Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2015, 43 (115), 99–107
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)

Assessing the impacts to vessel traffic from offshore wind farms in the Thames Estuary

Andrew Rawson, Edward Rogers

Marico Marine, (Marine and Risk Consultants Ltd)
Bramshaw, Southampton, SO43 7JB, UK, e-mail: Andrew.Rawson@marico.co.uk

Key words: navigational safety, offshore, wind farms, AIS, vessel traffic, risk analysis

Abstract

The development of offshore renewable energy installations can introduce additional hazards to the safe navigation of shipping in often already crowded waterways. Developers and decision makers must predict and properly manage the potential risks imposed on navigating vessels from wind farm developments, in a complex and uncertain environment. Considerable analysis has been undertaken to model navigational risks to vessel traffic around wind farms; however this work is generally predictive and there is little understanding as to whether the modelling, central to the consideration of navigation safety, accurately reflects the post-constructed navigation risks. It is therefore important for decision makers to understand the uncertainties present in the analysis, both in terms of the assessment of risk and the implementation of any risk reduction measures. This paper presents a comparative analysis of the change in vessel traffic in the Thames Estuary before and after the construction of five offshore wind farms. The analysis demonstrates how the impact on vessel traffic is specific to the location of each development, driven by traffic management measures and other local constraints. Therefore the accurate modelling of this impact requires the input of experienced navigators, regulators and other knowledgeable stakeholders. The results of this analysis can be used to improve the predictive modelling of vessel traffic around offshore wind farms and other offshore installations, leading to a reduction in the uncertainty of vessel traffic modelling in the future.

Introduction

The development of Offshore Renewable Energy Installations (OREI) in the twenty-first century has placed a greater demand on space in increasingly crowded waterways and seas. Developments such as large offshore wind farms, as well as smaller wave, and tidal devices, inevitably overlap with other marine users; commercial shipping, fishing, oil and gas, leisure and environmental interests. When faced with applications to further develop marine energy, decision makers must make judgements between many stakeholder groups with conflicting values, often with great uncertainty on likely impacts.

Offshore wind farm sites are strategically selected to minimise their impacts upon existing marine users, which forms a core part of a government's marine spatial planning policy (Hajduk, 2009). In the United Kingdom (UK), much of the territorial seabed is owned by the Crown Estate, which leases potential areas for wind farms to developers who must then apply for consent. The zones for which a developer seeks consent are therefore preselected, the Department for the Environment and Climate Change and the Crown Estate have conducted several regional and national strategic environmental assessments (SEA) to identify locations for leases. These assessments identify exclusions which prohibit development, such as oil and gas, aggregates, international shipping lanes, and also constraints including other environmental and socioeconomic uses. One SEA treated a Traffic Separation Scheme (TSS) as a maximum constraint, and commercial, fishing and recreational traffic routes as a relative constraint (BMT Cordah, 2003). Furthermore, technological barriers have prevented offshore wind farm developers from placing turbines in deep waters and, as such, many inshore windfarms are generally located in shallow waters with low shipping densities.

In the UK, as part of an application for consent to construct and operate a wind farm, a developer is required to submit an Environmental Impact Assessment (EIA) under Section 36 of the Electricity Act. The EIA consists of a number of chapters covering all aspects by which a development may have impacts. One impact is that on navigational safety, overseen by the Maritime Coastguard Agency (MCA), whereby a developer "should evaluate all navigational possibilities, which could be reasonably foreseeable, by which the siting, construction, establishment and de-commissioning of an OREI could cause or contribute to an obstruction of, or danger to, navigation or marine emergency response" (MCA, 2008a). The Navigation Risk Assessment (NRA) is distributed among a number of statutory and non-statutory consultees who are invited to comment. Where a consensus is not reached the Department of Trade and Industry, Department for Transport and MCA weigh the evidence and make a recommendation to government ministers.

An NRA typically utilises a number of means to understand the potential impacts to navigation from the construction, operation and decommission of an offshore windfarm. These include qualitative methodologies such as hazard identification utilising local stakeholder engagement, and quantitative assessment methodologies including vessel traffic analysis, modelling and simulation at both system level and vessel level (e.g. full bridge simulation).

Vessel traffic analysis represents a cost effective approach to understand the baseline characteristics of shipping activity in the vicinity of a proposed offshore wind farm. Data can be collected from the Automatic Identification System (AIS) for commercial shipping, a radar survey for recreational and fishing vessels, or visual observations for smaller craft. The use of vessel traffic modelling and risk analysis forms a core part of many NRAs as a quantitative approach to assessing both baseline characteristics and possible impacts on navigational safety brought about by the proposed development.

However, for these models to be accurately applied and to produce meaningful results there needs to be a fundamental understanding of how the baseline traffic profile is likely to change post construction. Even minor discrepancies between modelled traffic routes and actual routes can have significant implications on the results of risk analysis. Without a process for reliably predicting this impact, decision makers may be misled by unreliable traffic models. With much of the attention and analysis performed prior to a development's consent being granted, there are few case studies available which contrast the initial and resulting traffic profile which would enable better prediction for future projects.

The purpose of this paper is therefore to provide a comparative analysis of vessel traffic before and after the installation of several wind farms in the Thames Estuary. A discussion of the changes in vessel routes and the underlying factors which have caused this is used to provide guidance to risk analysts in better understanding the impact of future wind farm projects.

