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Anholt Offshore Wind Farm

Analysis of Risks to Ship Traffic

December 2009

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Reviewed by MHOP/LEAC/AGL
Approved by LWA

Rambøll Olie & Gas
Teknikerbyen 31
2830 Virum
Denmark

Telefon +45 4598 6000
www.ramboll-oilgas.com

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Abbreviations

AIS – Automatic Identification System

ALARP – As Low As Reasonably Practical

DHI – Danish Hydraulic Institute

DMA – Danish Maritime Authorities

DaMSA – Danish Maritime Safety Administration

DP – Dynamically Positioned

EFR – Expected Future Route

EfS – Efterretninger for Søfarende

FSA – Formal Safety Assessment

GBS – Gravity Based Structure

HOB - Head on Bow

IMO – International Maritime Organisation

NSC – National Survey of Cadastre

OOW – Officer Of the Watch

RACON – Radar Beacon

ROV - Remotely Operated Vehicle

UTM – Universal Transverse Mercator

VMS – Vessel Monitoring System

VTS – Vessel Traffic Service

1. Summaries

1.1 Dansk resumé

Ændringer i sejladssikkerheden som følge af Anholt havmøllepark-projektet er blevet vurderet.

De nuværende skibstrafikruter i nærheden af undersøgelsesområdet inklusive to færgeruter (Grenå-Anhot og Grenå-Varberg) er blevet identificeret og grundigt beskrevet. Søfartsstyrrelsen arbejder for tiden på en omlægning af de eksisterende trafikruter i Danmark, herunder ruter i området mellem Anholt og Djursland. Omlægningen af ruterne vil tidligst træde i kraft i år 2013 og den præcise placering af nye ruter er endnu ikke fastlagt. Gennem kommunikation med maritime myndigheder er det blevet fastslået at to trafikruter, der på nuværende tidspunkt krydser gennem undersøgelsesområdet, forventes at blive nedlagt og at en ny traffikrute vil blive introduceret tre sømil vest for undersøgelsesområdet. Denne fordeling af ruter danner grundlag for analysen i denne rapport.

To færgeruter krydser på nuværende tidspunkt undersøgelsesområdet. På baggrund af Energistyrelsens udmeldinger er basis for analysen at begge færger vil blive omlagt således at der sejles syd om undersøgelsesområdet efter etablering af havmølleparken.

En matematisk model baseret på undersøgelsesområdets karakteristika (vind, mølle layout etc.) og skibstrafik information er blevet anvendt til at estimere frekvensen af skib-mølle kollisioner. Følgende scenarier er inkluderet i modellen:

- Head on Bow (HOB) kollision indtræffer hvis et skib er direkte på kollisionskurs med en vindmølle og ingen undvigelsesmanøvrer udføres. Denne kollisionstype betegnes også kollision som følge af menneskelig fejl.

- Drivende skibskollision indtræffer hvis et fartøj pga. sammenbrud i fremdriftsmaskineriet driver ind i en vindmølle.

- Knæk-i-rute kollision indtræffer hvis et fartøj forsømmer at dreje når en rute har et knæk og efterfølgende kolliderer med en forhindring.

- Kollision som følge af fejl i styresystemet indtræffer hvis roret sætter sig fast i en yderposition. Fartøjet vil efterfølgende foretage en cirkulær bevægelse, der kan føre til kollision.

Det er antaget at risici relateret til skib-skib kollisioner ikke vil blive påvirket af oprettelsen af havmølleparken. Sammenlignet med den nuværende situation bør det planlagte nye rute layout, forventet indført i 2013, generelt øge sejladssikkerheden og være konstrueret med havmølleparken for øje.

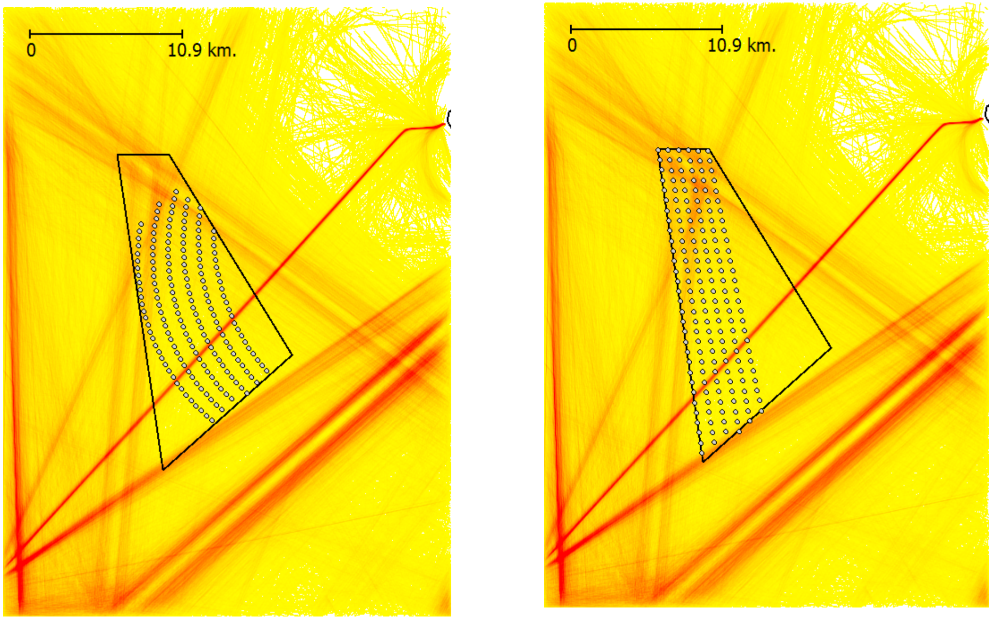


Figure 1-1. Vindmølle layout Arcs 2.3 (venstre) og Radials 2.3 (højre). Størrelsen af de enkelte møller er overdrevet for at tydeliggøre tegningen.

Frekvensanalysen estimerede en returperiode for skib-mølle kollisioner på 172 år for vindmølle layoutet radials og 217 år for vindmølle layoutet arcs (Se Figure 1-1). Acceptkriterier opstillet af Søfartsstyrelsen placerer disse resultater i ALARP-området, hvor en mere detaljeret risikoanalyse er påkrævet.

Risikoen for påvirkninger af miljøet i form af olieudslip og risikoen for tab af menneskeliv blev vurderet for begge vindmølle layouts og sammenholdt med relevante risikoacceptkriterier.

Risikoen forbundet med olieudslip blev vurderet ved hjælp af en risikomatrix. Både risikoen for betydelig, alvorlig og katastrofal påvirkning af miljøet blev fundet at være acceptable i forhold til de opstillede acceptkriterier.

Risikoen forbundet med katastrofal påvirkning af miljøet blev vurderet acceptabel fordi den estimerede returperiode for katastrofal påvirkning var meget høj. En vigtig antagelse i analysen er at en kritisk kant (se sektion 11.1.2) på et gravitationsfundament ikke er placeret højere end 1 m. over havbunden. Højden på den kritiske kant er relevant i forhold til et scenarium, hvor et skib kolliderer med et mølle fundament og skroget bliver revet op af en skarp kant på et havmøllefundament (Slide-along-collision). Hvis den valgte type af gravitationsfundamenter har skarpe kanter der er placeret højere end 1 m. så er den nærværende analyse ikke fyldestgørende. Det er så overladt til koncessionstageren at vise at den valgte løsning er kollisionsvenlig. Kravet om kollisionsvenligt design er primært rettet mod de mest eksponerede rækker af møller. De mest eksponerede møller er den første række af møller tættest på A- og EFR-ruten.

Risikoen for tab af menneskeliv er vurderet ud fra den mest udsatte person på henholdsvis et passager skib og et fragt- eller tankskib. Den individuelle risiko for et besætningsmedlem på tank- eller fragtskib eller en person på et passager skib er fundet acceptabel i forhold til de opstillede kriterier.

Der er givet anbefalinger til sikkerhedsforanstaltninger, der vil øge sejladssikkerheden i området under driftsfasen af Anholt havmøllepark. Blandt andet er det anbefalet at forbudszonen, der etableres under konstruktionsfasen, fastholdes indtil det nye trafikrute layout er blevet effektueret.

Nærværende rapports fokus er driftsfasen. Udarbejdelsen af en risikoanalyse i forhold til anlægsfasen bør pålægges koncessionstageren. Dette skyldes at væsentlige forhold i analysen afhænger af den pågældende entreprenørs konstruktionsteknik. Et helt centralt forhold er f.eks. hvilken havn byggematerialer udskibes fra eller om materialer transporteres til området direkte fra producenten. Desuden vil forskellige typer af konstruktionsfartøjer kræve længere eller kortere tid på stedet og dermed have forskellige påvirkninger på den almindelige skibstrafik.

Krav om analyse af forholdene i anlægsfasen vil blive fremsat af Søfartsstyrelsen når projektet er konkretiseret.

1.2 English summary

The risks to the maritime traffic due to the proposed Anholt Offshore Wind Farm have been assessed.

The current ship traffic routes including the two main ferry routes (Grenå-Anholt and Grenå-Varberg) in the vicinity of the project area have been identified and described thoroughly. Maritime authorities in Denmark, Sweden and Norway are currently working on rearranging existing shipping routes including routes close to the project area, where the wind farm is planned to be located. The remapping of the routes will not be in effect until 2013 at the earliest and the exact location of the new routes has not yet been finally chosen. Through communication with maritime authorities it has been established that two traffic routes currently intersecting the project are expected to be terminated and a new traffic route will be introduced 3 nautical miles west of the project area. This distribution of routes is the basis of the analysis in the present report.

Currently there is two ferry routes, which intersect the project area. Based on notification from Danish Energy Agency the basis of the analysis is that both ferries will be rerouted and pass south of the project area after the construction of the wind farm.

A mathematical model utilising the project area characteristics (wind, turbine layout etc.) and the ship traffic information has been applied in order to estimate the frequency of ship-turbine collision due to the following scenarios:

- Head on bow (HOB) collision occur when a vessel is directly on collision course towards a turbine and no evasive actions are carried out. This collision type is also referred to as a collision due to human error.

- Drifting ship collision can occur when a vessel suffers a propulsion machinery failure and drifts towards a turbine.

- Bend-in-route collision is a result of vessels failing to make a turn when a route has a bend and subsequently collides with a turbine.

- Control system (steering) failure resulting in circular motion due to the rudder being fixed in a left or right position and potentially leading to a collision.

