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ARTICLE

Allision risk analysis of offshore petroleum installations on the Norwegian Continental Shelf—an empirical study of vessel traffic patterns

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Abstract The Norwegian Petroleum Safety Authority (PSA) requires offshore petroleum operators on the Norwegian Continental Shelf (NCS) to perform risk assessments of impacts (allisions) between passing ships and offshore installations. These risk assessments provide a basis for defining the allision accidental load that the installation shall be designed for. Even though the risk of allision is small, the potential consequences can be catastrophic. In a worst-case scenario, an allision may result in the total loss of an installation. The ageing industry standard allision risk model, COLLIDE, calculates the risk of impacts between passing (non-field-related) ships and installations based on Automatic Identification System (AIS) data. Both the COLLIDE risk model and a new Bayesian allision risk model currently under development are highly sensitive to variations in vessels' passing distances, especially close proximity passings. Allision risk assessments are typically performed during the design and development phase of an installation, which means that historical AIS data are used "as is", disregarding future changes to the traffic pattern when the new installation is placed on a location. This article presents an empirical study of one of the most important variables used to calculate the risk of allision from passing vessels, namely passing distance. The study shows that merchant vessels alter course to achieve a safe passing distance to new surface offshore petroleum installations. This indicates that the results of current allision risk assessments are overly conservative.

Keywords AIS · Traffic pattern · Risk analysis · Allision · Collision · COLLIDE

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1 Introduction

Operators of offshore petroleum installations on the Norwegian Continental Shelf (NCS) are required to assess the risk of ship impacts from both field-related ship activity and (unrelated) passing vessels. Allision risk assessments of passing vessels typically start with a mapping of the traffic pattern around a proposed location, using Automatic Identification System (AIS) data for a (recent) 12-month period. Since these assessments must be completed before commissioning, the AIS data available at the time of such studies represent the traffic pattern before the physical installation is actually placed in the field. Hence, the applicability and validity of these data and their impact on the results of risk analysis may be questioned, which is the purpose of this article. Allision risk assessments are typically performed as part of a much larger quantitative risk analysis (QRA), and challenging the status quo of how such assessments are being performed is an important task, as stated by Goerlandt et al. (2016). The lack of procedures based on empirical evidence may also result in too much subjectivity in risk assessments, making replication of results difficult, even when based on the same input data (Goerlandt and Kujala 2014).

The Merriam-Webster dictionary (n.d.) defines an allision as “the running of one ship upon another ship that is stationary - distinguished from collision”. An allision in this context is an impact between a ship and a fixed manmade object, such as offshore surface installations. The Norwegian Petroleum Safety Authority (PSA) has claimed that the estimated risk of allision from passing vessels is believed to be too conservative, and this may be due to overestimation caused by not accounting for changes in the traffic pattern once a new installation is put on location. Estimating the risk posed by passing vessels is typically done using the COLLIDE risk model (Haugen 1998).

A new Bayesian allision risk model is under development. Some of the most important parameters with regard to allision risk are the expected passing distance and the behaviour of ships passing nearby an installation. The new allision risk model is based on the existing industry standard allision tool “COLLIDE” (Haugen et al. 1994; Haugen and Vollen 1989). It takes into account the effect of new knowledge, technology and equipment that have become standard onboard vessels and installations during the last decade, in order to address some of the shortcomings of the existing COLLIDE model (Hassel et al. 2014). The application of Bayesian Belief Networks (BBNs) in the context of maritime traffic and maritime risk assessment has become increasingly popular in recent years, and the methodology is well suited for the maritime domain (Hänninen 2014).

The claim that the presence of offshore petroleum installations has an effect on the traffic pattern and location of shipping lanes has been accepted since the very first allision risk models, by Haugen and Vollen (1989) and Spouge (1991). Nevertheless, it has not been studied sufficiently, nor verified empirically. To the best of our knowledge, the only available empirical study based on AIS data is a Master’s thesis by Skarestad (2010), which investigated if there were any significant changes to traffic patterns around temporary drilling installations, by comparing AIS data from reference periods before and after the temporary installations were on location. The study looked at all vessels passing within 12 nm (nautical miles, 1 nm = 1852 m) of the installations and found that there was no significant change to the relative traffic volume inside a 3-nm passing distance. The study mentions that the 3-nm passing distance may be too great a distance to observe any significant changes and states that a quick test of 1 nm produced more promising results, without going into further detail.

Allision risk from visiting vessels is the topic of several other research and industry actors (Gibson 2015; IOGP 2010; Sandhåland et al. 2015; Tvedt 2014) and, most recently, a joint industry project (JIP) with participants DNV GL, Lloyds, Safetec Nordic, Statoil and ConocoPhillips. The most comparable research to risk assessments of this kind is that of ship impacts with offshore wind energy installations (Dai et al. 2013) or bridge pylons (Hansen et al. 2013). The structural aspect of allision scenarios has been studied in detail by several researchers (Amdahl and Johansen 2001; Amdahl et al. 2012; Storheim and Amdahl 2014; Zhang et al. 2015) and is not addressed in this study.

Comparative studies using AIS data for other aspects of vessel traffic patterns, such as the risk of ship-bridge impacts in narrow inland waterways, have also been conducted. Xiao et al. (2015) compared traffic patterns from a narrow Dutch waterway with a wide Chinese waterway, using AIS. Ship-bridge impacts have many similarities to ship-offshore installation impacts, and risk model methodology for both cases shares many elements, as shown by Hansen et al. (2013). However, navigation in open waters is very different from navigation in inland waterways and confined waters (Kujala et al. 2009; Montewka et al. 2014; Montewka et al. 2012).

Allision risk assessments dealing with open water navigation must investigate traffic spread across a much larger area and has the added challenge of dealing with larger angles of course deviations, as described by Wolfram and Naegeli (2004). Povel et al. (2010) has used AIS data to investigate the allision risk for offshore wind energy installations but focused on drifting vessels and simply used reference data from Fujii and Mizuki (1998) to determine the probability of powered passing vessels being on a collision course. For inland waterway navigation, one may claim that all vessels are to a certain degree on a "collision course" as they have very small margins when passing under bridges with multiple pylons crossing the waterway. Still, Proske and Curbach (2005) found that the average probability of a bridge (pylon) in their study being hit by a ship was 2.11E−05 per ship passing. This means that navigators are generally good at avoiding obstacles, new and old, as could be expected.