Traffic modelling is a predictive activity and each of the developments studied made predictions on what the future traffic profile would be; however a retrospective analysis to compare those predictions against reality has rarely been conducted.

Navigational Safety of Wind Farms

Routeing Decisions around Wind Farms

Vessels navigate clear of a wind farm for the simple reason of avoiding collisions with turbines. The spacing between turbines is commonly such that it would not be prudent for a large commercial vessel to transit between turbines at distances of less than 1,000 metres, as this would place a significant constraint on the manoeuvrability of a vessel to avoid a collision or to correct for a human error or mechanical failure before contacting a turbine.

For vessels navigating around wind farms, there are three factors which dictate how they plan their passage. Firstly, the distance should be a comfortable buffer so that if an incident was to occur on board, or another vessel was encountered, there would be sufficient sea room to make an evasive manoeuvre.

Secondly, concerns have been raised over the visibility of a wind farm. Visually a wind farm may obscure smaller craft, such as recreational, fishing and maintenance vessels. If a sufficient clearance is given from the edge of the wind farm then there is more time to respond to a collision situation involving such craft. Furthermore concern has been raised regarding the impacts of wind turbines on marine radar. Reports of reflections, false echoes and other spurious effects have been seen when navigating near to a wind farm (MCA & QinetiQ, 2004). It is not the wind turbines themselves which create these effects; it is more often inadequate radar setup and configuration (Marico Marine, 2007). A vessel may therefore choose to navigate further from a wind farm to reduce these effects and improve their situational domain awareness.

Finally, the safety distance a vessel chooses to navigate around a wind farm is weighed against commercial pressures associated with additional distance, fuel and passage time requirements. In general, and where no other constrains are present, commercial shipping typically follows straight routes between waypoints to reduce transit time and fuel costs. Additional deviations from this route to pass obstacles increases costs and may make some routes uneconomical (Toke, 2010).

A further impact of offshore wind farms on navigational safety is the change in collision risk as a result of the concentration of vessel routes. If a wind farm is located adjacent to another navigational constraint, or adjacent to another wind farm, then vessels transiting in between have reduced room in which to manoeuvre to avoid a collision, often referred to as "choke points" (MCA, 2008).

Vessel Traffic Risk Analysis of Wind Farms

The increasing availability of AIS in particular has led to the development of a considerable number of tools and techniques for modelling traffic risk. These include statistical analysis of vessel activity, geometric analysis of vessel routes (Christensen et al., 2001; Mazaheri & Ylitalo, 2010; Wawruch & Stupak, 2011) and more computational time domain models which have been used throughout the industry for several decades (Fujii & Tanaka, 1971; Goodwin, 1975; Pietrzykowski & Uriasz, 2009, Rawson et al., 2014). A number of these techniques are routinely used within NRAs in support of wind farm developments, however, much of this analysis is predictive requiring judgements on future traffic routes. Given the high sensitivity of the analysis results to the input traffic route configuration, accurate prediction of this input is essential.

Much of the academic research has focused on risk modelling techniques and tools with little focus on the correct prediction of traffic routes. Where research has sought to model the change in risk of a future development, one nautical mile is often given as a distance between the new vessel route and the wind farm boundary (Weintrit et al., 2012).

Industry Guidance

Much of the analysis and guidance provided for safe passing distances from offshore wind farms has been industry led. One of the most significant efforts to categorise the safe passing distance of shipping from a wind farm was established by the MCA in 2004 in response to new developments in the Greater Wash area of England (MCA, 2008a). The template defines a shipping route as 90% of the lateral distribution of vessel transits and comments on the acceptability of the distance from this route to the offshore wind farm. The distances are based upon domain theory, a safety buffer around a navigating vessel, and the impacts of turbines on radar. Distances from turbines are given the following "risk classification":

- 0 to 0.45 nm is intolerable – significant impacts upon radar and navigational risks;
- 0.45 to 2 nm is tolerable – medium/high risk – based on collision regulations and ship domains. 1 nm is the minimum acceptable distance to the boundary of a TSS;
- 2 nm to 3.5 nm is tolerable – low risk;
- > 3.5 nm – very low risk.

This guidance was adapted as part of the Atlantic Coast Port Access Route Study (ACPARS) conducted by the US Coastguard (USCG) from 2011 which sought to determine whether existing and projected uses of waterways required alterations to routeing measures (USCG, 2012). Areas were characterised based on the proximity to shipping routes as Red (< 1 nm), Yellow (1–2 nm) or Green (>2 nm). This would act as an indication of where should and should not be further developed for offshore renewable energy. The working group however was unable to "predict changes in traffic patterns or determine the resultant change in navigational safety risk given different siting scenarios of offshore renewable energy installations" (USCG, 2012: i).

The limitations of the ACPARS study were expanded on by the Pacific Northwest National Laboratory (2014) by modelling the change in vessel traffic following offshore wind developments and analysing the change in risk profile. Whilst the report does not explicitly state what figure they modelled as the distance vessels choose to navigate off a wind farm, a review of the outputs suggests that a 5 nm offset was chosen.