It has been assumed that the risks related to ship to ship collision are not affected by the introduction of the wind farm. Compared to the current situation the new transit route layout, planned in effect from 2013, will increase maritime safety and be constructed keeping the wind farm in mind.

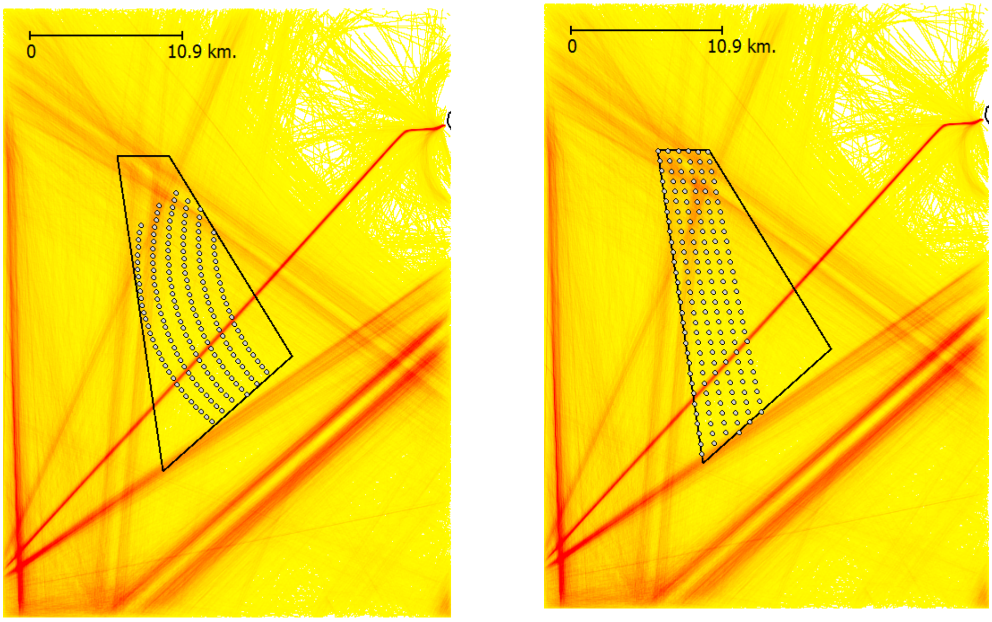


Figure 1-2. The wind farm layouts Arcs 2.3 (left) and Radials 2.3 (right). The turbine radii have been exaggerated for the sake of clarity.

In the collision frequency assessment the return period of ship-turbine collision is estimated to be 172 years for the radials turbine layout and 217 years for the arcs turbine layout (see Figure 1-2). Compared with the collision frequency criteria provided by the DMA the results were placed in the ALARP region and a more detailed risk evaluation was required.

The risks of impact to the environment in terms of oil spill and the risk of loss of life were evaluated against the risk acceptance criteria for both wind farms layouts.

The risk of oil spill was assessed using a risk matrix. Both the risk of significant, severe and catastrophic impact on the environment was estimated to be acceptable according to the defined criteria.

The risk of catastrophic impact was assessed to be acceptable, because the estimated return period of catastrophic impact was extremely high. A key assumption in the analysis was that a critical edge (see section 11.1.2) on a GBS (Ground Based Structure) foundation would rise at most 1 m. above the sea bed. The height of a critical edge is relevant to a scenario where a ship collides with the foundation and the ship hull is torn by a sharp edge (Slide-along-collision). If the chosen solution for GBS foundations has sharp edges rising higher than 1 m. then the present analysis will not be applicable. It is then left to the nominated developer to show that the chosen solution is collision friendly. The demand for collision friendly foundation design is primarily requested for the most exposed rows of turbines. The most exposed turbines are the first row closest to the A- and EFR-routes

The risk of loss of life was evaluated based on the risk to the most exposed person on passenger ships and tanker/cargo ships. For the most exposed person on passenger ships and tanker/cargo ships the risk were acceptable according to the defined criteria.

A number of recommendations on how to increase maritime safety during the operational phase of the wind farm have been put forward. Amongst others, it is recommended that the safety zone which is established during the construction phase is continued until the new transit route layout is in effect.

The focus of the present risk analysis is the operational phase. The task of conducting a risk analysis of the construction phase should be appointed to the entrepreneur. This is because many of the key parameters in the risk evaluation will depend on the construction technique of the entrepreneur. Such parameters include which harbour building materials is shipped from and building materials could also be shipped directly from the production site. Further more different construction vessels will be on site for different periods of time and thus have varying impacts on the regular ship traffic.

A request for a risk analysis of the construction phase will be put forward by the DMA when the project has been concretized.

2. Introduction

2.1 Background

In 1998 the Ministry of Environment and Energy empowered the Danish energy companies to build offshore wind farms of a total capacity of 750 MW, as part of fulfilling the national action plan for energy, Energy 21. One aim of the action plan, which was elaborated in the wake of Denmark's commitment to the Kyoto agreement, is to increase the production of energy from wind power to 5.500 MW in the year 2030. Hereof 4.000 MW has to be produced in offshore wind farms.

In the years 2002-2003 the two first wind farms was established at Horns Rev west of Esbjerg and Rødsand south of Lolland, consisting of 80 and 72 wind turbines, respectively, producing a total of 325,6 MW. In 2004 it was furthermore decided to construct two new wind farms in proximity of the two existing parks at Horns rev and Rødsand. The two new wind farms, Horns rev 2 and Rødsand 2, are going to produce 215 MW each and are expected to be fully operational by the end 2010.

The 400 MW Anholt Offshore Wind Farm constitutes the next step of the fulfilment of aim of the action plan. The wind farm will be constructed in 2012, and the expected production of electricity will cover the yearly consumption of approximately 400.000 households. Energinet.dk on behalf of the Ministry of Climate and Energy is responsible for the construction of the electrical connection to the shore and for development of the wind farm site, including the organization of the impact assessment which will result in the identification of the best suitable site for constructing the wind farm. Rambøll with DHI and other sub consultants are undertaking the site development including a full-scale Environmental Impact Assessment (EIA) for the wind farm.

The present report is a part of a number of technical reports forming the base for the EIA for Anholt Offshore Wind Farm.

The Environmental Impact Assessment of the Anholt Offshore Wind Farm is based on the following technical reports:

- Technical Description
- Geotechnical Investigations
- Geophysical Investigations
- Metocean data for design and operational conditions
- Hydrography including sediment spill, water quality, geomorphology and coastal morphology
- Benthic Fauna
- Birds
- Marine mammals
- Fish
- Substrates and benthic communities

- Benthic habitat
- Maritime archaeology
- Visualization
- Commercial fishery
- Tourism and Recreational Activities
- Risk to ship traffic
- Noise calculations
- Air emissions

2.2 Content of specific memo

This document presents the ship collision risk analysis carried out for the operational phase of the Anholt Offshore Wind Farm. The scope of the analysis is to assess risks to ship traffic resulting from the introduction of the wind farm.

The current ship traffic situation has been studied in detail on the basis of AIS (Automatic Identification System) data. The ship traffic description is used as input for a ship-turbine collision frequency model and in the consequence assessment. The risks related to loss of lives and environment impact is compared to relevant risk acceptance criteria.

3. Project description

This chapter describes the technical aspects of the Anholt Offshore Wind Farm. For a full project description reference is made to /7/. The following description is based on expected conditions for the technical project; however, the detailed design will not be done until a developer of the Anholt Offshore Wind Farm has been awarded.

3.1 Offshore wind farm project description

3.1.1 Site location

The designated investigation area for the Anholt Offshore Wind Farm is located in Kattegat between the headland Djursland of Jutland and the island Anholt - see Figure 3-1. The investigation area is 144 km^2, but the planned wind turbines must not cover an area of more than 88 km^2. The distance from Djursland and Anholt to the project area is 15 and 20 km, respectively. The area is characterised by fairly uniform seabed conditions and water depths between 15 and 20 m.

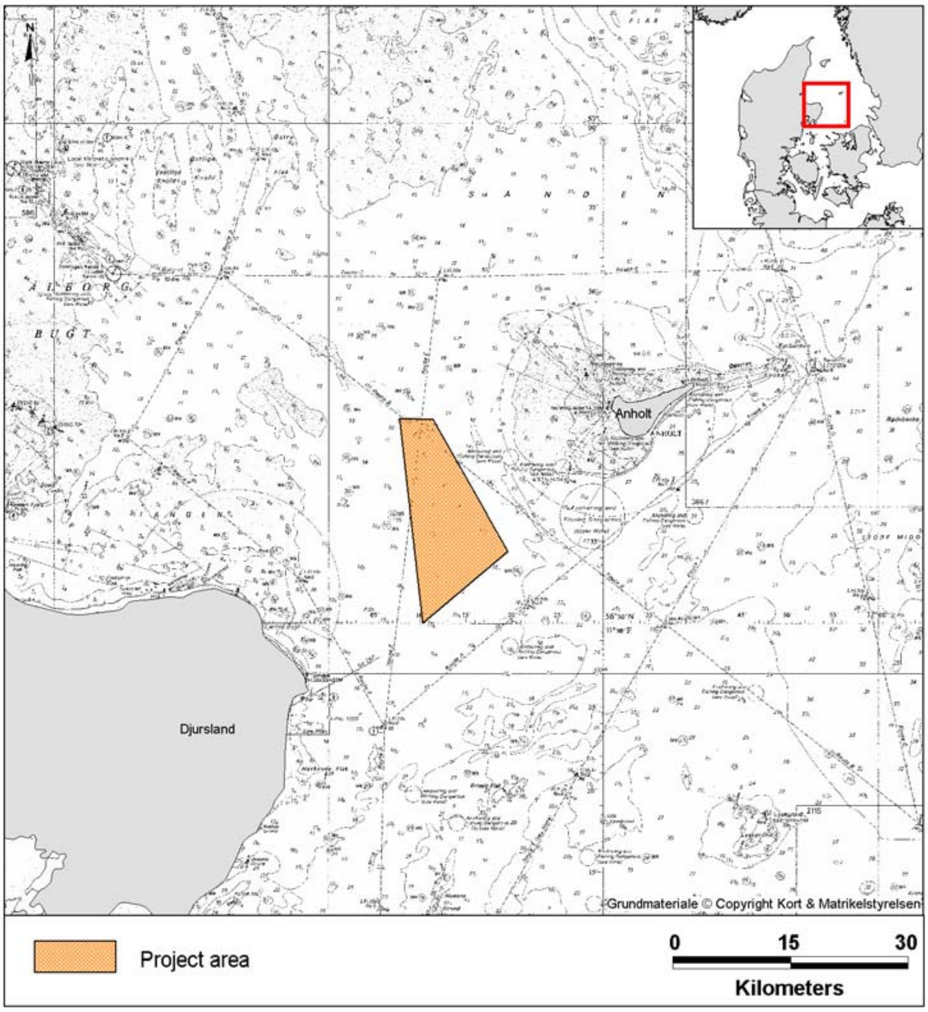


Figure 3-1 Location of the Anholt Offshore Wind Farm project area.