Over the last half decennium, the petroleum exploration on the NCS has accumulated over a couple of thousand installation years, but only two recorded incidents have been recorded of impacts between Norwegian installations and non-field-related vessels (Vinnem 2014). The first incident was in 1988, when a submerged submarine allided with the steel jacket of the Oseberg B platform, about 140 km west of Bergen. The other incident was when a small cargo ship allided in a "glancing blow" after coming head on towards the Norwegian-operated Norpipe H7 steel jacket platform on the German Continental Shelf in 1995, as seen in Fig. 1. In both cases, no lives were lost and the damage was limited, but both allisions could just as easily have caused major accidents, if the point of impact had been nearby risers or other critical elements (Vinnem 2014). Worldwide, several allisions with non-field-related vessels have been reported (Gibson 2015; IOGP 2010), and there have been more than ten incidents on the UK Continental Shelf (UKCS) alone, where several came close to causing major accidents (Okstad and Håbrekke 2008).

The main objective of this article is to investigate changes to the traffic pattern of merchant vessels passing offshore oil and gas installations on the NCS. The article

Fig. 1 Photo of the MS Reint-H7 allision, taken by the crew on the nearby standby vessel

presents an empirical study of one of the most important variables used to calculate the risk of allision from passing vessels, namely passing distance to the offshore installation. The results of the study show that merchant vessels alter course to achieve a safe passing distance to new surface offshore petroleum installations, which means that the current use of AIS data in allision risk assessments is overly conservative.

For the purpose of illustrating the effect of this parameter, the most recent new petroleum production installations in the Norwegian sector have been selected. Since 2010, seven new petroleum production installations have been located on the NCS: Gjøa (semi-submersible), Goliat (Sevan Stabilized Platform (SSP)), Edvard Grieg (fixed installation—jacket), Gudrun (fixed installation—jacket), Knarr (Floating Production, Storage and Offloading (FPSO)), Skarv (FPSO) and Valemon (fixed installation—jacket), as seen in Fig. 2. Five of these are in the North Sea, and Goliat is in the Barents Sea, with significant traffic volumes, whereas Skarv in the Norwegian Sea has much lower traffic volumes along with Knarr in the northern part of the North Sea. The traffic patterns around these seven installations are studied in this article, before and after the actual installations were introduced on location. Field-related vessels and offshore installation support vessels are not part of the scope of work for this article.

Section 1 provides the background for the research, while Sect. 2 describes the data processing and general methodology. Section 3 analyses the findings and results. Section 4 contains the discussion, while the conclusion is found in Sect. 5.

2 Methodology

2.1 Allision risk assessment

An allision risk assessment begins with the collection, processing and interpretation of AIS data. A chaotic mesh of interwoven lines (AIS tracks), as can be seen on the left side in Fig. 3, are systematically processed to identify shipping lanes and routes in a 10-nm radius around a given position, as seen on the right side in Fig. 3. The main goal of the processing is to identify the number of ships in each route, the direction and passing distance of each route and the standard deviation of each route. These attributes, together with ship information, provide the basis for further calculations, by, for example, COLLIDE. Since multiple parameters influence the results, it can be hard

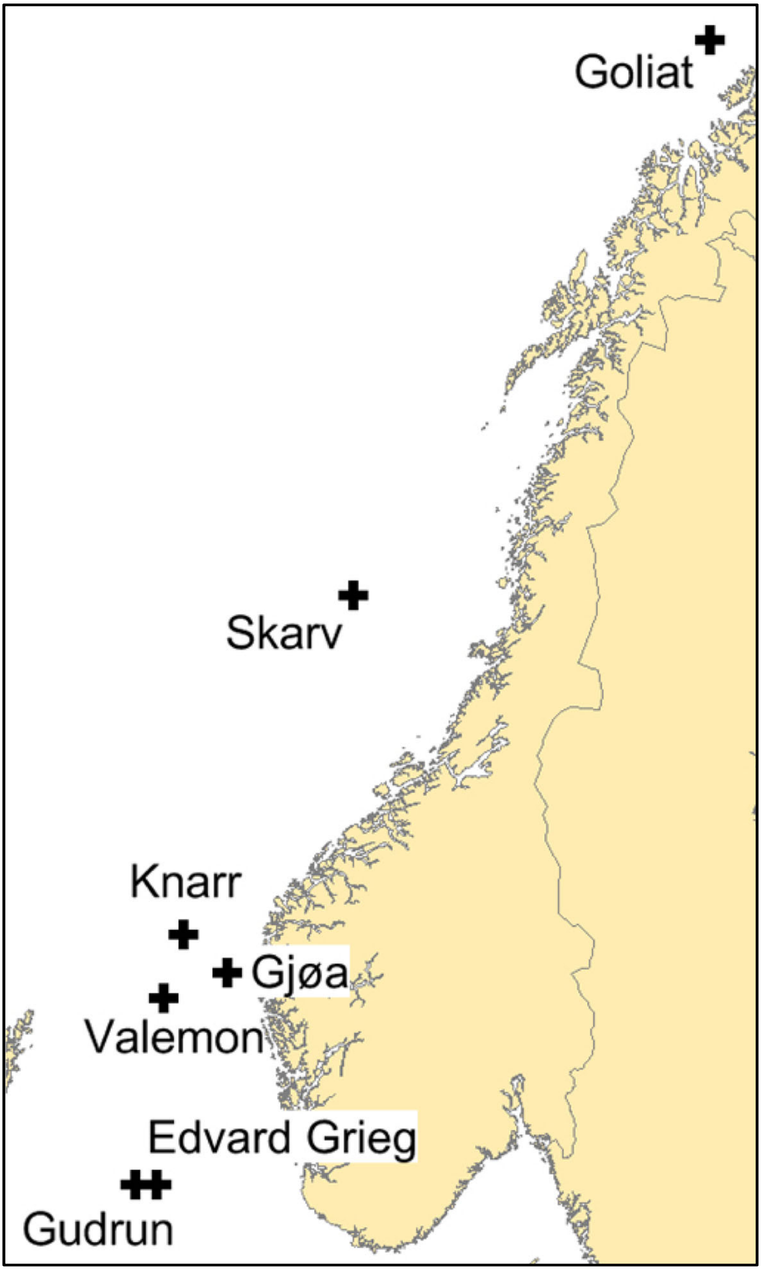

Fig. 2 Map of the seven petroleum production installations installed on the NCS between 2010 and 2015

to state categorically that one or the other is most important, but allision risk models are highly sensitive to the passing distance and the probability of a vessel being on a collision course. This is not surprising, as the act of striking an object requires close proximity and a collision course, so obviously, the passing distance between a ship and an installation is a crucial factor.