The UK NOREL working group estimates that 2 nm should be given between a shipping lane and a wind farm boundary (Nautical Institute et al., 2013). Where a shipping lane is located in between two wind farms, the minimum distance should be a buffer of 2 nm to port, 6 boat lengths for vessel navigation and a buffer of 2 nm to starboard. Guidance from the Netherlands however, provides a template for developers suggesting a turning circle of 6 boat lengths and a safety buffer of 500 metres from the edge of a shipping lane. This provides sufficient space between a navigating vessel and the wind farm to avoid a collision or rectify a mechanical failure before a collision occurs. For major shipping routes this may be up to 1.5 nm.

A UK guidance document for assessing the risks of offshore wind farms does not provide a single figure and suggests that judgements must be made regarding the relocation and distribution of routes. Where a route intersects a wind farm, the modelled route should consider "the origin and destination of traffic, navigable water space and the presence of other obstructions" (DTI, 2013: 100).

NRAs undertaken for individual developments often contain traffic modelling with predicted passing distances, the majority of which are one nautical mile, with an unspecified lateral distribution from the centreline of this route. The impact assessment for Navitus Bay modelled commercial traffic as leaving 1 nm between the wind farm boundary and their route, although ferry operators expressed a preference for a 2 nm passing distance during consultation (Anatec, 2014). Similarly, the Triton Knoll impact assessment modelled a passing distance of 1 nm (Strategic Marine Services, 2011). The NRA for the Thanet Offshore Wind Farm, used a minimum distance of 500 metres, however, each vessel route was modified using new waypoints identified by master mariners through consultation between 0.5 and 1 nm from the site boundary (Marico Marine, 2005).

Alternative guidance is also provided to shipping companies and navigators in how they should passage plan around a wind farm. For example, MGN 372 states that "where adequate safe water exists it may be prudent in planning the voyage of larger vessels to set tracks at least 2 nm clear of turbine fields" (MCA, 2008b). Similarly guidance from Steamship Mutual (2009: 3) states that it "would be prudent for vessels when engaged in passage planning to lay off courses at least 2 nautical miles clear of wind farms".

Methodology

Study Area

The study areas of this analysis are those wind farms within the Thames Estuary of the UK. The Thames Estuary comprises of the southern North Sea approaches to a number of important ports in the South East of England including Felixstowe, Harwich and the Port of London. The area is navigationally complex with numerous sand banks and other dangers to shipping. Navigation is therefore strongly regulated and controlled with buoyed routes, pilotage and cover by Vessel Traffic Services (VTS).

This area was also one of the first development zones for offshore wind in the world with a capacity of more than 1,700 Megawatts (MW). The locations of the wind farms under study are shown in Figure 1.

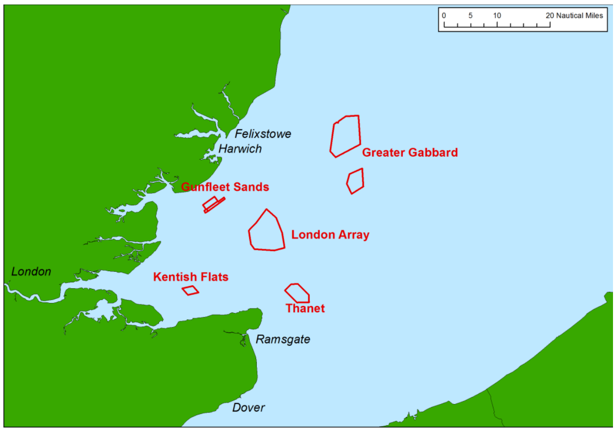

Figure 1. Location of Thames Estuary Wind Farms

Data Sources

Data from vessel traffic surveys and shore based AIS listening stations was collected to represent both pre and post construction of five different windfarm sites, located in the Thames Estuary. Each dataset is one month in duration to provide comparison between multiple data sources, and provide a snapshot of traffic flow. The compiled datasets were processed and presented using a Geographic Information System (GIS). A comparison of the date extents and the commissioning dates are shown in Table 1.

Table 1. Study Wind Farms

Site Name	Date of Commissioning	1^{st} Dataset	2^{nd} Dataset
Greater Gabbard	2012	2006	2013
Kentish Flats	2005	2004	2013
London Array	2013	2006	2013
Thanet	2010	2005	2013
Gunfleet Sands	2010	2006	2013

This study focuses primarily on the impacts upon third party navigating vessels and therefore vessels engaged in maintenance or construction activities associated with that particular development have been removed from the analysis. The risk of collision with these vessels is a prominent hazard, however this is not considered as part of this study.

Furthermore, the use of AIS data alone for this analysis limits the applicability of this study to smaller vessels such as fishing and recreational craft that are not mandated to carry AIS. The collection of data is often conducted as part of the pre-consent NRA, however no comparable datasets exist post construction to enable a comparative analysis.

Results

The development of the Greater Gabbard Offshore Wind farm was planned for the site of two shallow shoals near to high density shipping routes. Little traffic intersected the site due to the shallow water depths; however several high density shipping routes passed within 0.3 nm of the site boundary. To better manage the risk of increased vessel traffic in the Thames Estuary, particularly those vessels of a deep draught, and the construction of the wind farm, the Sunk Traffic Separation Scheme (TSS) established a two way scheme around the Greater Gabbard shoals.

The impact of the introduction of the TSS during the construction of the wind farm resulted in a significant change in the traffic flow around the wind farm boundary (Figure 2). A one nautical mile separation zone to the south and west of the northern section created a safety buffer for navigating vessels. Elsewhere around the site cardinal marks were used at a distance of one nautical mile from the windfarm to provide a secondary boundary. The activity of fishing vessels is also apparent immediately to the east of the northern site.