3.1.2 Offshore components

3.1.2.1 Foundations

The wind turbines will be supported on foundations fixed to the seabed. The foundations will be one of two types; either driven steel monopiles or concrete gravity based structures. Both concepts have successfully been used for operating offshore wind farms in Denmark /18/, /19/.

The monopile solution comprises driving a hollow steel pile into the seabed. A steel transition piece is attached to the pile head using grout to make the connection with the wind turbine tower.

The gravity based solution comprises a concrete base that stands on the seabed and thus relies on its mass including ballast to withstand the loads generated by the offshore environment and the wind turbine.

3.1.2.2 Wind turbines

The maximum rated capacity of the wind farm is by the authorities limited to 400 MW /20/. The farm will feature from 80 to 174 turbines depending on the rated energy of the selected turbines corresponding to the range of 2.3 to 5.0 MW.

Preliminary dimensions of the turbines are not expected to exceed a maximum tip height of 160 m above mean sea level for the largest turbine size (5.0 MW) and a minimum air gap of approximately 23 m above mean sea level. An operational sound power level is expected in the order of 110 dB(A), but will depend on the selected type of turbine.

The wind turbines will exhibit distinguishing markings visible for vessels and aircrafts in accordance with recommendations by the Danish Maritime Safety Administration and the Danish Civil Aviation Administration. Safety zones will be applied for the wind farm area or parts hereof.

3.1.3 Installation

The foundations and the wind turbine components will either be stored at an adjacent port and transported to site by support barge or the installation vessel itself, or transported directly from the manufacturer to the wind farm site by barge or by the installation vessel.

The installation will be performed by jack-up barges or floating crane barges depending on the foundation design. A number of support barges, tugs, safety vessels and personnel transfer vessels will also be required.

Construction activity is expected for 24 hours per day until construction is complete. Following installation and grid connection, the wind turbines are commissioned and are available to generate electricity.

A safety zone of 500 m will be established to protect the project plant and personnel, and the safety of third parties during the construction and commissioning phases of the wind farm. The extent of the safety zone at any one time will be dependent on the locations of construction activity. However the safety zone may include the entire construction area or a rolling safety zone may be selected.

3.1.3.1 Wind turbines

The installation of the wind turbines will typically require one or more jack-up barges. These vessels stand on the seabed and create a stable lifting platform by lifting themselves out of the water. The area of seabed taken by a vessels feet is approximately 350 m^2 (in total), with leg penetrations of up to 2 to 15 m (depending on seabed properties). These holes will be left to in-fill naturally.

3.1.3.2 Foundations

The monopile concept is not expected to require any seabed preparation.

The installation of the driven monopiles will take place from either a jack-up platform or an anchored vessel. In addition, a small drilling spread may be adopted if driving difficulties are experienced. After transportation to the site the pile is transferred from the barge to the jack-up and then lifted into a vertical position. The pile is then driven until target penetration is achieved, the hammer is removed and the transition piece is installed.

For the gravity based foundations the seabed needs most often to be prepared prior to installation, i.e. the top layer of material is removed and replaced by a stone bed. The material excavated during the seabed preparation works will be loaded onto split-hopper barges for disposal. There is likely to be some discharge to water from the material excavation process. A conservative estimate is 5% material spill, i.e. up to 200 m^3 for each base, over a period of 3 days per excavation.

The installation of the concrete gravity base will likely take place using a floating crane barge, with attendant tugs and support craft. The bases will either be floated and towed to site or transported to site on a flat-top barge. The bases will then be lowered from the barge onto the prepared stone bed and filled with ballast.

After the structure is placed on the seabed, the base is filled with a suitable ballast material, usually sand. A steel 'skirt' may be installed around the base to penetrate into the seabed and to constrain the seabed underneath the base.

3.1.4 Protection systems

3.1.4.1 Corrosion

Corrosion protection on the steel structure will be achieved by a combination of a protective paint coating and installation of sacrificial anodes on the subsea structure. The anodes are standard products for offshore structures and are welded onto the steel structures.

3.1.4.2 Scour

If the seabed is erodible and the water flow is sufficient high a scour hole will form around the structure. The protection system normally adopted for scour consists of rock placement in a ring around the in-situ structure. The rock will be deployed from the host vessel either directly onto the seabed from the barge, via a bucket grab or via a telescopic tube.

For the monopile solution the total diameter of the scour protection is assumed to be 5 times the pile diameter. The total volume of cover stones will be around 850-1,000 m^3 per foundation. For the gravity based solution the quantities are assessed to be 800–1100 m^3 per foundation.

3.2 Transformer platform and cable project description

An offshore transformer platform will be established to bundle the electricity produced at the wind farm and to convert the voltage from 33 kilovolts to a transmission voltage of 220 kilovolts, so that the electric power generated at the wind farm can be supplied to the Danish national grid.

3.2.1 Transformer platform

Energinet.dk will build and own the transformer platform and the high voltage cable which runs from the transformer platform to the shore and further on to the existing substation Trige, where it is connected to the existing transmission network via 220/440 kV transformer.

The transformer platform will be placed on a location with a sea depth of 12-14 metres. The length of the export cable from the transformer station to the shore of Djursland will be approximately 25 km. On the platform the equipment is placed inside a building. In the building there will be a cable deck, two decks for technical equipment and facilities for emergency residence.

The platform will have a design basis of up to 60 by 60 metres. The top of the platform will be up to 25 metres above sea level. The foundation for the platform will be a floating caisson, concrete gravitation base or a steel jacket.

3.2.2 Subsea Cabling

The wind turbines will be connected by 33 kV submarine cables, so-called inter-array cables. The inter-array cables will connect the wind turbines in groups to the transformer platform. There will be up to 20 cable connections from the platform to the wind turbines. From the transformer platform a 220 kV export cable is laid to the shore at Saltbæk north of Grenå. The cables will be PEX insulated or similar with armouring.

The installation of the cables will be carried out by a specialist cable lay vessel that will manoeuvre either by use of a four or eight point moving system or an either fully or assisted DP (Dynamically Positioned) operation.

All the subsea cables will be buried in order to provide protection from fishing activity, dragging of anchors etc. A burial depth of minimum one meter is expected. The final depth of burial will be determined at a later date and will vary depending on more detailed soil condition surveys and the equipment selected.

The cables will be buried either using an underwater cable plough that executes a simultaneous lay and burial technique that mobilises very little sediment or a Remotely Operated Vehicle (ROV) that utilises high-pressure water jets to fluidise a narrow trench into which the cable is located. The jetted sediments will settle back into the trench.

3.2.3 Onshore components

At sea the submarine cable is laid from a vessel with a large turn table. Close to the coast, where the depth is inadequate for the vessel, floaters are mounted onto the cable and the cable end is pulled onto the shore. The submarine cable is connected to the land cable close to the coast line via a cable joint. Afterwards the cables and the cable joint are buried into the soil and the surface is re-established.

On shore the land cable connection runs from the coast to compensation substation 2-3 km from the coast and further on to the substation Trige near Århus. At the substation Trige a new 220/400 kV transformer, compensation coils and associated switchgear will be installed. The onshore works are not part of the scope of the Environmental Statement for the Anholt Offshore Wind Farm. The onshore works will be assessed in a separate study and are therefore not further discussed in this document.

4. Procedure of analysis

In order to assess the risk to the ship traffic originating from the planned wind farm between Djursland and Anholt the procedure illustrated in Figure 4-1 is applied.

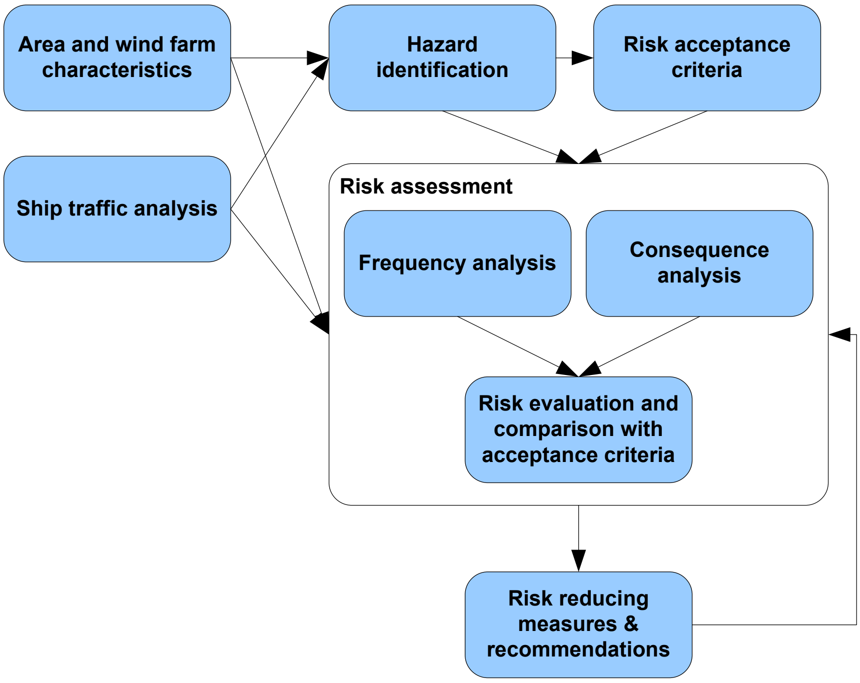


Figure 4-1 Overview of procedure of analysis.

The first step in the risk assessment is to identify the hazards to maritime safety resulting from the introduction of the wind farm. The scope is to identify those hazards directly relating to the ship traffic by introduction of the wind farm. In the hazard identification process information regarding the considered area (wind, bathymetry, wind farm characteristics etc.) and the ship traffic situation is utilised. The hazard identification is described in section 5.