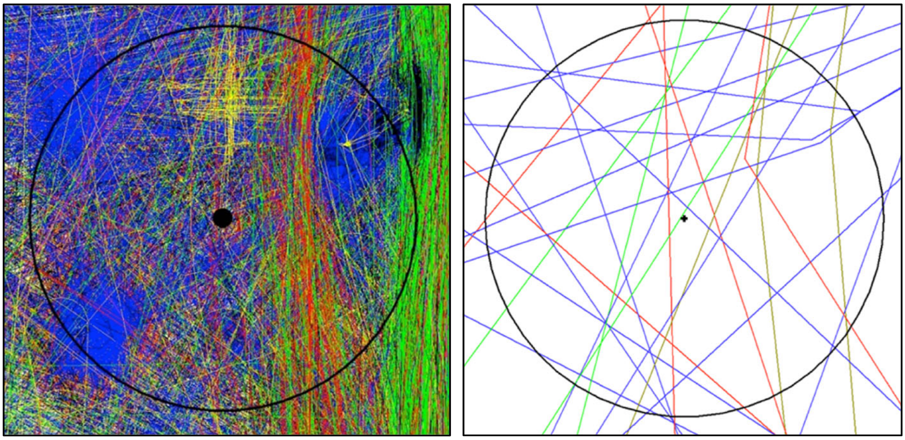

Fig. 3 *Left*: unprocessed AIS data for 12 months. *Right*: result of traffic study, showing routes

2.2 Data collection

AIS data for the seven locations have been collected using the Christian Michelsen Research (CMR) online portal,[1] which provides access to AIS data from the Norwegian Coastal Administration (NCA). The older datasets have been collected from archived Vissim[2] data, provided by Safetec Nordic, as the CMR portal only has AIS data going back 2 years. The AIS data for the traffic patterns after the installations were commissioned on location are from April 2015 to April 2016, while data from before the installations were introduced are from May 2009 to May 2010 for the Gjøa installation, which was put on location in June 2010 and from June 2010 to June 2011 for the other installations. This has been done to ensure 12 months of data for both the "before" and "after" scenarios. Using AIS data from several years before most installations are placed on location is beneficial, since fixed installations in particular are introduced on location in steps, with the jacket being installed well in advance of the topside module.

For Gjøa, the before dataset is from immediately before the installation came on location, while the after dataset is from several years after. For Goliat, the situation is opposite, with the before dataset being from several years ahead of the installation coming on location, while the after dataset being from immediately afterwards. This should not matter significantly, as any tracks related to the installation or field-related traffic are removed during the processing and filtering. However, it may be argued that a dataset shortly after an installation is introduced may not see the same level of changes to the traffic pattern, as the traffic has not had much time to adjust. This would only mean that any findings of significant change are conservative, as one could expect a more significant change as more time passes. For datasets from immediately before an installation is introduced, one may claim that significant field-related work and vessel activity could trigger a change in traffic pattern even before the installation has arrived, but this would again only mean that any observations would be less significant, making

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[1] http://aisnorge.aisonline.com/stat/

[2] http://vissim.no/products/vessel-traffic-management

the results from this study conservative. One may expect more field-related activity, and for a longer period for fixed installations, than floating installations, but some preparatory activity would be required in any case.

A lot of field-related traffic is common in the months before an installation is installed, and this may influence the traffic pattern on the location. Thus, using an "old" dataset is preferable, to capture the "real" traffic pattern, undisturbed by field-related activity of any kind. This issue is less problematic for floating installations and either way something that is taken care of, by processing and filtering, which will be described in more detail later.

The datasets have been limited to a radius of 4 nm around the installations as the study predominantly aims to investigate how the traffic pattern changes within a radius of 1–2 nm from the installations. To properly compare the traffic patterns, however, it is also necessary to see at what distance the traffic remains unchanged. Hence, a distance of 4 nm was deemed appropriate. Incidentally, experience from allision risk assessments has shown that vessel traffic passing at a distance greater than 4 nm usually has a negligible risk contribution (Kleiven 2016).

There is a guard zone (GZ) of 500 m (meters) around each installation, where no vessel is allowed to enter without specific permission. The area of particular interest is therefore just outside this guard zone, as it is expected that no traffic inside the guard zone would be found. According to the head of the Statoil Operations Centre, Grethe Strøm (2015), the individual offshore installation manager (OIM) decides if a violation of the guard zone should be reported to the police for investigation, but according to Strøm, this is seldom done unless the violation results in some form of unwanted event or impact.

AIS raw data consist of a long list of data points with a set of attributes, such as "International Maritime Organization (IMO) number", "Maritime Mobile Service Identity (MMSI) number", "ship name", "ship type", "flag state", "date", "destination", "to port", "from port", "navstatus" and more. AIS data are often riddled with "ghost entries" where most or even all critical data fields are empty or corrupted. CMR/NCA data typically have a lower ratio of such bad data, than the Vissim data (Kleiven 2016). To properly process the data in a way that enables comparative analysis, the raw data files that usually come in some form of comma- or tab-separated file format must be converted into a file format that can be visually plotted in a geographic information system (GIS) tool, in this case the software application MapInfo Professional.[3]

2.3 Filtering of data

The left part of Fig. 4 shows an example of how a typical AIS dataset looks like before data processing. The red rings in Fig. 4 show a passing distance of 4, 3, 2 and 1 nm and installation guard zone of 500 m. Field-related activity is clearly shown around an installation northwest of the location, as a big "thistle". Just south-southeast of the location is another characteristic thistle showing field-related activity. In order to focus on unrelated shipping traffic passing through the area of concern, all field-related activity and other irregular vessel traffic are filtered away, as shown on the right part of Fig. 4. Such thistles may, however, cause a certain degree of shielding, as field-

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[3] http://www.pitneybowes.com/us/location-intelligence/geographic-information-systems/mapinfo-pro.html

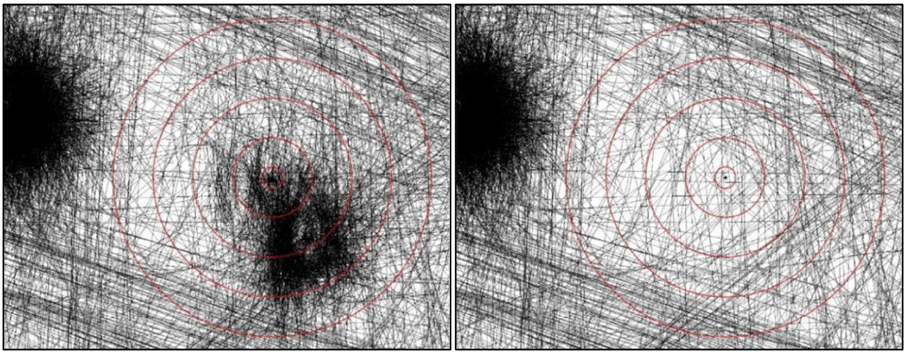

Fig. 4 Example of irregular tracks (*left*) that have been filtered away (*right*) (north is up)

related vessels hover around an area before the installation has come to the location. Such activity may have a shielding effect causing less passing vessels to transit through the thistle before the installation has arrived. A shielding effect in the before data would make the results slightly more conservative. Most of the after data contain some degree of a thistle around the new installations, as many installations have some field-related activity close by. This may influence the results by enhancing the repulsive effect on passing traffic, arguably making the results less conservative. Investigating if field-related activity close by an installation enhances the effect of ships increasing their passing distance could be studied in further work, but at this point, it is of less importance, as we must first determine if there is a significant change in traffic patterns at all.

