 in 1987. This contradicts the previous statement that the number of incidents would increase with the number of platforms in operation. However, in the 6-year period between 1981 and 1987 this is not the case. This further strengthens the idea that the regulations form 1974 have been

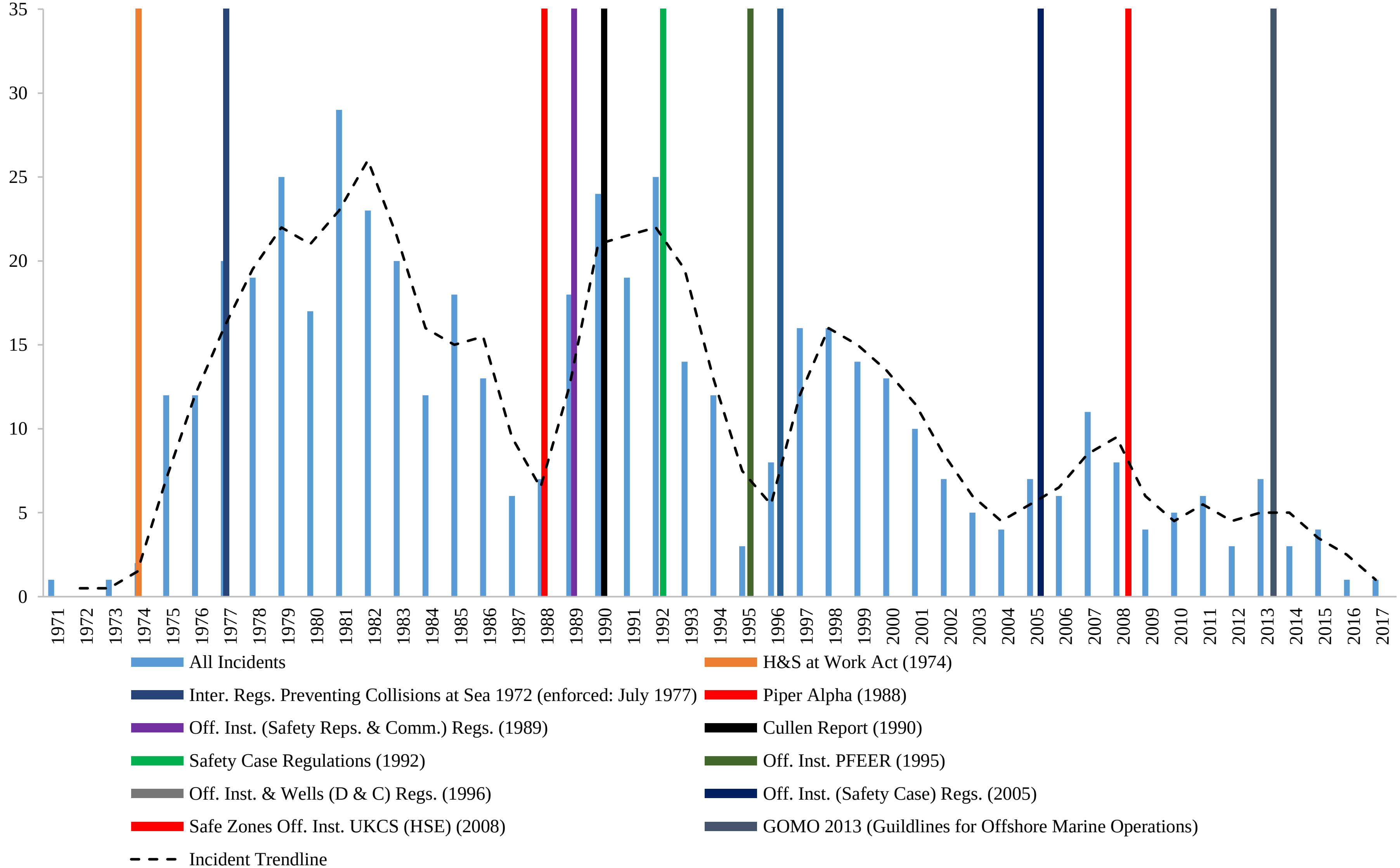

Figure 7: the number of ship to platform collision incidents per year, along with key offshore safety regulations and events.