The basis of the ship traffic analysis is AIS-data covering the period from the 1st of January 2008 to the 31st of December 2008. The overall traffic pattern in Kattegat is first discussed and the navigation routes which are most critical to the risk assessment are identified. A detailed description of these routes is given including annual number of movements, ship type distribution, ship size distribution and distribution of traffic across the route as described in section 9.

A statistical model for estimating the annual frequency of ship-turbine collisions is developed. The model includes a statistical description of traffic routes and a geometrical description of routes and turbines. Four collision scenarios form the basis of the frequency calculations, namely head on bow, drifting ship, bend-in route and control system failure, see section 10.

The consequences from ship-turbine collision are analysed with respect to loss of lives and impact on the environment in terms of oil spill as described in section 11.

By combining the frequency and consequences of a ship-turbine collision the risk is obtained and compared to relevant risk acceptance criteria. The risk acceptance criteria applied in the analysis are discussed in section 6.

Finally risk reducing measures and recommendations on how to increase maritime safety in the area surrounding the wind farm are given based on the conclusions of the risk analysis, see Section 13.

A number of key factors in the risk assessment will not be determined until later in the project programme, when offers have been received from nominated developers. Such factors include the specific distribution of turbines within the project area, the size of turbines and the type of turbine foundation. In the present report the aim is to treat these factors conservatively yet realistically. If the applied approach is too conservative the obtained results will not be very helpful in the decision making process, so the aim is to supply results for different feasible options.

5. Hazard identification

Based on past experience with offshore risk analysis and communication with the DMA the following hazards have been identified relating to the operational phase of the wind farm:

- Hazards of ship-ship collision due to the wind farm.
- Hazards related to ship-turbine collision
    - Hazard from high voltage to persons onboard ships
    - Hazard from damage to ship from collision, particularly sharp edges on gravity foundations
    - Hazard to persons onboard ships from collision with blades

A risk analysis of the construction phase is left to the nominated developer and this is discussed further in Section 14.

Ship-ship collision
The borders of the project area have been chosen such that there is a safety distance of three nautical miles to future traffic lanes. The changes in traffic routes have been decided independently of the wind farm location and it is assumed that they will increase maritime safety. For this reason risks relating to ship-ship collision are assumed to decrease and are therefore not investigated further.

Leisure crafts and fishing vessels
Leisure crafts and fishing vessels are discussed in Section 9.4 and 9.5. Kattegat is popular amongst leisure sailors and there is some fishing activity within the area. The activity of larger fishing vessels (> 15 meters) operating in the area can be characterised as very limited and the bulk of fishing vessels native to local harbours are smaller than 10 meters.

In Denmark it is not common practice to have complete sailing prohibition in offshore wind farms. After the construction of the wind farm there could be a ban on anchoring, diving or trawling, but leisure crafts and fishing vessels will most likely still be operating in the area.

Turbine foundations are not designed to withstand impact from larger ships; however they are designed for extreme weather and fatigue. It is therefore assessed that foundations will be able to withstand collisions with leisure crafts and the type of fishing vessels currently operating in the area.

It is judged that on most cases a collision between a turbine and a leisure craft or fishing vessel will not result on severe damage to the leisure craft/fishing vessel.

6. Risk acceptance criteria

In order to determine if the risks related to ship-turbine collision is acceptable or not acceptance criteria must be established. The DMA have put forward a criterion related to ship-turbine collision frequency (return period) as shown in Table 6-1. A detailed consequence assessment is mandatory if the return period is less than 300 years. If the return period is more than 300 years a consequence assessment may be carried out depending on the ship traffic circumstances. This interpretation of the acceptance criteria is in line with the acceptance criteria established in Germany, /3/.

Table 6-1. Risk acceptance criteria for a ship-turbine collision.

Return period	Acceptability
< 50 years	Unacceptable
50 – 300 years	ALARP - Different risk reducing measures must be considered.
> 300 years	Acceptable

Different risk acceptance criteria are applied depending on the types of risk analysed. In general the following risks are considered:

- Environmental risk acceptance criteria
- Human fatality risk acceptance criteria
- Economical risk acceptance criteria.

Currently there are no general standards for the risk acceptance criteria related to the above stated risks, /3/. In the following only consequences related to the environment and human safety are considered. The economic consequences are as such not related to the safety of the ships, but more relevant for the operator of the wind farm.

It is assumed that the environmental impact from a ship colliding with a turbine is mainly due to an oil spill from the ship. Discharge of various chemical or lubrication oils from the turbine is of very limited amount and is therefore considered negligible compared to the amount of oil discharged from a ship. The risk acceptance criteria proposed in /2/ is adopted. This approach is similar to one of the approaches discussed in /3/. A risk matrix is used to assess the environmental risks. The frequency at which a specific consequence occurs is combined with severity of the consequence to determine the risk level. The risk matrix is shown in Figure 6-1, where green represents the acceptable region, yellow represent the As Low As Reasonable Practicable (ALARP) region and red indicates that the risk is unacceptable.

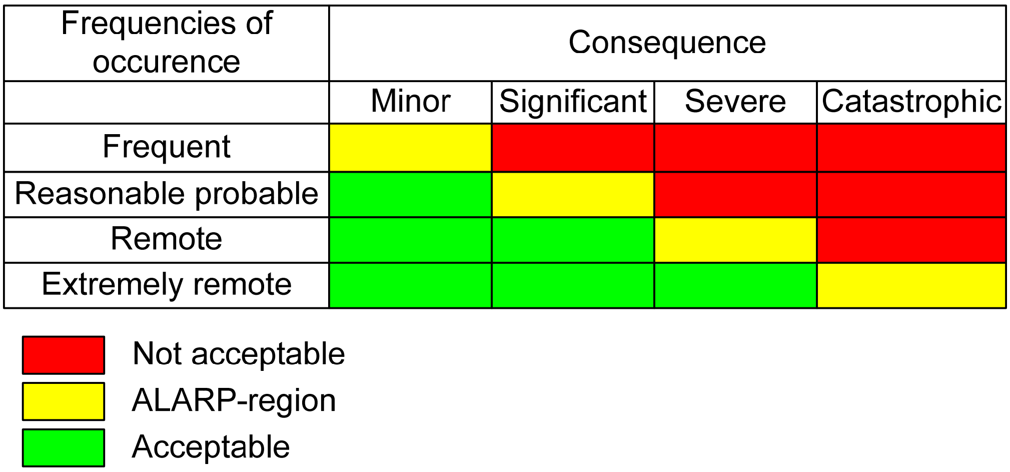


Figure 6-1 Risk matrix used for evaluating environmental risks.

The consequence ranking applied in the analysis is given in Table 6-2 and the frequency ranking is shown in Table 6-3.

Table 6-2. Consequence ranking for environmental risks.

Consequence	**Environment**
Minor	No impact on the marine environment
Significant	Operating supplies from wing tanks or tanks in the double bottom spill into the water; no structural damage to inner hull or double bottom
Severe	One or more holds/compartments are penetrated; cargo flows is discharged into the water; inner hull and double bottom is penetrated
Catastrophic	The ship breaks apart and/or sinks

Table 6-3. Frequency ranking for environmental risks.

Frequency ranking	**Frequency interval**	**Return period interval**
Frequent	frequency > $2 \cdot 10^{-1}$	Return period < 5 years
Reasonable probable	$2 \cdot 10^{-1} \geq$ frequency > $2 \cdot 10^{-2}$	5 years < return period < 50 years
Remote	$2 \cdot 10^{-2} \geq$ frequency > $2 \cdot 10^{-3}$	50 < return period < 500 years
Extremely remote	$2 \cdot 10^{-3} \geq$ frequency	500 years < return period

The risk of loss of lives is assessed in terms of Individual Risk (IR), where IR is the risk of loss of life for the maximum exposed individual on tanker/cargo ships and passenger vessels. The guideline for the Formal Safety Assessment (FSA) by IMO, /12/, proposes the acceptance criteria for individual risk listed in Table 6-4. These criteria are based on figures established by UK HSE generally applied in the offshore industry. It should be noted that acceptance criteria refers to the total risk an individual is exposed to (including fire, collision etc.). Therefore, the risk originating from ship-turbine collision is a subset of this number.

Table 6-4. Acceptance criteria bounds for individual risk.

Individual risk to	Broadly acceptable fatality risk per year	Maximum tolerable fatality risk per year
Crew member	10^{-6}	10^{-3}
Passenger	10^{-6}	10^{-4}

7. Assumptions

This section lists some of the main assumptions used in the report.

7.1 Transit route layout

A frequency analysis has been conducted using the present day transit route layout and the result found was an unacceptably low return period for ship-turbine collisions (for more details see Appendix 16.1). The collision frequency results for the present day traffic have been discussed with the DMA and it was established that the current layout of transit routes is not expected to be continued.

Maritime authorities in Denmark, Sweden and Norway are currently working on changing the layout of existing transit routes. The official location of new routes has not yet been made public and new routes will not be in effect until 2013 at the earliest. Both the B- and E-routes are expected to be terminated and a new traffic route will be introduced 3 miles west of the project area. The current transit route layout is shown in Figure 9-2. It is a basic assumption of the present report, that these route alterations will be effectuated.

7.2 Ship-ship collisions

The borders of the project area have been chosen such that there is a safety distance of three nautical miles to future traffic lanes. The changes in traffic routes have been decided independently of the wind farm location and it is assumed that they will increase maritime safety, i.e. the risks relating to ship-ship collision are assumed to decrease.

7.3 Frequency model parameters

It is assumed that ships will drift in the direction of the wind with a drifting speed of one knot. A sensitivity study has been conducted on the drifting speed. It was found that the drifting speed does have a significant effect on the frequency calculations, but the main conclusion that the results fall into the ALARP-region still holds true (see Section 10.7.2).

In the main calculations turbine radius at sea level is set to 5 m. A sensitivity study has also been conducted on this parameter and it was found that the influence on the frequency calculations was insignificant (see Section 10.7.1).

7.4 Ferry route

There are two ferries operating in the vicinity of the project area, namely the M/F Anholt (Anholt-Grenå) and Stena Nautica (Varberg-Grenå). It has not yet been decided whether it will be possible for the ferries to pass through the project area after the construction of the wind farm. Based on notification from Danish Energy Agency the basis of the analysis is that both ferries will sail around the wind farm (see Section 9.3).