The original datasets for each of the seven locations have been processed to filter out all tracks outside the scope of this study and are thus categorized as “noise”. This includes all tracks with any form of identifiers in the data, such as destination, to port or from port being equal to the installation in question, or “ship type” being “drillship” or “seismic vessel”, indicating that it is field-related traffic going to or from the installation in question or operating in the vicinity around an installation (field-related traffic to neighbouring installations has not been filtered away, as long as the supply vessels and similar offshore support vessels passing by the location in question are behaving as normal passing vessels within 4 nm of the installation in question, meaning that their tracks are predominantly straight lines within the 4-nm radius).

Straight tracklines are obviously good candidates for a comparative analysis, as the traffic is clearly passing through the area. However, some tracks have course changes that are significant, without any indication or information in the data that can explain why. Such tracks cannot be filtered away unless there is some clear indication of why the course was changed. Tracks with course changes of less than 90° have thus not been excluded from the dataset simply due to the course change. If the course changes are frequent and/or in excess of 90°, it may be possible to exclude the tracks without any explicit information in the data to explain the erratic behaviour. A visual inspection of the tracks can sometimes be sufficient to categorize a track as “passing traffic” or not. Some tracks that are not perfectly straight will always remain though, as seen in the right half of Fig. 5.

In addition to data that have some sort of identifier indicating field relation, it is possible to visually identify offshore-related vessels by considering the tracklines. If

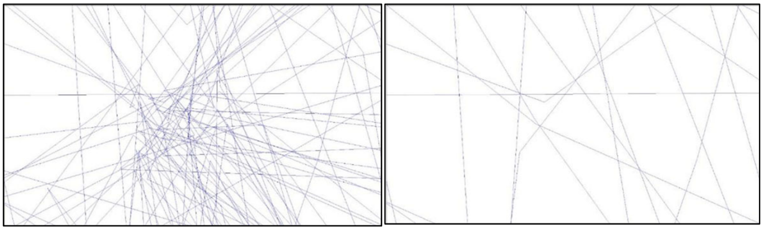

Fig. 5 Detailed example of irregular tracks (*left*) that have been filtered away (*right*)

data rows are missing key information, this makes it possible to filter away vessel traffic that is behaving in a very "non-merchant vessel" manner. An example of this is shown in Fig. 5, where the left image has several tracks that have tracklines with turns in excess of 90° and even 180° turns. After filtering away traffic with field-related behaviour, we are left with the right image, with predominantly straight lines, representing "normal" vessel traffic passing the location.

2.4 Analytical tools

The CMR online portal[4], which is the web interface for the NCA's AIS database, is only accessible to government agencies, but access may be granted to third parties based on legitimate needs, see Fig. 6 (Åsheim 2015). This typically means actors who cooperate with public services to provide maritime traffic surveillance, oil spill prevention or traffic risk assessments. The online portal enables users to extract AIS data from the last 2 years, based on a range of possible parameters. The data excerpt is saved as a tab-separated file, which is subsequently used in geographic information system (GIS) software, in this case MapInfo, to visualize and process the data. The older datasets from archived Vissim[5] data, provided by Safetec Nordic, had already been adapted for use in MapInfo.

In the study presented in this article, the data were manually processed in MapInfo, using the built-in Structured Query Language (SQL) functionality in the software, along with manual and visual inspection of the data tables and graphical representation of the data. Obtaining the results and numbers for each installation and distance/area was done using SQL queries. Further details on how this was done are presented in the following section.

3 Analysis and results

3.1 Ship traffic data

Processing and filtering of both datasets (before and after) for each location provide us with an overview of all locations and distances before and after installations were introduced on location, as shown in Table 1. The installations are anonymized in

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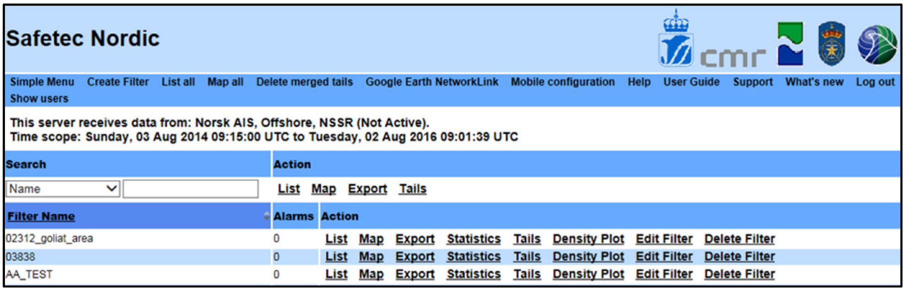
[4] http://aisnorge.aisonline.com/stat/

[5] http://vissim.no/products/vessel-traffic-management



This server receives data from: Norsk AIS, Offshore, NSSR (Not Active).
Time scope: Sunday, 03 Aug 2014 09:15:00 UTC to Tuesday, 02 Aug 2016 09:01:39 UTC

Search	Action
Name	List Map Export Tails

Filter Name	Alarms	Action
02312_goliat_area	0	List Map Export Statistics Tails Density Plot Edit Filter Delete Filter
03838	0	List Map Export Statistics Tails Density Plot Edit Filter Delete Filter
AA_TEST	0	List Map Export Statistics Tails Density Plot Edit Filter Delete Filter

Fig. 6 Screen capture of CMR AIS server web interface

Table 1, as access to the NCA's AIS database requires that no single unit can be identifiable in published research.

Table 2 shows the average number of passings for each distance category for all installations.

Table 3 shows the total number of passings for each distance category for all installations.