increasingly enforced and have reduced the number of incidents. However, it is also possible to state that the level of reporting of the collision incidents has decreased. This is a much more difficult claim to validate, as there is not any possible way to determine whether an incident has happened and has not been reported. This is part of the reasoning behind the Asset Integrity Case, as the only way wireless sensor will not detect and log any information is if it is faulty. On the other hand, a human has the ability to choose not to carry out an action. Hence, it is difficult to accurately determine the level of under-reporting that would have taken place between 1981 and 1987. This is part of the rationale for dynamic risk assessment and automation to assist with the enforcement of these regulations (Loughney & Wang, 2017).Continually, the time between 1988 and 1994, in terms of collision incidents, is very interesting. The year 1988 is well known in the offshore industry and indeed the world as the year of the Piper Alpha disaster in which 167 crew members lost their lives in the July of that year. When one examines the collision incidents that were reported in 1988, more than 60% were reported after the loss of Piper Alpha on 6th July (Department of Energy, 1990) (Inge, 2007) (Oil & Gas UK, 2008). This may suggest that a large-scale disaster, such as Piper Alpha, triggered an increase in the level of incident reporting. However, the number of collision incidents in 1988 alone is not enough to state this with any conviction. What is interesting however, is that the number of collision incidents increases to 21 in 1989, from 8 in 1988. This is a drastic increase in terms of the number of reported incidents in the North Sea, after a large-scale offshore disaster. Furthermore, in 1989 the Offshore Installations (Safety Representatives & Safety Committee) Regulations were published. This stated that the workforce could elect safety representatives from amongst themselves. This may have increased the level of reporting of collision incidents in 1989. However, it appears to be too much of a drastic increase from the previous year to conclusively state that the new regulations in 1989 resulted in a considerable number of reported incidents. It seems much more likely that a combination of the Piper Alpha disaster and the release of the Offshore Installations (Safety Representatives & Safety Committee) Regulations contributed to the vast increase in reported collision incidents.

In 1990 the Cullen Report was published which was public enquiry into the Piper Alpha disaster. The report was heavily critical of the platform operators. Lord Cullen made 106 recommendations within his report, all of which were accepted by industry. The responsibility of implementing these recommendations has been outlined in Section 1. By 1993, all had been acted upon and substantially implemented. Furthermore, the HSE also developed and implemented Lord Cullen's key recommendation (Department of Energy, 1990). This large-scale enforcement of strict regulations can be seen by the decrease in the number of reported incidents from 1989 – 1995. This is evidence that the number of offshore incidents can be positively affected, in a short time, from the consequences of a severe accident and the subsequent operational and regulation changes.

If the number of collision incidents is examined from the Cullen Report in 1990 to all installation SCs, being accepted in 1995, it can be seen that the number of incidents per year decreases rapidly from 27 to 3 respectively. This is again a massive fluctuation in the number of incidents following a series of key regulations being enforced. Its shows that the release of new regulations prompts the level of incidents to decrease as the regulations are enforced. However, as 1995 is a number of years after the Cullen Report and the introduction of SCs, it is possible that an element of complacency in terms of reporting has occurred. This can be seen from the number of incidents between 1995 and 2004. The number of collision incidents increases from 3 in 1995, to a peak in 1999 of 22, then to a new low of 5 in 2004. This fluctuation could be attributed to just the number of incidents increasing after 1995 due to the increase of the average number of installations operating in the UKCS from 289 to 319 in 1999. However, the increase in installations does not correlate well with the increase in incidents.

What appears to be more likely is at the low point of 3 collisions in 1995, a new set of regulations were introduced and enforced, including the Offshore Installations Prevention of Fire and Explosion, and Emergency Response (PFEER) along with the Offshore Installation (Design & Construction) Regulations in 1996. At that point, the number of incidents increases and peaks in 1999. It is likely that the increase of new regulations prompts a more proactive response in the accuracy of incident reporting.