8. Area and Wind Farm Characteristics

8.1 Waves

The wave heights in the vicinity of the project area are highly correlated with the wind due to the confined waters. However, a higher contribution of waves from northerly and southerly directions is seen due to the longer free fetch in these directions compared to the westerly directions. Wave heights exceeding 2.0 m are seen less than 0.5% of the time while wave heights above 1 m occur about 15% of the time, /15/. Significant wave heights at (634012 E; 6286388 N) (UTM32) are depicted in Figure 8-1.

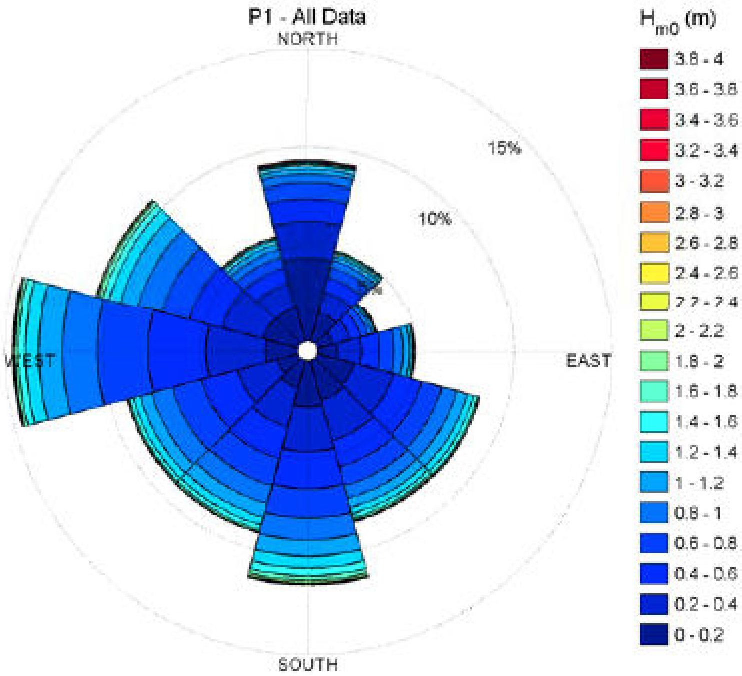


Figure 8-1 Significant wave height analysis based on modelled Metocean data (1979-2007), /15/. Significant wave height, H_{m0}, is defined as four times the standard deviation of the instantaneous displacement from the mean sea level.

8.2 Tide

Water level variations due to tide in Kattegat are on average relatively small. Under severe weather conditions, however, water level variations will increase significantly. Statistical analyses of the water level variations were carried out in /15/ based on model data from the period 1979 to 2007. Results are given in Table 8-1 and shows for example that the 50 year return period high water level is approximately 1.5 m MSL and the low water level for the 50 year return period is about -0.8 m MSL in the north-eastern part of the project area. The return period is describing the average period of time between events, /14/.

	Extreme value for return period [years]		
	25	**50**	**100**
HW (mMSL)	1.41	1.53	1.66
LW (mMSL)	-0.78	-0.83	-0.88

Table 8-1 Extreme water level analysis based on modelled Metocean data (1979-2007). /15/.

8.3 Current

Surface current information have been extracted from the DHI's 3D regional model, ´Vandudsigten' at (642018E; 6265325N (UTM-32)) at the southern limit of the project area. The current rose for depth averaged current speeds in Figure 8-2 clearly points out that the current in the vicinity of the project area is oriented in the N-S axis and is predominantly north- going. The depth averaged current speeds reaches a maximum magnitude of about 1 m/s, but exceeds 0.2 m/s less than 5% of the time.

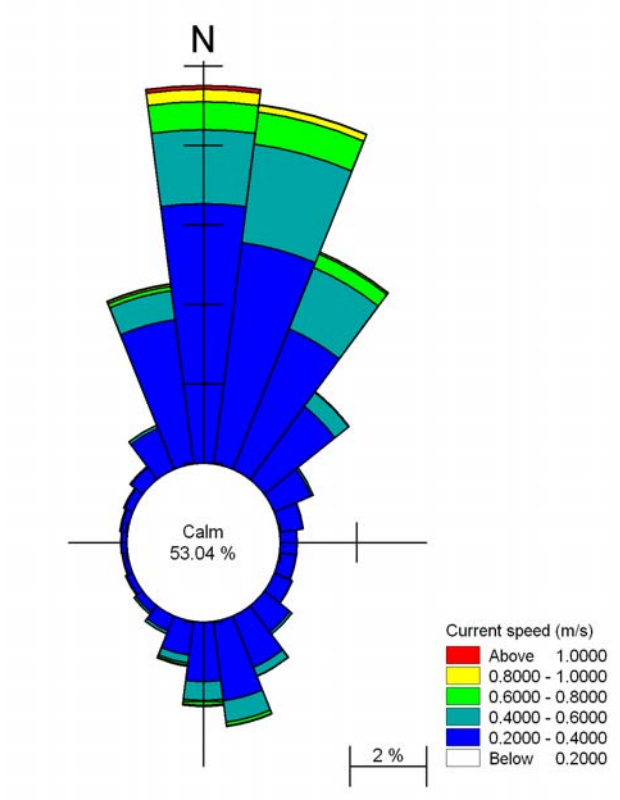


Figure 8-2 Hindcast surface current covering the period from 1998 to 2008 extracted at (642018E; 6265325N (UTM-32 (WGS84))) from DHI's Vandudsigten 3D regional model. Directions are defined as "going to", /14/.

8.4 Water depth

The water depth in the project area is depicted in Figure 8-3. The depths are mean values which have been corrected for high and low tide and error in measurement. The water depth in the project area is between 14 and 20 meters and the maximum draught registered for ships in the area is 15 meters (Table 11-4). This means that there is no significant probability of ships grounding should they enter or approach the project area.

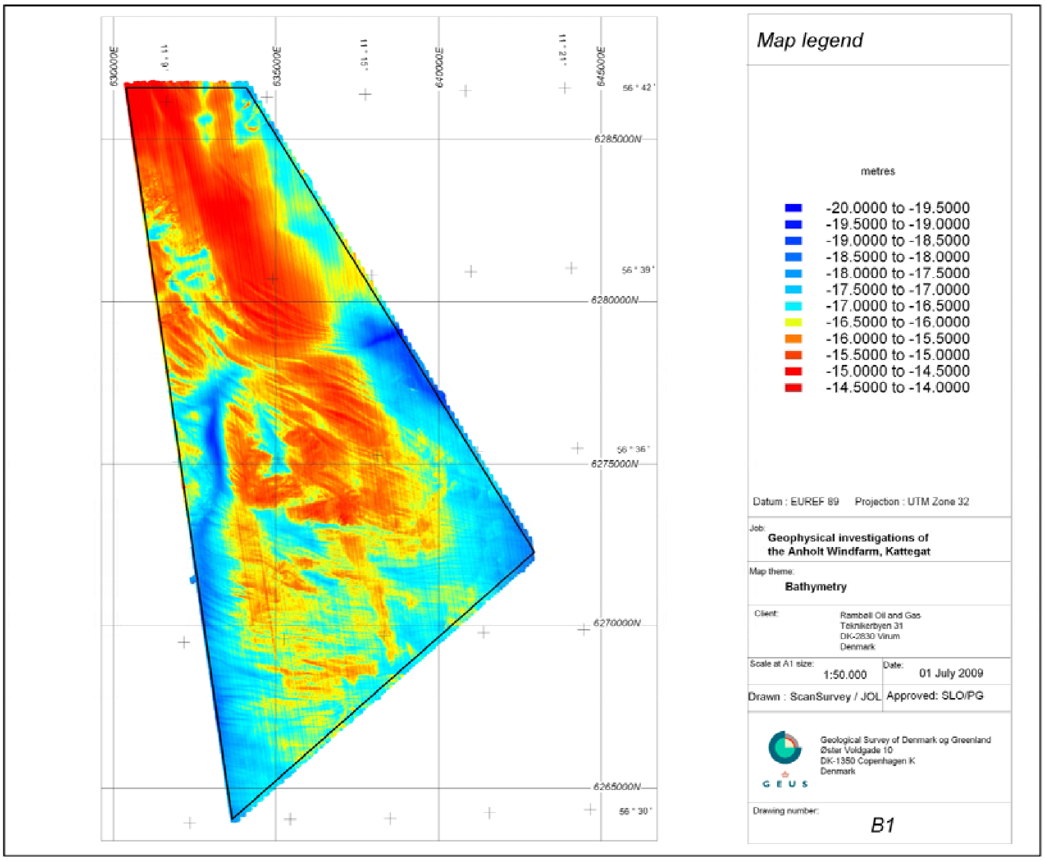


Figure 8-3. Bathymetry, /8/.

8.5 Wind

The wind direction distribution is obtained from data measured by a meteorological mast on the western tip of Anholt at an elevation of 10 m. The data is averaged over the ten year period from 1st of January 1999 to the 31st of December 2008. It is assumed that the wind statistics are applicable to the project area.

The deterministic wind direction distribution is given in Table 8-2. It should be noted that the wind direction refers to the direction where the wind is blowing from. For a more illustrative view the wind rose is plotted in Figure 8-4, where it is clear that the prevailing wind direction is South-West.

Table 8-2. Wind direction distribution in the project area.

Wind direction	Frequency in percent
North	5.4%
North-north-east	5.5%
East-north-east	5.0%
East	6.1%
East-south-east	7.0%
South-south-east	9.2%
South	9.2%
South-south-west	13.9%
West-south-west	11.1%
West	13.5%
West-north-west	9.3%
North-north-west	4.8%

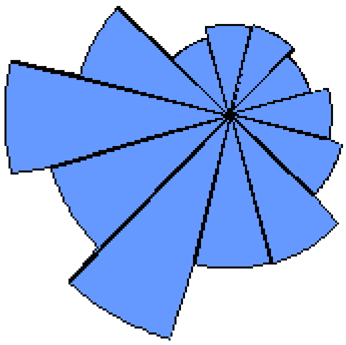


Figure 8-4. Wind distribution for the project area.

Return periods for hindcast wind speeds have been extracted from the DHI’s 3D regional model, ´BANSAI’ at (642018E; 6265325N (UTM-32)) at the southern limit of the project area. Return period for modelled wind speed is given in Figure 8-5.