Table 3 shows that the most recent AIS datasets are almost twice as large as the older sets. An increase in the general ship traffic activity could account for some of this increase, but not all. It is more likely that the majority of the increase is due to the different nature of the two data sources. The CMR data are more comprehensive and from a larger set of AIS receivers and generally hold a higher standard of data quality. Additionally, the Vissim dataset is a massive dataset for the entire Norwegian coast, meaning that many tracks are continuous for long stretches and time periods, counting as a single passing/data entry even if a vessel goes back and forth between two destinations. The CMR online portal lets users collect data for a restricted area; in this

Table 1 Number of ships passing installation at various distances

Installation		<GZ	GZ–1 nm	1–2 nm	2–3 nm	3–4 nm	Total
A	Before	3	17	42	72	103	237
	After	0	5	48	166	358	577
B	Before	12	53	135	236	388	824
	After	0	19	123	364	607	1113
C	Before	55	142	253	380	546	1376
	After	0	64	552	947	1379	2942
D	Before	19	100	293	561	1002	1975
	After	0	46	266	718	3535	4565
E	Before	43	162	302	447	607	1561
	After	0	24	290	681	1621	2616
F	Before	0	4	45	115	107	271
	After	0	1	34	47	62	144
G	Before	2	17	39	55	84	197
	After	0	19	85	150	209	463

Table 2 Average number of ships (across all locations) passing installation at various distances

		<GZ	GZ–1 nm	1–2 nm	2–3 nm	3–4 nm	Total
Average	Before	19	71	158	267	405	920
	After	0	25	200	439	1110	1774

case, a circular area with a radius of 4 nm around each location has been used. AIS tracks going in or out of this circle are cut, as seen in Fig. 7, and thus count as separate passings/data entries, potentially making the dataset artificially larger/more numerous.

3.2 Normalized results

Since the two datasets (before/after) have a different total number of passings, normalizing the data helps to better understand the results. Table 4 shows the average normalized number of passings for each distance category, while Fig. 8 is a visual representation of the same data.

The results show a significant decrease in traffic within 1 nm of an installation, once it is placed on location. Between 1 and 3 nm, there is also a decrease, while traffic outside 3-nm distance seems to be unaffected.

The total number of ships passing the seven locations in the study (after phase) is over 12,000, and not a single passing was observed within the guard zone once an installation is introduced, where there had been a total of 134 passings across the sample space previously (as shown in Table 3). Ships passing at a distance of less than 1 nm, but outside the guard zone, were more than halved, from almost 500 initially (7.7%) to less than 200 (1.4%) after the introduction of the installations (as shown in Table 4).

Looking more closely at vessels passing within 2000 m of the installations, the change in traffic pattern becomes even more evident. Table 5 shows the normalized average values distributed across segments of 500-m increments. The results are also presented in Fig. 9, which shows that traffic clearly shifts and seeks away from the installations.

3.3 Variance amongst the installations

Looking at the variation across the seven installations in our study, as shown in Fig. 10, we see that all traffic passing within 500 m (GZ) stops once an installation arrives on location. Traffic passing outside the GZ but within 1000 m also declines significantly, with the biggest change for installation D, which goes from 31.0 to 0%, and at the other end of the spectrum, we find installation B, which goes from 18.0 to 6.5% traffic within this segment. Some of the explanation for the significant change at installation D may

Table 3 Total number of ships (across all locations) passing installation at various distances

		<GZ	GZ–1 nm	1–2 nm	2–3 nm	3–4 nm	Total
Total	Before	134	495	1109	1866	2837	6441
	After	0	178	1398	3073	7771	12,420

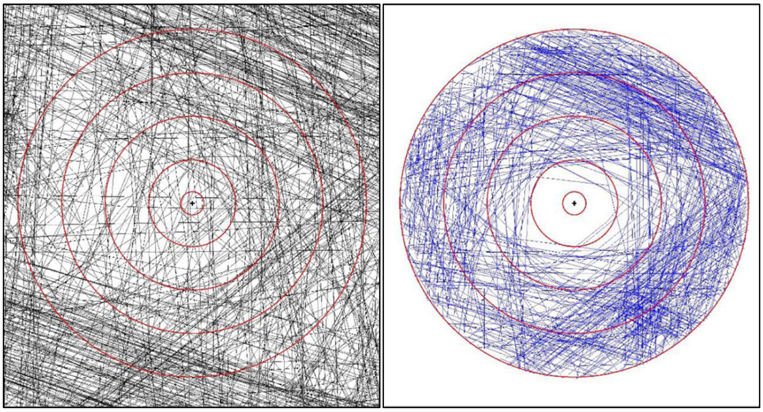


Fig. 7 AIS data of vessel traffic pattern, before (*left*) and after (*right*) introduction of installation on location

be due to additional measures implemented at this location, specifically designed to divert traffic away from the installation. However, the overall reduction is quite significant for all installations, and even the “worst” amongst them (installation B) has its traffic in this segment more than halved. In the third distance segment (1000–1500 m), the variance has two outliers, while the rest is fairly consistent. Installation A actually doubles its traffic in this segment, going from 30.4 to 60.0%, while installation F, on the other hand, goes from 20.0% traffic to 0. Installation A is located in an area with very few other offshore installations, and the geographical location together and a traffic composition with less variations with regard to vessel type and flag may explain why traffic around this installation is behaving somewhat differently compared to the other installations. Installation F had only five passings inside 2000 m in the before dataset and only one passing in the after dataset, which explains why the variance for this installation is so different. For the last segment (1500–2000 m), the number of passings for installation F actually went from 4 to 1, but the normalized results show an increase from 80% of traffic to 100% of traffic in this segment, due to the miniscule dataset. The biggest variance came from installation D, which is not surprising, since it had the biggest decrease in the second segment. Similarly, installation A had the lowest variance, as it had most of its change in the third segment. Overall, the changes in traffic in this segment were fairly consistent. Even though traffic reduction is observed in the 1–3-nm range too, the effect is most pronounced inside a 1-nm range.

3.4 Changes to traffic pattern

The results of this study show that traffic that naturally has a passing distance greater than 1 nm (1852 m) will mostly repeat its tracks and pay no heed to new obstacles that

Table 4 Normalized average number of ships (across all locations) passing installation at various distances

		<GZ (%)	GZ–1 nm (%)	1–2 nm (%)	2–3 nm (%)	3–4 nm (%)	Total (%)
Average (normalized)	Before	2.1	7.7	17	29	44	100
	After	0.0	1.4	11	25	63	100