The Thanet Wind Farm also used cardinal marks as a mitigation measure to divert vessel traffic around the development (Figure 3). The proposed site was located in an area often transited through by vessels, located near to the Dover Straits and the ports of London, Harwich and Felixstowe.

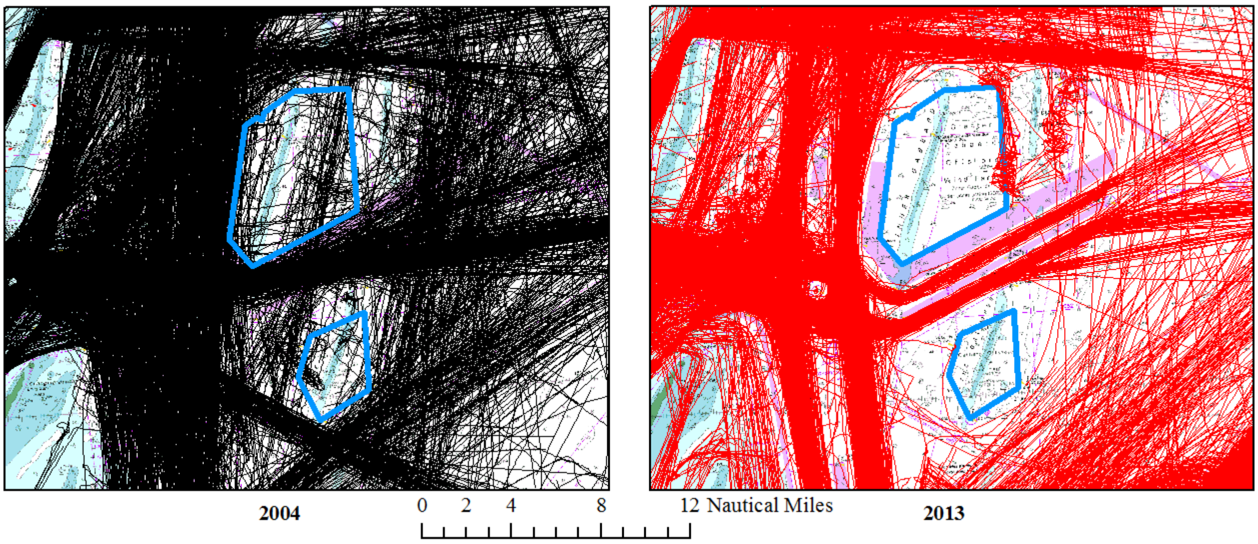

Figure 2. Comparison of vessel traffic at Greater Gabbard Wind Farm

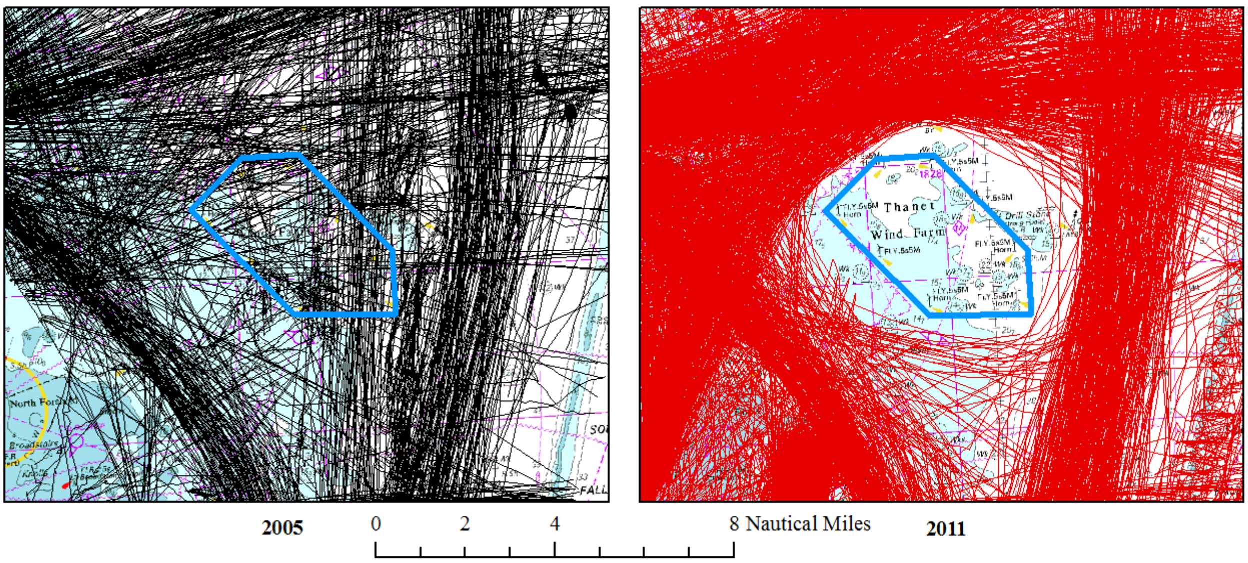

Figure 3. Comparison of vessel traffic at Thanet Wind Farm

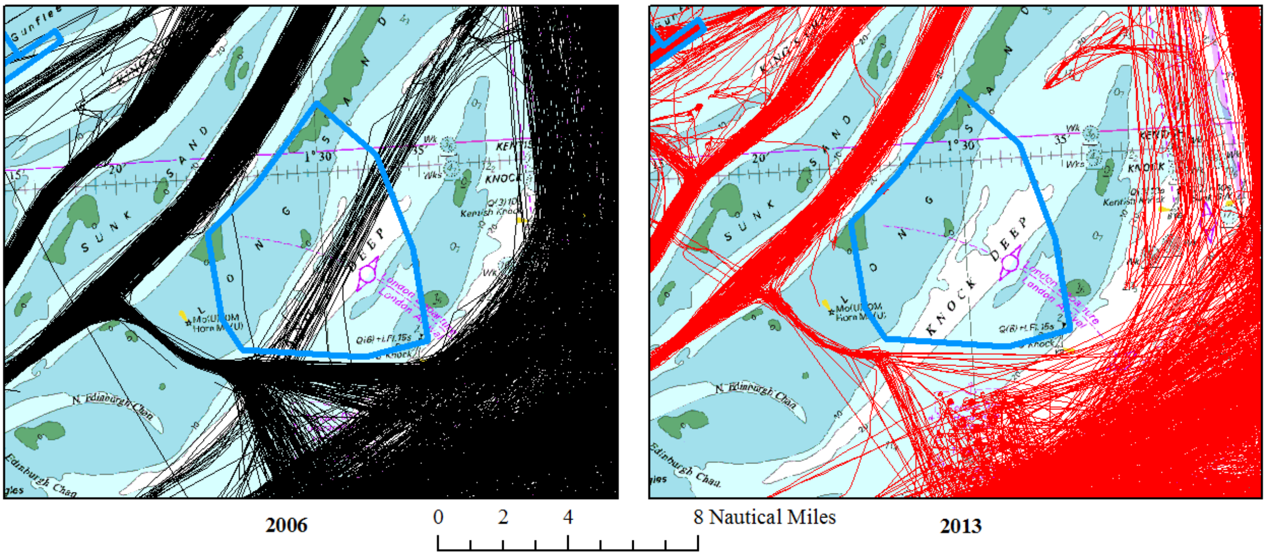

Figure 4. Comparison of vessel traffic at London Array Wind Farm

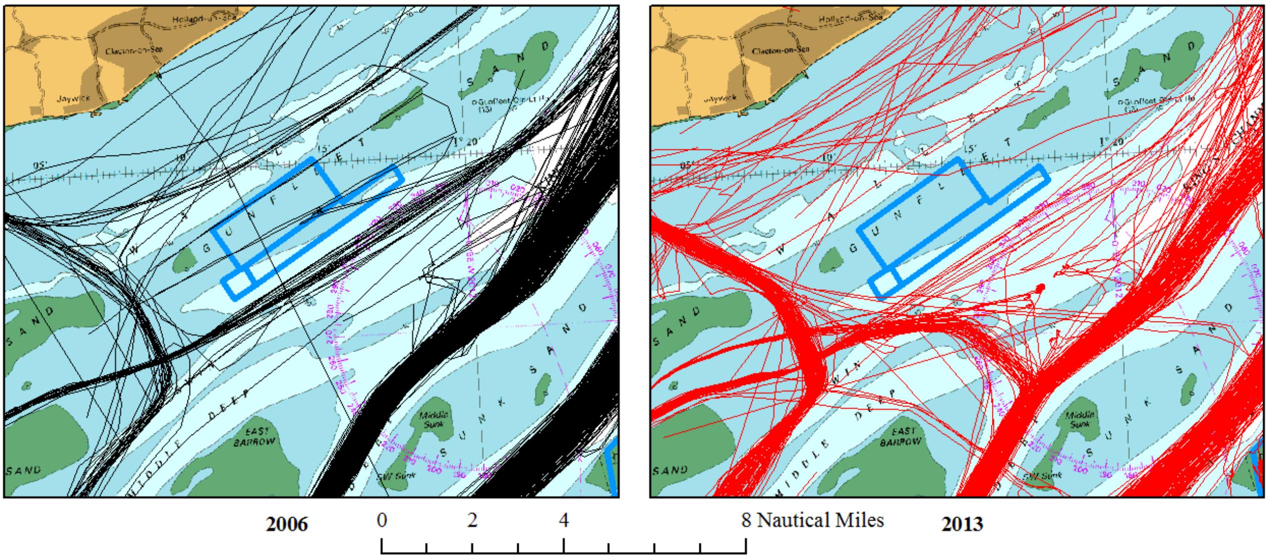

Figure 5. Comparison of vessel traffic at Gunfleet Sands Wind Farm

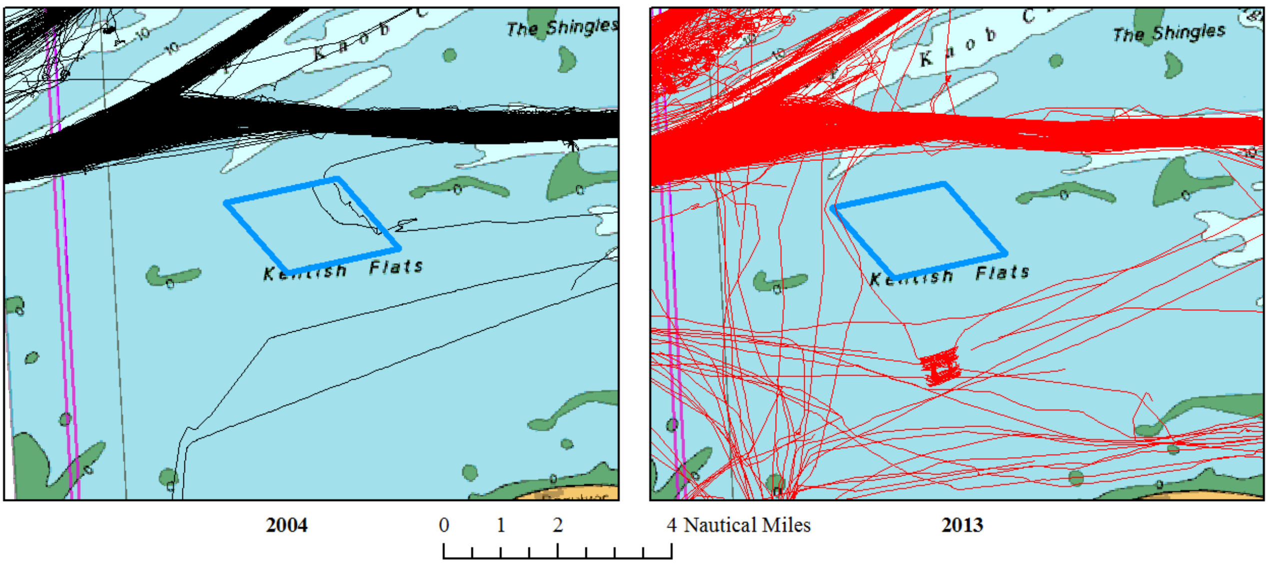

Figure 6. Comparison of vessel traffic at Kentish Flats Wind Farm

Two cardinal marks are strategically placed to the east and north of the site and they have the effect of changing the routing of vessel traffic in the area. The northern cardinal keeps much of the shipping bound for the Thames clear from the northern limits of the site by one nautical mile. For vessel traffic to the east, originating from the Dover Straits, the cardinal mark predates the wind farm's construction marking both the Drill Stone shallows hazard and acting as a turning point for vessels transiting northwest. Vessel traffic to the northwest originating from Ramsgate, where no marks are used, transits between 0.5 and 1 nm from the site.

The remaining wind farms at the London Array (Figure 4), Gunfleet Sands (Figure 5) and Kentish Flats (Figure 6) were all developed in areas of low shipping density, with large commercial vessels already constrained by physical access such as insufficient depth. The use of early