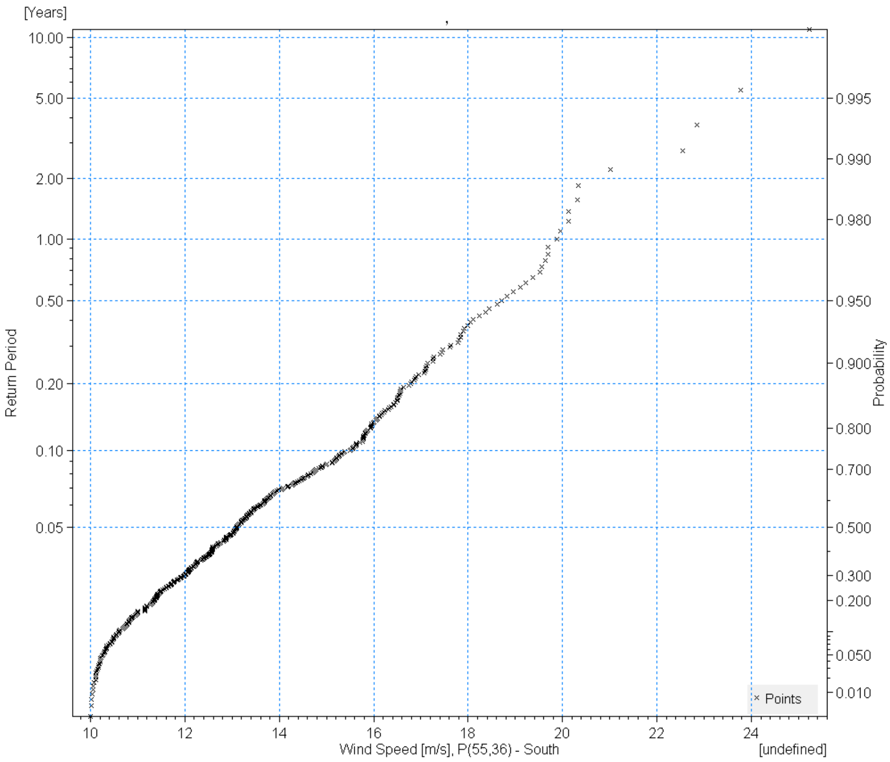


Figure 8-5. Return period and probability for modelled wind speeds at (642018E; 6265325N (UTM-32 (WGS84))), /14/.

8.6 Wind farm characteristics

As mentioned earlier certain key factors in the risk assessment will not be determined until later in the project programme, when offers have been received from the nominated developers. The wind farm characteristics such as the distribution of the turbines within the project area, the size of turbines and the type of turbine foundation are such factors. This section discusses the feasible options which have been chosen for the analysis.

8.6.1 Turbine layout

Once constructed, the wind farm will feature from 80 to 174 turbines depending on the rated energy of the selected turbines. The rated energy is 2.3 MW for smaller turbines and 5.0 MW for larger turbines (/7/). The collision frequency will depend both on the number of turbines and the tower/base radius. The maximum tower radius of turbines is approximately 2.5 meters regardless of the rated energy of the turbine.

The collision frequency depends not only on the dimensions of the turbines, but also on the dimensions of the considered ships. The length and width of ships are however much larger than the tower radius of both small and large turbines. This means that a large number of turbines will constitute the greatest risk in terms of collision frequency.

Two turbine layouts will be included in the analysis, and these are denoted Arcs 2.3 and Radials 2.3. Each layout consists of 174 turbines with a tower radius of 2.5 meters. As the two layouts consist of the largest number of turbines, they are considered realistic worst case layouts.

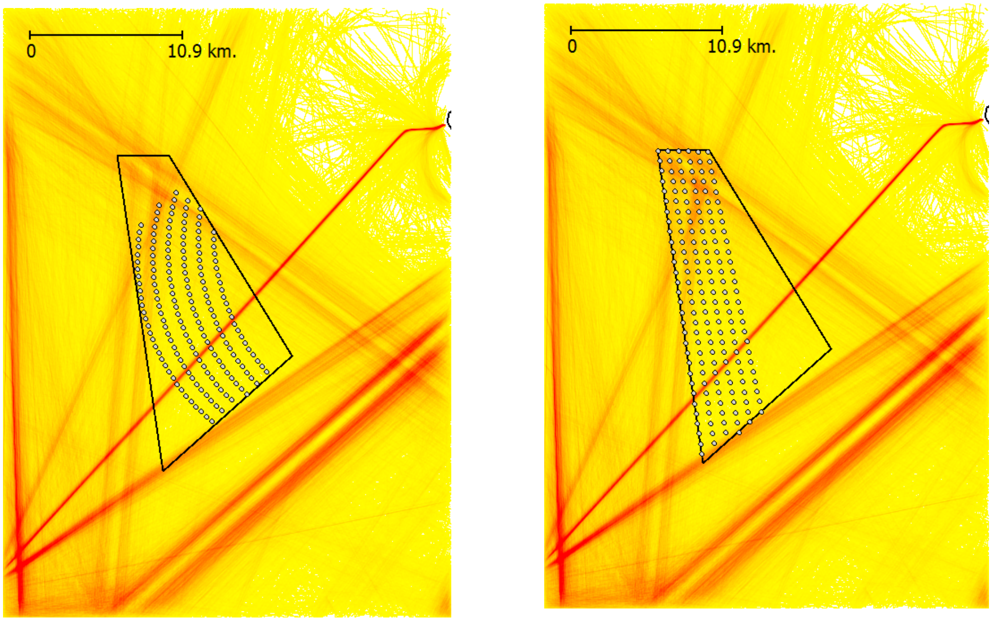
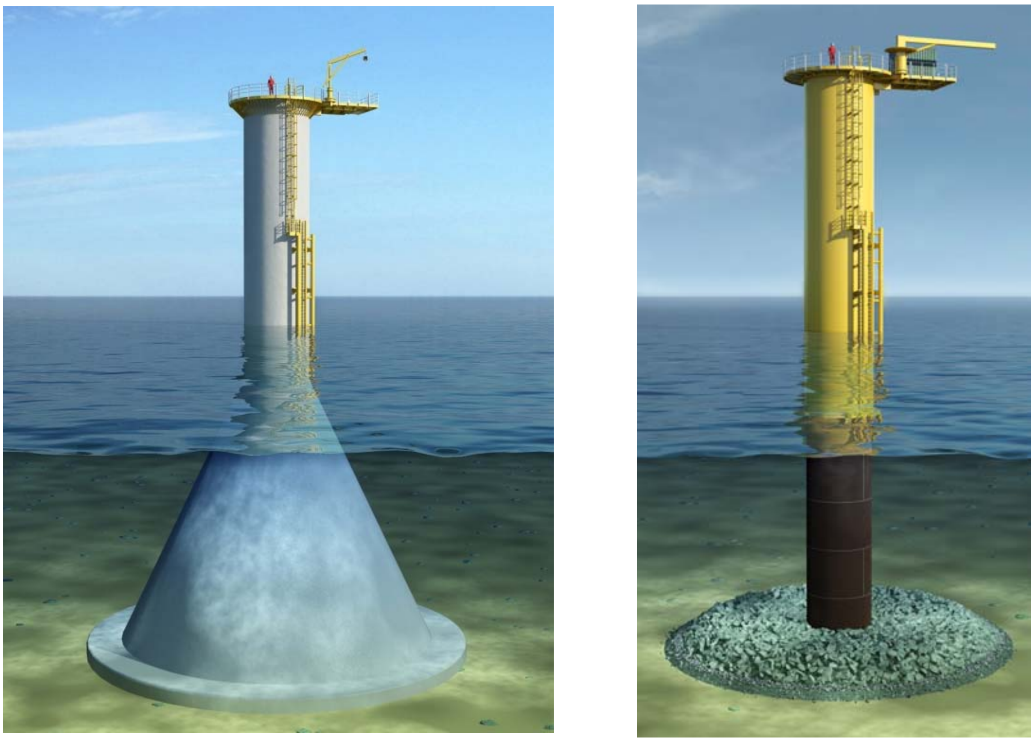


Figure 8-6. The farm layouts Arcs 2.3 (left) and Radials 2.3 (right). The turbine radii have been exaggerated for the sake of clarity.

8.6.2 Turbine foundation

When analysing the consequences of ship-turbine collisions it is important to consider the foundation design with regards to collision friendliness. The foundation types proposed for the Anholt Offshore Wind Farm are steel driven mono piles and/or concrete Gravity Based Structures (GBS). Characteristics of each foundation type are discussed below.



Figur 8-1 Typical GBS cone and monopile foundations, /7/.

Mono pile

The mono pile foundation consists of a single steel beam, which is drilled into the seabed. The diameter of the tower is approximately 5 meters for both larger and smaller turbines.

In finite element simulations of ship-turbine collisions, mono piles has been found to be the most collision friendly type of foundation (see /1/). Only bulking of the ship hull occurs and there is a minimal risk of hull rupture. Furthermore, it has been found that for drifting ship collisions, the monopole is pushed away from the ship and does not fall onto the vessel.

Gravity base structure

Foundations of the type GBS are held in place without drilling or anchoring. The main tower is attached to a base which is kept in place by gravity. The base consists of a concrete or steel container, which is positioned on the seabed. The container is then filled with sand or rocks and kept in place by gravity.

Less research has been identified on the GBS than the mono pile with regards to collision friendliness. Initial work, /1/, has shown that the collision behaviour of GBS will be similar to that of mono piles *if* the GBS base is below that of the ship hull bottom. In this case ships can collide with the tower, but not the base structure. In some cases the impact energy can even be translated into sliding energy by the ship shifting the whole turbine structure, /1/.

In case the GBS base is *not* below the ship hull bottom the GBS can *not* in itself be considered a collision friendly foundation type. This is because a sharp edge on the GBS base can cause significant tearing of the hull if the ship slides along the edge. For this to happen the ship must have a critical draught, which makes such an impact possible.

The height of the GBS base will depend on the specific type/brand of turbine, and the foundation might and might not be fitted with a cone/skirt. The water depth in the investigation area, however, is quite large so only very few ships will have a critical draught. This is investigated further in Section 11.1.2.

8.6.3 Transformer station

The Anholt Offshore Wind Farm will feature an offshore transformer station located on a platform. The platform will have a design basis of up to 60 by 60 metres. The top of the platform will be up to 25 metres above sea level and the foundation for the platform will be a concrete gravitation base, a steel jacket or a monopile foundation.

The platform will be located on the eastern border of the investigation area within the 100 m. by 100 m. area depicted in Figure 8-7. The extent of navigational markings and safety zones will be established between the contractor and the authorities.