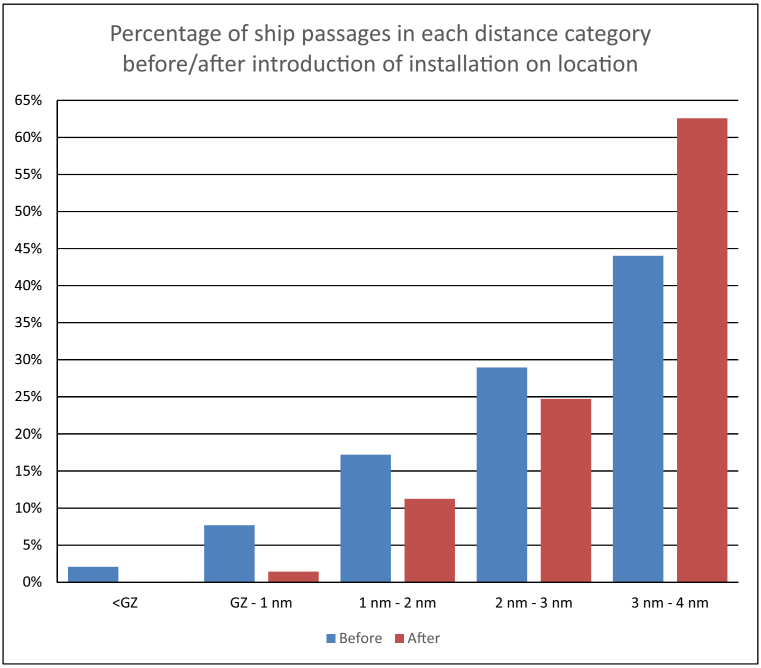


Fig. 8 Normalized results across all installations, before and after commissioning

appear 1 nm or more away from their course. However, traffic that suddenly finds a new obstacle within 1 nm of their intended track will alter course in order to achieve a passing distance close to 1 nm. The results in Fig. 10 could be interpreted such that these deviations vary considerably depending on local conditions around these installations and possibly aspects of the dominating traffic in the lanes around these installations, factors that are unknown unless an extensive effort could be invested to interview all relevant crews on these vessels regarding their manoeuvring around installations. One could perhaps expect to see differences in navigational behaviour around installations with heavier traffic density compared to those with lesser traffic density, but no such observations could be found in the data. Although there are differences between the installations, it is not possible to draw any conclusions based on traffic density. Other factors such as proximity to ports or special geographical areas could perhaps also have an effect on the navigational behaviour, but such things would have to be investigated in future research.

A quick regression analysis of the data in Table 5 shows that both exponential, power and polynomial (cubic) regression achieved R^2 values of 0.99, with the only

Table 5 Normalized average number of ships (across all locations) passing installation at distances inside 2000 m

		<GZ (%)	GZ - 1000 m (%)	1000–1500 m (%)	1500–2000 m (%)
Average (normalized)	Before	10.7	21.7	29.2	38.4
	After	0.0	2.2	20.6	77.3

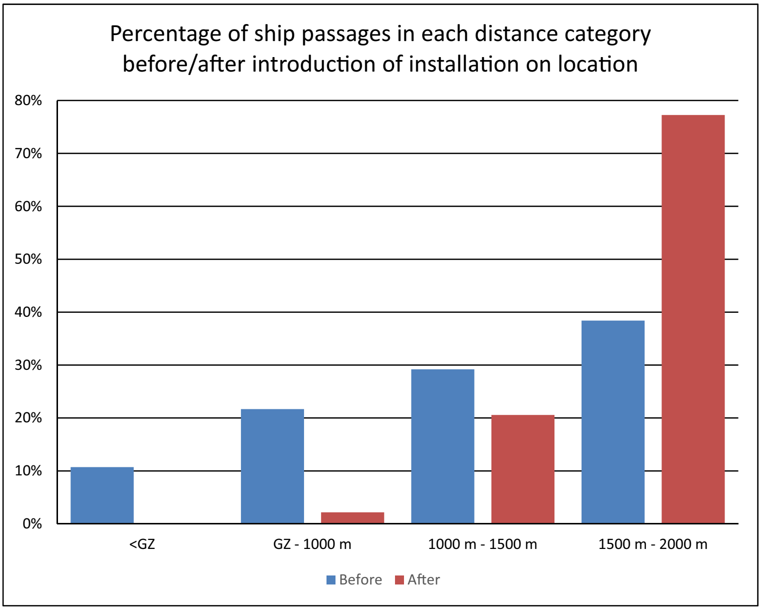


Fig. 9 Normalized results across all installations, before and after introduction on location, inside 2000 m

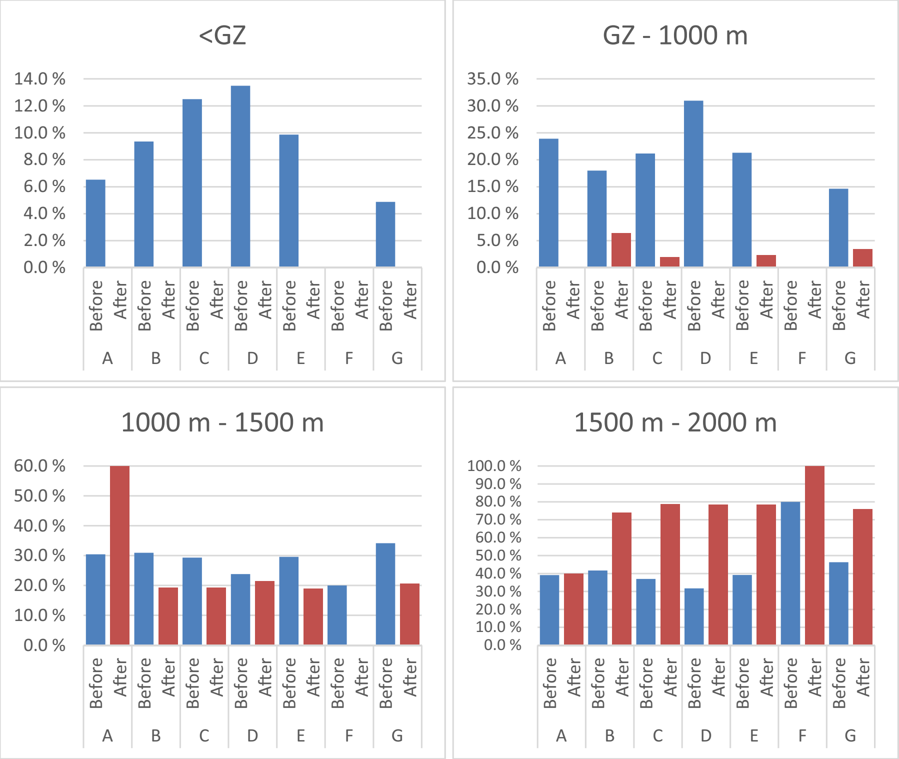


Fig. 10 Normalized results for all seven installations, before and after commissioning, inside 2000 m

difference between the different types found in the third decimal. The polynomial regression had the best fit within the dataset, which is shown in Fig. 11 but does not extended well beyond the dataset. The power and exponential regressions fit better outside the dataset, with a more consistent shape of the regression line. A more detailed regression analysis of a wider dataset could determine if a power or exponential function would fit best, but this has not been performed in this study.