This trend can be seen yet again from 2004 to 2012, where the number of collision incidents per year increases from 5 in 2004 to 12 in 2007 and then decreases to 4 in 2012. This could be attributed to the Offshore Installations (Safety Case) Regulations 2005 being enforced in 2006. As with the regulations in 1995 and 1996, the number of incidents increases, peaks and then begins to decrease. However, the number of collision incidents becomes much steadier and does not fluctuate as much as previous years, as an increase from 5 to 12 is not a huge increase, but it is an increase none the less. Furthermore, in 2008 the document entitled Safety Zones around Oil & Gas Installations in Waters around the UK is introduced by the HSE as well as G-OMO. More specifically, Chapter 8 of G-OMO as this targets the area of offshore collision risk management, including near misses. Therefore, it makes sense to state that this introduction has assisted with the maintained low number of incidents between 2009, with 4, and 2017, with 3.

5 Discussion

The database compiled in this research contains an amalgamation of ship/platform collision data from several widely differing sources and so potentially represents the most complete record of collision incidents on the UKCS in particular from 1996 to 2017. Furthermore, the data presented should be interpreted with some caution, as it is highly likely that some degree of under-reporting of incidents has occurred. Primarily this is thought to be of those incidents where little or no damage resulted to the installation.

In the time period of 1971 to 2017, the general trend of ship/platform collision incidents, in accordance with the outlined criteria, has demonstrated a decrease in the number of incidents. Similarly, while there were few incidents involving moderate or significant damage, the number of incidents involving minor damage has also decreased. This may be attributed to the adoption and application of improved working practices. While the cumulative trend of incidents has decreased there are fluctuations within the incident frequencies. It can be seen for all installations that there are peaks in the data in 1981, 1992, 1997, 2007 and 2013. This can possibly be attributed to the release of regulations in 1974/1975, key events from 1988 to 1990 and SC regulations and amendments 1996 and 2005. The periodic release in SC regulations can potentially be a factor in the reporting and occurrence of ship/collision incidents as ship collision is seen as being a Major Accident Hazard as it is an event which may cause major damage to the installation and therefore subject to regulatory requirements. Hence, changes in practices through regulations may affect the occurrence frequency of results in the immediate years after the regulations are released. Similarly, it is also possible that the release of new or amended regulations may result in improved working practices in terms of the level and quality of incident reporting. This can be backed up further by analysing collision incidents across the different installation types (fixed, floating and jack-up).

5.1 Completeness of the data

The compiling of this database involved rigorous cross checking of incidents across the five data sources utilised to avoid any repeated entries and to confirm that the relevant data had been used. Similarly, comprehensive checking was applied to the data entries to ensure that all relevant data was obtained in order to produce the most accurate data base possible. Furthermore, where data entries were not fully complete, such as where the name of the installation was given and the date of the incident, further sources of information were utilised to complete said entries to provide information on the vessel type, the type of installation, the month of occurrence, the geographical location *etc.* Many data entries were deemed to be incomplete, and the best possible effort was made to fully complete these entries. Unfortunately, not all data entries were able to be 100% completed. In some cases, these entries have an unspecified installation type or date and hence identifying the correct incident when analysing various sources of information was difficult to impossible.

Regarding the damage classification for the data entries, more often than not the damage classification was stated using the relevant descriptors in the incidents reports. However, some data entries have an unspecified damage classification but contain a damage report. In this event the incident reports were examined and if the damage report gave a substantial description of the incident and the consequences, then a damage classification could be assigned to the incident.