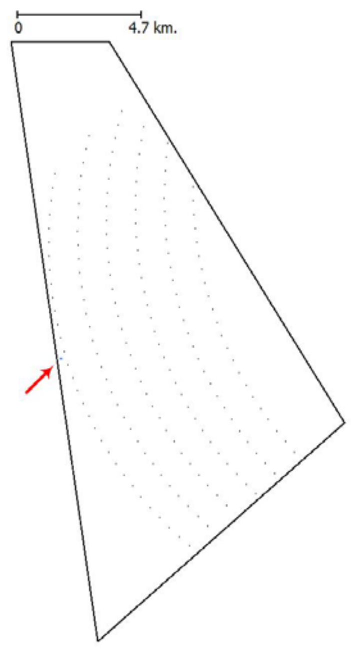


Figure 8-7. The transformer station will be located within the 100 m. by 100 m. square indicated by the arrow.

9. Ship traffic analysis

This section presents the ship traffic analysis and includes traffic data and ship distributions for use in later analysis. The ship distributions include ship type, ship size and transverse distributions for each traffic routes in the vicinity of the project area, see Figure 9-1.

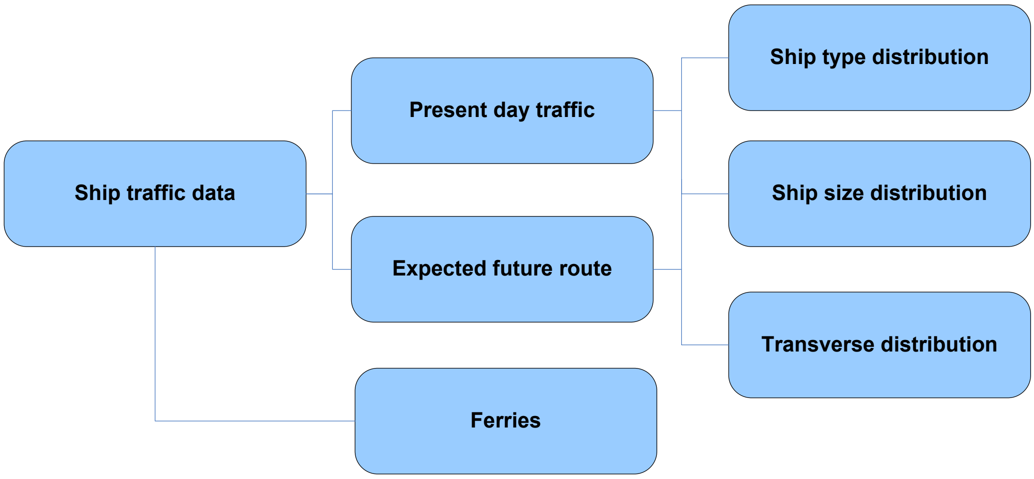


Figure 9-1. Methodology for the ship traffic analysis.

The project area is located in Kattegat between Djursland and Anholt and there are a number of official transit routes which crosses Kattegat (Figure 9-2). Not all routes carry the same traffic load though and most traffic cross Kattegat by the use of the T-route. Presently there are three official traffic routes which are relevant to the ship collision analysis of the wind farm, namely the A-, B and E-route. In this section the traffic on these routes is analysed in details.

As mentioned in Section 7 maritime authorities in Denmark, Sweden and Norway are working on changing the layout of existing transit routes and the two traffic routes currently intersecting the project area are expected to be terminated. Instead a new traffic route will be introduced 3 miles west of the project area. The location of this Expected Future Route (EFR) as well as an estimate of the traffic load on it is presented in this section along with ship type, ship size and transverse distributions.

There are two main ferry routes crossing the project area:

- The ferry between Anholt and Grenå
- The ferry between Varberg (Sweden) and Grenå

Their current and future sailing patterns are discussed in Section 9.3.

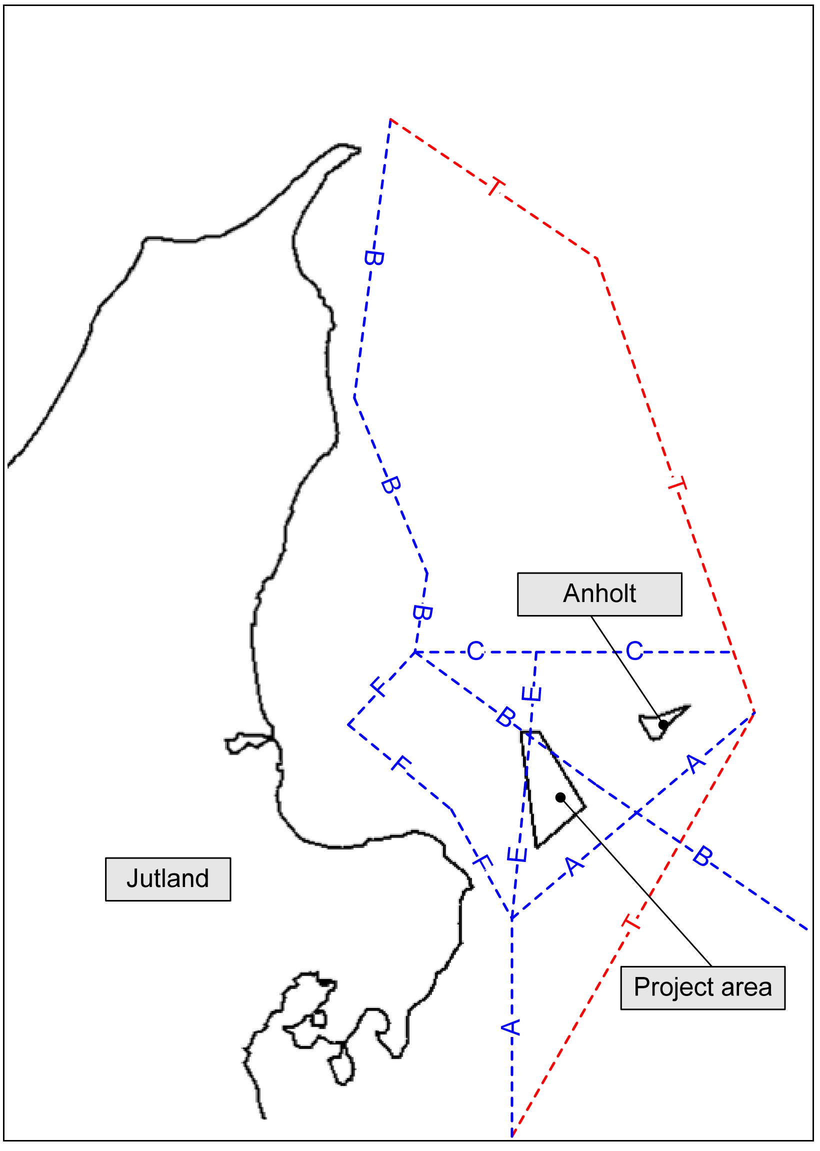


Figure 9-2. Official transit routes in Kattegat.

9.1 Data

The ship traffic data originates from Automatic Identification System (AIS) data supplied by the DaMSA. AIS is an automatic system to exchange information between ships and between ships and land-based stations. A ship equipped with AIS continuously transmits information regarding its name, location, destination, speed and course.

The International Maritime Organization (IMO) decided that by the end of 2004 all ships exceeding a gross tonnage of 300 GT are fitted with AIS. However, it should be noted that there are some exceptions; for example, naval ships are not obliged to carry AIS.

The AIS data which form the basis of the analysis cover the period from the 1st of January 2008 to the 31st of December 2008. The annual number of movements on each route is computed by analysing the number of ship crossings of report lines perpendicular to each route.

9.1.1 Report lines

To determine the precise location of routes and the annual number of movements the AIS-data has to be processed further. This is done by examining the ship crossings of key report lines introduced across each relevant route. The location of the report lines was chosen based on an inspection of a ship traffic density plot. In Figure 9-3 a ship traffic density plot of the area is shown together with the identified routes. The colour scale ranges from yellow (low ship density) to red (high ship density).

For each report line detailed information about each ship and the specific crossing were obtained.

9.1.2 Quality of AIS data

In /6/ comparisons was made between AIS data and data from Drogden observation station. It was found that 7% of the registrations from the observation station did not figure in the AIS data. Therefore the annual number of movements found based on AIS data is corrected by a factor of 1.076.

9.2 Present day transit traffic

There are a number of different transit routes in Kattegat and the ones which are relevant to the present analysis are the official routes denoted A, B and E. The official routes each consist of a southbound and a northbound lane. The north- and southbound lanes will be handled separately in the collision frequency analysis, as they constitute a risk to different parts of the wind farm.

West of the project area there is an unofficial ship traffic lane. An unofficial lane is unmarked in sea charts, but ships, which know the area well, choose to sail here anyway. Because this lane is not marked in seacharts it does not have the two lane appearance of the official lanes.

The annual number of movements on each route is given in Table 9-1.