marine spatial planning to select sites away from shipping routes is the most effective measure for reducing the impact of the development on navigational safety. For a number of early wind farms, technological constraints required the use of shallow water depths to install and maintain wind turbines effectively. These locations, located atop of existing navigational hazards, are generally away from main shipping routes and the impact is therefore minimal. As these constraints are overcome it is expected that offshore wind farms will move into deeper waters leading to greater conflicts with the safe navigation of shipping.

London Array was sited adjacent to the Black Deep channel to the Port of London and north of the main Princes Channel. Many of the larger commercial vessels transited clear of the site and therefore no additional mitigation was implemented. Those vessels which used this channel prior to the construction were exclusively aggregate dredgers.

Gunfleet Sands Offshore Wind Farm is located on the Gunfleet Sands bank to the north of the Kings Channel. The area of development was also clear of the main shipping routes. Similarly Kentish Flats was located more than a mile to the south of the Princes Channel route into the Thames and there is little evidence of any impact upon traffic flow.

Discussion

The analysis of the wind farms in the Thames Estuary show a range of impacts upon vessel traffic profiles and different management strategies employed to manage any additional risk imposed on navigating vessels. Several of the sites have been planned completely clear of the main shipping routes, however, where the installations do interact with routes, the use of traffic separation schemes and cardinal marks have resulted in significant alterations to marine traffic flow and therefore navigational safety. The use of cardinal marks is common during construction periods, when turbine structures are either unmarked or not fully commissioned to keep the waterway clear of shipping.

There are three significant inputs required to model the change in vessel traffic around the development. Firstly, the route of vessel traffic – how a vessel passes a wind farm. Secondly, the offset of the vessel traffic – how far from the development is the Closest Point of Approach (CPA) of the desired route. Finally, the distribution of the vessel traffic, a measure of the spread of the traffic across this route should also be considered.

The routeing of vessel traffic can be described as how a vessel chooses to navigate around a wind farm. As part of the passage plan, a navigator takes into account the local conditions, obstacles, bathymetry, local regulations and many other factors before deciding where to mark waypoints. When faced with an obstacle to avoid, provided there is adequate water or no other restrictions, a vessel would choose the shortest route around a wind farm.

The offset is a measure of the CPA a navigator chooses to place their waypoint from the boundary of the wind farm site. Vessels transiting too close to the boundary of a wind farm risk colliding with the structures or another vessel as a result of a mechanical failure, by having insufficient time to react to a developing situation, experiencing radar anomalies or by failing to identify smaller craft among the turbine structures. Assuming a navigator wishes to reduce the deviation of their course to minimise transit time, this variable represents a comfort factor on mitigating these aforementioned risks.