4 Discussion

4.1 Data basis and applicability

This study has investigated all the production installations introduced on the NCS since 2010, amounting to seven new installations. The sample size may not be very large, but it is not feasible to extend the timeframe backwards, as archived AIS data from that far back are not readily available, and the timeframe already extends to the present day, making a larger timeframe very difficult. The geographical diversity of the sample size is deemed satisfactory, as it spans several key shipping lanes, seas and areas with different traffic volume and pattern. The distance between the installation furthest north and the installation furthest south is over 1000 nm, equivalent of the entire western seaboard of the USA.

It has been shown in Sect. 2.2 that the time periods vary considerably with respect to how long before and after installations that the datasets have been obtained. It was further shown in Sect. 2.2 that the effect of these differences would most likely be that the results of the analysis would be conservative.

The difference in the number of vessel passings does not invalidate the comparative study, because this can easily be solved by normalizing the results. Even if the comparison had been done using the same data source, one could expect a certain

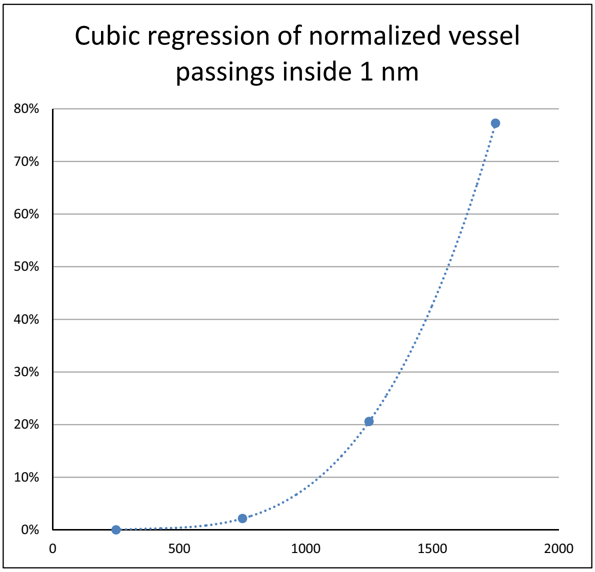


Fig. 11 Regression of normalized results across all installations, after introduction on location, inside 2000 m

variation in the total number of vessels/tracks/data entries. Any form of error, such as continuous tracks or cut tracks, should affect the data equally across the entire area, yet the presented results are clear. The sample of seven installations is spread across 5 years and with a significant geographical spread and a large variation in traffic density (from about 200 tracks to almost 4500, as seen in Table 1).

Seven installations are relatively few as a sample size, but there are no more installations available where AIS data may be established before and after installation. There are, as noted previously in Sect. 3.3, distinct variations between the extent to which the lanes deviate around an installation, depending on a lot of local factors and traffic aspects for each of the lanes around these installations. The average values established in the study should, on the other hand, be relatively representative.

The Norwegian Sea and North Sea have shipping lanes with levels of traffic that are highly comparable to busy waterways in other parts of Europe, so the majority of installations in the sample size are exposed to high levels of shipping traffic. Overall, the installations in this study have a good diversity regarding when they were introduced, installation type, geographical location, traffic exposure and other relevant attributes. The sample size could be increased by including installations on the neighbouring UKCS if access to (especially historical) UK AIS data had been possible, but we do not believe that the results would be different if additional installations from the UKCS had been included in the study. A way to improve the quality of the study would be to have access to AIS data from the same source for the before and after periods, but this would require long-term planning, exceeding the scope of this study. Using data from temporary exploration drilling installations, as done by Skarestad (2010), could increase the sample size of number of installations, as there has been on average about 50 exploration drilling operations each year since 2010 (NPD 2016). However, such operations are typically not very well documented and information about exact location and timeframe for the operations may be difficult to obtain on a large scale. These operations typically last about 3 months each, so it would be necessary to compare AIS data from an equivalent period before operations, with data from when these operations were ongoing, as opposed to before and after for the permanent installations studied in this article. If sufficient information about exact location and time periods could be obtained for a large set of exploration drilling operations, it could be interesting to see if the results from this study could be replicated with the temporary installations. However, mixing temporary and permanent installations in a joint dataset could be considered for future work.

It could be argued that all of the ships recorded in the present study are behaving responsibly; none of them pass inside the guard zone. These ships will never collide with an installation, at least as long as their navigational and propulsion equipment is intact. Those ships that pose a real threat are those that behave irresponsibly. There are anecdotal stories about ships that pass right through fields with several installations, sometimes fearsomely close to installations, without responding to radio calls and without performing evasive course actions. These are the real threats but may not be captured by statistics from ships behaving responsibly. But this is a generic complicating factor for all use of statistics in order to capture operational performance. It cannot be eliminated and therefore has to be kept in mind when making conclusions.

4.2 Comparison with other relevant studies

This study has demonstrated that shipping traffic adjust their sailing track when new offshore petroleum installations are commissioned, by generally altering course to achieve a passing distance of at least 1 nm. The results clearly show how the traffic moves away from the installations to achieve a passing distance of 1–3 nm.

The study by Skarestad (2010) did not find any clear indications that the number of vessels passing within 3 nm of the two installations in the study decreased and states that a passing distance of about 1 nm seems to be a natural passing distance. The study was limited to two temporary installations, only on location for 100 and 85 days and with reference periods before and after of 100 days.

Although the results by Skarestad are valuable, we consider that the aspects indicated previously can explain the apparent conflicting results; hence, there is no real conflict between the results presented here and by Skarestad (2010). Having a long timeframe for allision research is an important factor, as allisions (with non-field-related vessels) do not happen very often.