It is important to note that the confidence with which the information should be assessed is to the level that it represents the "best case" as far as the frequency of incidents is concerned. In reality, it is likely that the frequency of incidents that result in less serious damage could well be higher than indicated in this research. More recently, it is believed that a much higher degree of accuracy has been achieved, in terms of information provided in incident reports, particularly for serious incidents. However, the issue with under-reporting is more associated with incidents that result in very little damage. This has a knock-on effect, *i.e.*, if the installation is floating and damage from a collision is minor to nonexistent, then the report may not be fully complete, and subsequently, the location of the incident may not be reported. This leads to an unspecified geographical location in the analysis, as it is very difficult to retrace where the incident took place as the installation may have moved to a new field. This lack of geographical information, more commonly associated with floating installations, has occurred repeatedly throughout the data gathering process. Furthermore, the operating experience of jack-up installations should also be considered, as the "best case" as an accurate number of installations operating per year was not accessible. This resulted in the meticulous compilation of the number of operational jack-up installations per year from 1996 to 2017. Little data is given as to which jack-up installations have been completely removed from service or when a jack-up has been moved off site. The information available was not accurate enough to completely determine the precise number of jack-up installation operating on the UKCS per year; hence, the number of jack-up installations gradually increases. However, this increase is not excessive, and it is assumed that only a small number of installations will have been removed from the UKCS. Therefore, any change in the operating experience of jack-up installations will be minimal and subsequently not have a great effect on the incident frequency trends or outcomes.

5.2 Vessel types

Over the full time period of 1971 to 2017 there have been a number of passing vessel collisions. In more recent times, in the past 20 years, there have only been 2 records of passing vessel collision. Both of these incidents resulted in significant damage to the installations and both vessels collided with fixed platforms (Jacket structure in 2002 and a fixed steel structure in 2007). This appears to be an example of passing vessels abiding by the regulations and not encroaching on the 500m zones. Similarly, both passing vessel incidents in 2002 and 2007 were attributed to human error as there were large delays in responses following the efforts of the respective platforms attempting to contact the vessels. The two incidents involving passing vessels have occurred in the southern North Sea. This is unsurprising as this area of the North Sea is the most congested in terms of commercial shipping on local coastal voyages (including passenger vessels), short distance voyages (UK and European Mainland), and long voyages (Northern European ports and International ports).

More than 98% of collision incidents on the UKCS have either occurred from attendant vessels or unspecified vessels in the incident reports. This is not completely surprising given the number of vessel in close proximity to offshore platforms and the time that they spend within that proximity. While this seems like a significant ratio, the fact is that the number of collision incidents has steadily decreased since the inception of SC regulations. The SC of a platform must give full details of the arrangements for managing health and safety and controlling major accident hazards on the installation, and vessel to platform collision events are considered as a major accident hazard. Hence with the continuous updating and enforcement, the general trend of collision incidents has decreased, with some periodic fluctuations.

6 Conclusion

From the information presented in the analysis, particularly in Section 4, it can be seen that the offshore industry can be said to be reactive in its approach to reporting incidents, especially in the area of ship to platform collisions. What is also apparent is that the fluctuation has gradually reduced from 1975 to 2017. This shows that the effect of introducing and amending regulations over time has a positive effect on the overall trend of collision incidents. This is particularly apparent regarding in-field vessels, where more than 98% of all collisions on the UKCS involve attendant vessels. Similarly, this research strengthens the research conducted by Oltedal (2012) and Hassel (2017) (Oltedal, 2012) (Hassel, et al., 2017), as presented in Section 1.1 clearly the future focus should be on the improvement of management and operational practices of attendant vessels. While this study identifies trends in ship to platform collisions, it would still be valid to state that the offshore industry would benefit greatly from having a dynamic risk-monitoring tool to aid with the continued enforcement of regulations across all areas of an offshore platform. Yet the enforcement of regulations is only one potential aspect of the control of vessels in the safety zone around offshore installations. Further research can be and has been conducted from the perspective of the vessel and an analysis of human factors displayed by crew members in a crisis situation. Multiple research studies have clearly demonstrated that perceptual errors and decision-based errors of the crew in tandem with an external component, outside of crew control, consistently causes collisions between two vessels (Uğurlu & Yıldız, 2016) (Uğurlu, et al., 2018) (Uğurlu, et al., 2020) (Yildiz, et al., 2021). Thus, further research can be applied to attendant offshore vessels to further understand the accident formation. The recommendation here is to then compare this to the trend analysis with regulations presented in this paper to further expand knowledge in this area. In the near future, a widely accepted and integrated offshore dynamic integrity-monitoring tool could be a distinct possibility to assist with the continued improvement of offshore safety management.

DECLARATION OF CONFLICTING INTERESTS

The authors declare the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article. This paper is the opinion of the authors and does not necessarily represent the belief and policy of their employers.

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