The use of traffic management controls in the Thames Estuary is aimed at offsetting the distance of shipping from the wind farms by one nautical mile in all cases. It can therefore be inferred that both the developers and the regulator see one nautical mile as a safe passing distance from an offshore wind farm to mitigate the risks associated with navigating near to wind turbines. It should however be noted that vessel traffic navigating near to the Thanet Wind Farm was recorded at 0.5 nm distance. The crew of some vessels therefore feels that it is safe to pass at half the distance thought safe by regulators. Further study of other wind farms, without traffic control measures, would yield a greater understanding of the perceived safety distance by passing merchant shipping.

The distribution of vessel traffic also compresses as it passes these obstacles and especially associated buoyage, as navigators attempt to reduce the distance sailed whilst maintaining a suitable passing distance off the obstruction. Shipping lanes in many analyses are modelled using uniform or normal (Gaussian) distributions, as is often evident in traffic separation schemes (Wawruch & Stupack, 2011). A number of nautical traffic models use the track distribution to model grounding and structure contact risks (Mazaheri & Ylitalo, 2010) and the results are therefore sensitive to the input modelling of traffic distribution.

In the absence of other obstacles, the vessel traffic analysed here shows a much more skewed distribution. To demonstrate this, gates were created across the adjacent shipping routes at the Thanet wind farm to investigate the distribution of traffic. A gate is a linear transect placed perpendicular to a traffic flow, with regular frequency counts of the direction and number of passing vessels used to create a frequency distribution. The results show that shipping is choosing to pass close to the marks in both directions, increasing traffic density in the immediate vicinity. The use of mitigation around wind farms may therefore have implications for collision modelling as vessel routes are concentrated. An assessment of navigation risk may therefore conclude that the collision risks associated with the resulting alteration of vessel routes is greater than the risks associated with vessels contacting with turbines. The accurate characterisation of this effect should be included in predictive traffic modelling around wind farms for the modelling of collision risk, through, for example, safety domain analysis.

Conclusions

Accurate traffic flow prediction is a vital input into risk modelling; with sensitive models even minor discrepancies can result in significant differences in the results of the analysis. Analysis should not only consider the risks associated with vessels contacting turbines, but the wider impacts on navigational safety including the creation of localised areas of high vessel density and the associated collision risks, as well as the relocation of vessel routes near to other navigational hazards. The use of mitigation measures such as buoyage to control traffic flow may have little impact on navigational safety by transferring the reduced risk of turbine contact to an increased risk of vessel collision.

The comparison of vessel traffic in the Thames Estuary before and after the development of several offshore wind farms shows that the impacts of the

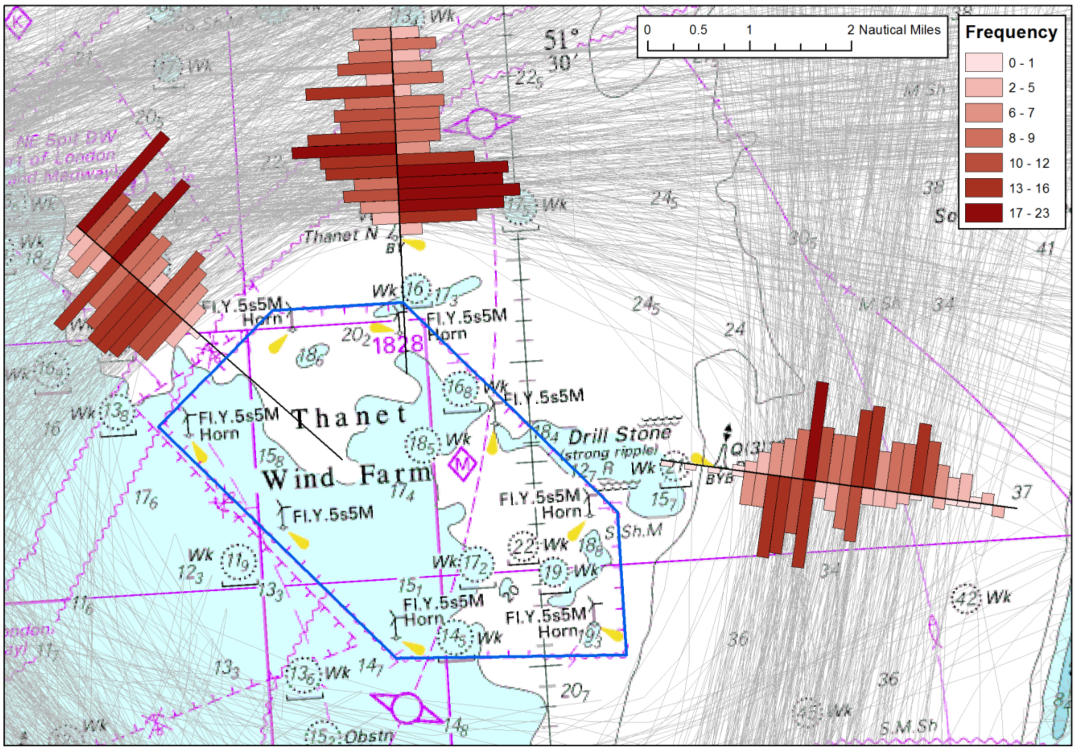

Figure 7. Vessel transit gates at Thanet Wind Farm after construction

development are idiosyncratic; unique to the situation, traffic profiles and navigational constraints of that particular development. Several of the wind farms are sited in areas of minimal vessel traffic and therefore the impacts on navigation are minor, demonstrating the importance of marine spatial planning. Furthermore, the use of traffic management measures associated with the development such as TSS or buoyage has a significant impact on vessel routeing which must be included in any traffic modelling. Engagement with developers, stakeholders and regulatory bodies throughout the consenting process is therefore necessary. In the absence of traffic management, the model should consider not only the development itself but also the presence and interaction with other navigational constraints. The guidance and input into traffic modelling of experienced navigators, local harbour masters and other knowledgeable stakeholders is essential in properly incorporating these factors.