4.3 Use of the data and impact on the results of allision risk studies

Current allision risk assessments use AIS data “as is” when performing traffic studies that serve as input to risk assessment calculations. Meaning, they typically collect AIS data for a 12-month period, before an installation is placed in a location. Similarly to the data processing done in this study, all “field-related” or “irregular” traffic is typically filtered out, but the final traffic picture may have data implying that there is a shipping lane that intersects or has a passing distance of less than 500 m to the proposed installation location. Many analysts will blissfully disregard that the traffic currently passing so close to the intended position of the installation obviously will have to adjust their sailing track once the installation arrives on location. Hence, many risk assessments are in reality calculating the risk of allision towards an “invisible installation that has been on location for the past 12 months”. Performing risk assessments while ignoring how the introduction of an installation will affect the future traffic pattern in an area results in overly conservative risk estimates. While erring on the side of caution is the hallmark of risk analysis, it is important to understand the potential consequences of being overly conservative. With increasing activity in the maritime domain, inefficient use of limited sea space may lead to potential conflicts in areas that may be overdesigned in terms of navigational safety. As can be seen in Fig. 12, offshore petroleum installations are not small objects, and they will obviously have an impact on their surroundings and traffic in the area. This study has identified and described this effect, and this new knowledge should be incorporated into current and new allision risk assessment models. Moving a route with 15 ships in it, from 500- to 1000-m passing distance, reduces the allision probability from about 1.3E−03 to about 6.5E−04 with a standard deviation of 0.4 nm and to about 8.6E−05 with a standard deviation of 0.2 nm. This could very well prove to be decisive for the overall risk analysis, as the PSA’s acceptance criterion is 1.0E−04, and the results are very sensitive to changes in passing distance, standard deviation (COLLIDE assumes normal distribution for all routes) and number of ships in a route.

Fig. 12 The Goliat platform (photo by Eni[6])

The old COLLIDE allision risk model may adapt to the findings of this study by manually processing the initial AIS traffic study that serves as input to COLLIDE calculations, along the lines of the findings in this study. Manually adjusting the AIS data in such a manner has already been done occasionally, though only as an attempt to predict traffic patterns several years into the future and based solely on expert judgement. This study has shown empirically how traffic moves away from a new installation, if there used to be ships traversing the area. Future risk assessments using COLLIDE should incorporate these findings by default.

The new Bayesian allision risk model under development by the authors has already added elements to the model to account for the findings of this study. It will be able to use AIS data for areas with existing installations as is or adjust AIS data gathered from a location before an installation is introduced. Adjustments of AIS data will be made according to the findings of this study, where traffic is seen to withdraw outwards towards a passing distance of about 1 nm. This is done by adding a node ("AIS data gathered while installation is on location") to the Bayesian model, with two states, "yes" and "no". This node will then subsequently influence other nodes, such as "passing distance" and "probability of being on a collision course". One of the strengths of the new risk model and using a Bayesian network as opposed to fault trees used in COLLIDE is better ability and flexibility to incorporate new knowledge and research such as the findings from this study.

4.4 Influencing factors and historical development

The original COLLIDE model calculated that a certain percentage of ships passing in the vicinity of offshore installations would in fact be drawn towards them, as they used the installations as waypoints or to confirm their position (Haugen et al. 1994), as navigation aids at the time were of a very different quality than that of today. In addition to the natural evolution of navigation, Statoil established a vessel surveillance centre in 1997 (Statoil Marin, now called Statoil Operations Centre), tasked with monitoring all ship activity near Statoil's installations and hailing any vessels on a potential collision course (PSA 2012). Over time, mariners have learned that heading towards an installation will result in calls from Statoil Operations Centre (or an equivalent third party responsible for traffic surveillance), asking them to divert their course away from the installation. This type of traffic surveillance and hailing has proved very effective as a

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[6] http://www.wsj.com/articles/italys-eni-set-to-begin-arctic-oil-quest-even-as-others-abandon-field-1448274602

precautionary measure, as registered incidents with vessels on a potential collision course have been in general decline over the last decade. In 2004, 43 incidents of vessels on potential collision course were registered, while in 2014, only a single incident was registered (PSA 2014). This barrier could be a contributing factor to the repulsive effect that offshore installations seem to have on traffic patterns on the NCS.

4.5 Future research

While the Statoil Operations Centre has had a quantifiable effect on traffic patterns on the NCS, it would be interesting to investigate if other risk control options would have a similar effect. There are no Traffic Separation Schemes (TSS) in close proximity to offshore petroleum installations on the NCS, but investigating what effect a TSS, VTS (for merchant traffic) or Notice to Mariners would have on navigational behaviour would be an interesting topic for future research. Additional research to investigate the validity of the results from this paper for other areas, outside the NCS, should also be considered for future research. It would also be interesting to investigate similarities in navigational behaviour in countries without shore-based monitoring services, such as the Statoil Operations Centre. Would we find navigational behaviour similar to that on the NCS prior to the implementation of the Statoil Operations Centre?

The variations in the results between the different installations in this study should also be investigated further, to establish how local factors such as proximity to busy ports and traffic density influence the traffic patterns and navigational behaviour. Installation size, type and design may also influence local traffic, so a more detailed case study of individual installations or areas could be performed, to try to identify relevant factors influencing navigational behaviour more specifically.

5 Conclusion

This article compares the vessel traffic patterns for seven installations on the NCS, comparing the vessel installation passing distance found in AIS data before and after the installations were placed in their locations. The study shows that the current methodology of calculating allision risk with AIS data as is leads to overly conservative estimates of allision risk. Vessel traffic will adjust their sailing tracks when a new offshore oil and gas installation are commissioned, by generally altering course to achieve a passing distance of at least 1 nm. The research clearly shows how the traffic moves away from the installations to achieve a passing distance of 1–3 nm. At the same time, there is a small, but not insignificant, volume (1.43%) of ships inside 1-nm radius, but outside the guard zone of 500 m.

Inside a 2000-m radius, the results are even more apparent, with a reduction from 21.7 to 2.2% at a distance of 500 m (GZ) to 1000 m. These results indicate that an allision risk model could, for example, assume an exponential or power distribution of the probability that a vessel would increase its passing distance, based on initial AIS data. As it can be assumed that vessels seek outwards on all sides of an installation, it would be an axisymmetric distribution. As demonstrated by Rawson and Rogers (2015), the entire lane does not necessarily move away, but rather, the vessels closest to an installation move towards the outer perimeter of the lane, while the ships already there remain, thus "compressing" the lane towards the outer boundary rather than moving uniformly. This effect has been observed in our research also, as proximity to an installation is the strongest indicator of how much ships will move away. This behaviour may increase ship-ship collision risk, but in our case of open water navigation, there is always ample space on either side of shipping lanes for evasive manoeuvres. For other areas, where space is restricted, or traffic density is very high, ships might be less likely to perform corrective deviations away from an installation, as they may have nowhere to manoeuvre. This means that normalization in such cases may not accurately reflect navigational behaviour if one is comparing low-traffic-density installations to high-traffic-density installations.

This study has not observed traffic within 500 m (GZ) for any of the installations in the after scenario. This could be expected, as active barriers such as traffic surveillance and hailing are common for most installations. The results, however, also show that traffic with a passing distance of less than 1 nm is reduced significantly as traffic seeks away from new installations. Supported by the empirical documentation in this study, future allision risk assessments should incorporate the reduction in vessel traffic within a 1-nm passing distance, when using historical AIS data as basis for the calculations.

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Compliance with ethical standards

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