References

1. Anatec (2014) *Navitus Bay Wind Park: Technical Appendix Volume B – Chapter 16 – Shipping and Navigation*. [Online] Available from: http://infrastructure.planningportal.gov.uk/projects/south-east/navitus-bay-wind-park/. [Accessed 13 March 2015]
2. BMT Cordah (2003) Offshore Wind Energy Generation: Phase 1 Proposals and Environmental Report. Cordah/ DTI.009.04.01.06/2003.
3. Christensen, C.F., Andersen, L.W. & Pedersen P.H. (2001) Ship collision risk for an offshore wind farm. in: *Structural Safety and Reliability: Proceedings of the Eighth International Conference, ICOSSAR'01*. Newport Beach, USA, 17–22 June 2001.
4. Department of Trade and Industry (2013) Methodology for Assessing the Marine Navigational Safety & Emergency Response Risks of Offshore Renewable Energy Installations (OREI). Department of Trade and Industry.
5. Fujii, Y. & Tanaka, K. (1971) Traffic Capacity. *The Journal of Navigation*. 24. pp. 543–552.
6. Goodwin, E.M. (1975) A statistical study of ship domains. *The Journal of Navigation*. 28. pp. 328–344.
7. Hajduk, J. (2009) Safety of Navigation and Spatial Planning at Sea. *TransNav: International Journal of Marine Navigation and Safety of Sea Transportation.* 3. pp. 261–266.
8. Marico Marine (2005) Thanet Offshore Wind Farm: Navigation Assessment. Thanet Offshore Wind Ltd.
9. Marico Marine (2007) Investigation of Technical and Operational Effects on Marine Radar Close to Kentish Flats Offshore Wind Farm. British Wind Energy Association.
10. Maritime and Coastguard Agency (2008a) Offshore Renewable Energy Installations (OREIs) – Guidance on UK Navigational Practice, Safety and Emergency Response Issues. MGN 371 (M+F).
11. Maritime and Coastguard Agency (2008b) Offshore Renewable Energy Installations (OREIs) – Guidance to Mariners Operating in the Vicinity of UK OREIs. MGN 372 (M+F).
12. Maritime and Coastguard Agency and QinetiQ (2004) Results of the electromagnetic investigations and assessments of marine radar, communications and positioning systems undertaken at the North Hoyle wind farm by QinetiQ and the Maritime and Coastguard Agency. MCA MNA 53/10/366.
13. Mazaheri, A. & Ylitalo, J. (2010) Comments on Geometrical Modeling of Ship Grounding. in: *5th International Conference on Collision and Grounding of Ships*, Espoo, Finland, 14–16 June 2010.
14. Nautical Institute and World Ocean Council (2013) *The Shipping Industry and Marine Spatial Planning: A professional approach*. [Online] Available from: http://www.nautinst.org/en/forums/msp [Accessed 8 April 2015]
15. Pacific Northwest National Laboratory (2014) *Risk Assessment for Marine Vessel Traffic and Wind Energy Development in the Atlantic*. [Online] Available from: http://tethys.pnnl.gov/sites/default/files/attachments/Nav-Risk-Final-9.2014.pdf [Accessed 09 April 2015]
16. Pietrzykowski, Z. & Uriasz, J. (2009) The Ship Domain – A Criterion of Navigational Safety Assessment in an Open Sea Area. *The Journal of Navigation*. 62. pp. 93–108.
17. Rawson, A., Rogers, E., Foster, D. & Phillips, D. (2014) Practical Application of Domain Analysis: Port of London Case Study. *Journal of Navigation*. 67. pp. 193–209.
18. Steamship Mutual (2009) *Navigation in the Vicinity of Offshore Renewable Energy Installations*. [Online] Available from: www.steamshipmutual.com/Risk-Alerts/RA02Navigation OREI.pdf [Accessed 2 April 2015]
19. Strategic Marine Services Ltd (2011) *Triton Knoll Offshore Wind Farm: Marine Navigational Safety Risk Assessment*. [Online] Available from: http://infrastructure.planningportal.gov.uk/projects/east-midlands/triton-knoll-offshore-wind-farm [Accessed 13 March 2015]
20. Toke, D. (2010) The UK offshore wind power programme: A sea-change in UK energy policy? *Energy Policy*. 39(2). pp. 526–534.
21. United States Coastguard (2012) Atlantic Coast Port Access Route Study Interim Report. USCG-2011-0351.
22. Wawruch, R. & Stupak, T. (2011) Modelling of Safety Distances Between Ships' Route and Wind Farm. *The Archives of Transport*. 23. pp. 413–420.
23. Weintrit, A., Neumann, T. & Formela K. (2012) Some Problems of the Offshore Wind Farms in Poland. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*. 6.