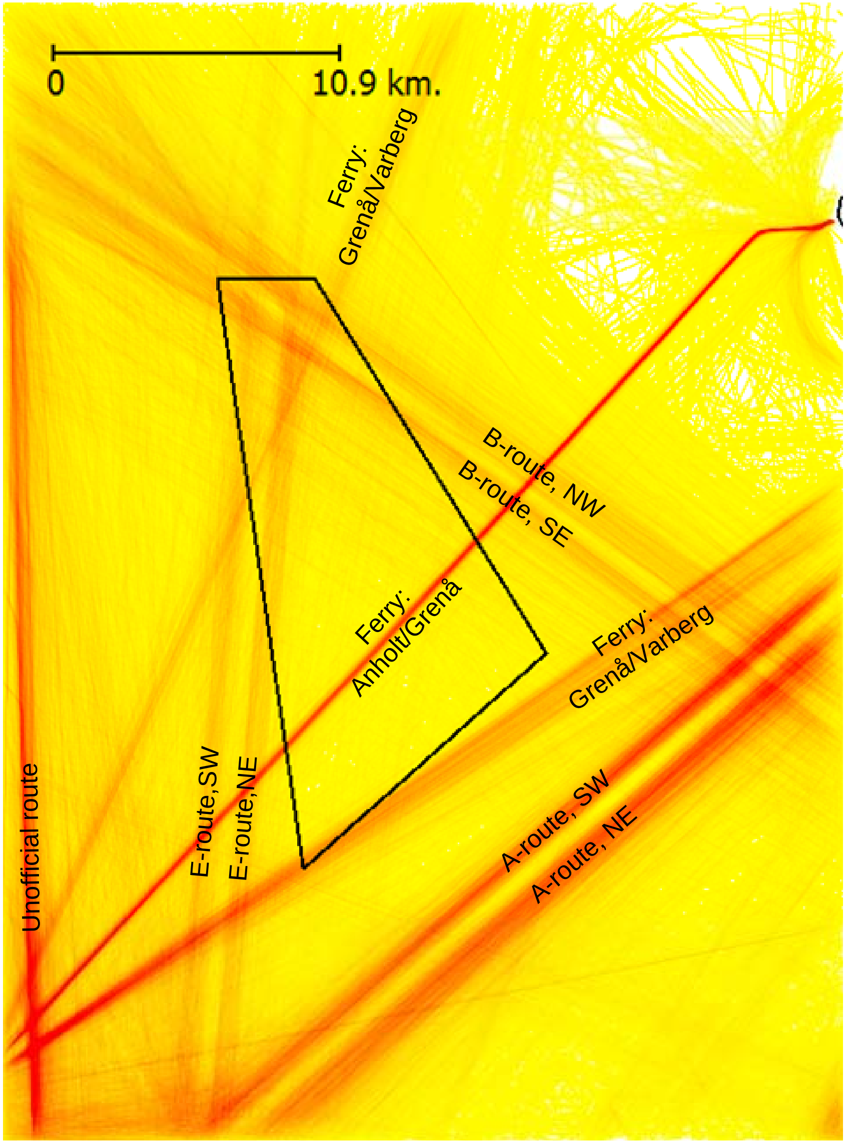


Figure 9-3. Density plot of ship traffic in the vicinity of the project area. Darker colours indicate higher intensity.

Table 9-1. Approximate number of annual movements on each route.

Route	Annual number of movements
A-route NE	1950
A-route SW	1200
B-route NW	850
B-route SE	900
E-route NE	550
E-route SW	650
Unofficial NW	750
Unofficial SE	950

9.2.1 Ship size distribution

The dimensions of the involved ships have a significant impact on the collision frequency, so in order to give an accurate description of these circumstances the size of vessels are included by adding ship classes to the frequency model. The ship size distributions are determined individually for each route from the AIS-data and vessels are grouped both in terms of width and length. Charts illustrating the distribution in length classes are given in Figure 9-4 and Figure 9-5 and the distribution in width classes are illustrated in Figure 9-6 and Figure 9-7. Ship classes distribution tables are listed in Appendix 16.2.

The ship dimension distribution on the B-, E-, and unofficial routes are quite similar as illustrated by the ship class distribution charts. On these routes most ships have length between 60 m. and 120 m. and width between 10 m. and 20 m. On the A-route the traffic is much heavier both in terms of annual number of movements and ship dimensions. Here most ships are longer than 120 m. and wider than 25 meters.

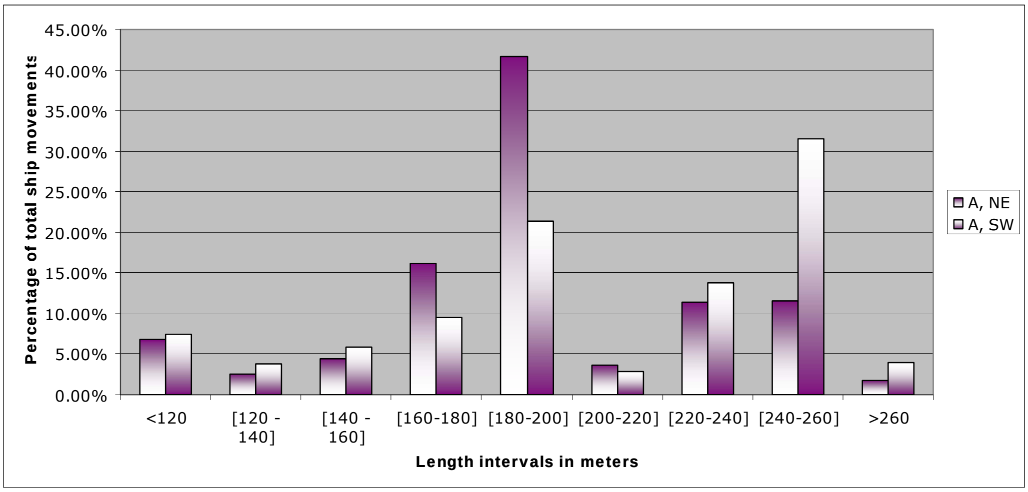


Figure 9-4. Length class distribution on the A-route.

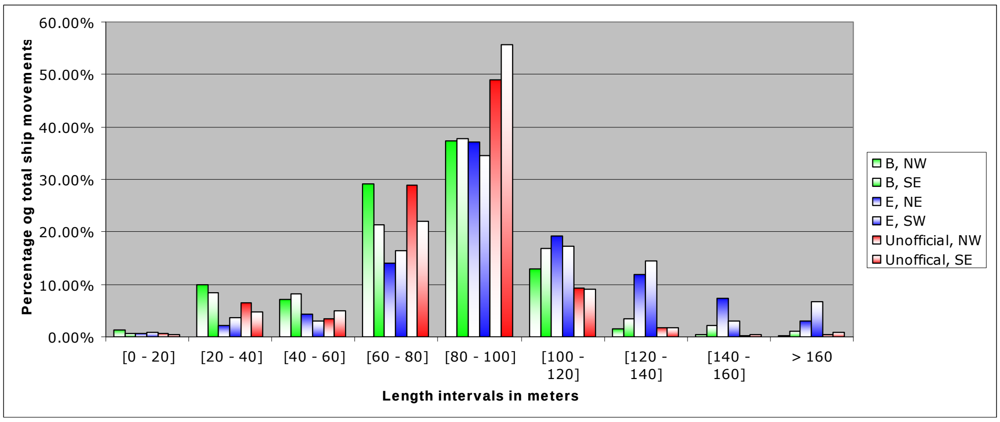


Figure 9-5. Length class distribution on the B-, E-, and unofficial routes.

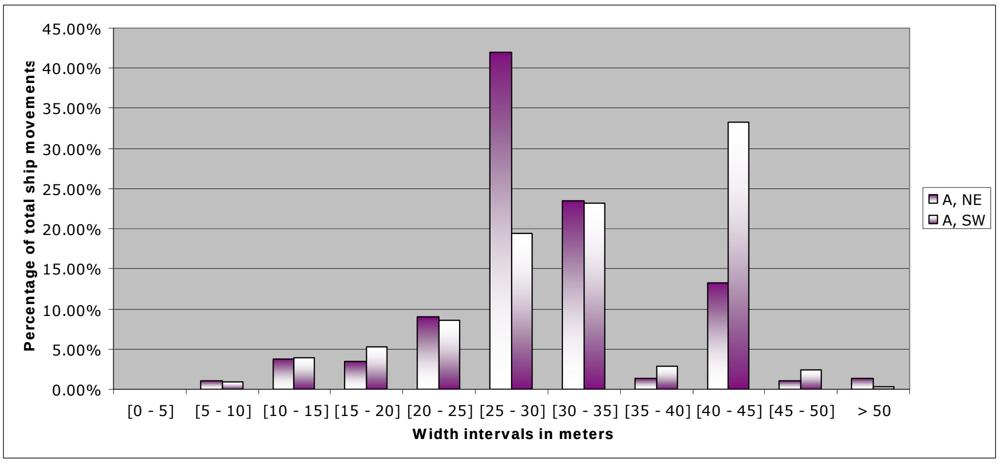


Figure 9-6. Width class distribution on the A-route.

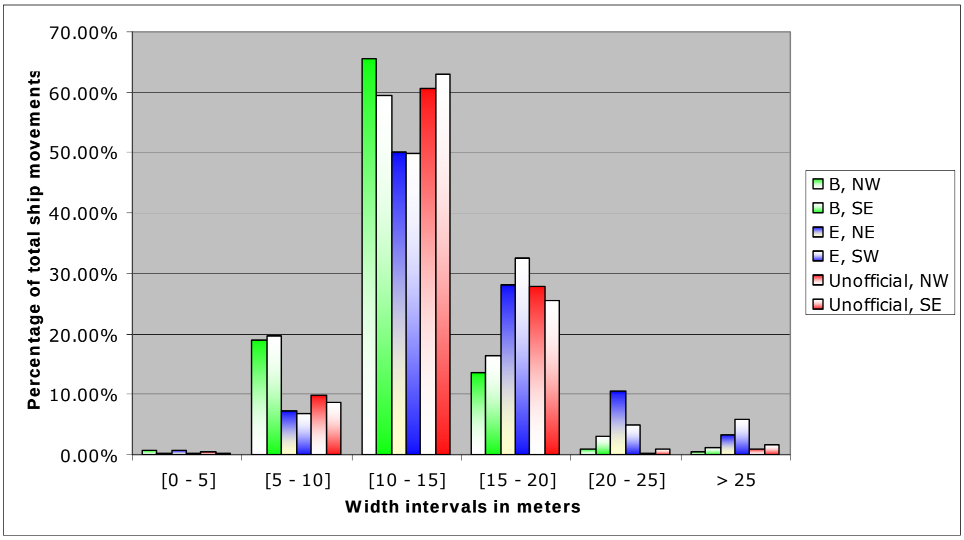


Figure 9-7. Width class distribution on the B-, E- and unofficial route.

9.2.2 Ship type distribution

For each route the ship type distribution is obtained from analysing the ship types crossing each the relevant report lines.

In the AIS data the ships are registered with two-digit code representing the ship type, /11/. For the present study the following ship type division have been applied

- Passenger ships. Ship type code 60 to 69
- Cargo ship. Ship type code 70 to 79
- Tanker ship. Ship type code 80 to 89
- Other. All other codes – also unknown ship types.

In Table 9-2 the ship type distribution is shown for each route. For all routes tanker and cargo ships account for most of the traffic. The A-route is mainly governed by tanker traffic, while cargo traffic is most pronounce on the other routes. A very limited number of passenger ships are travelling along the considered routes. In Figure 9-8 the actual number of ships in each category on each route is shown.

Table 9-2. Ship type distribution.

Ship type	A-route	B-route	E-route	Unofficial
Passenger	1%	0%	1%	0%
Cargo	30%	75%	53%	66%
Tanker	63%	7%	33%	20%
Other	6%	18%	12%	13%

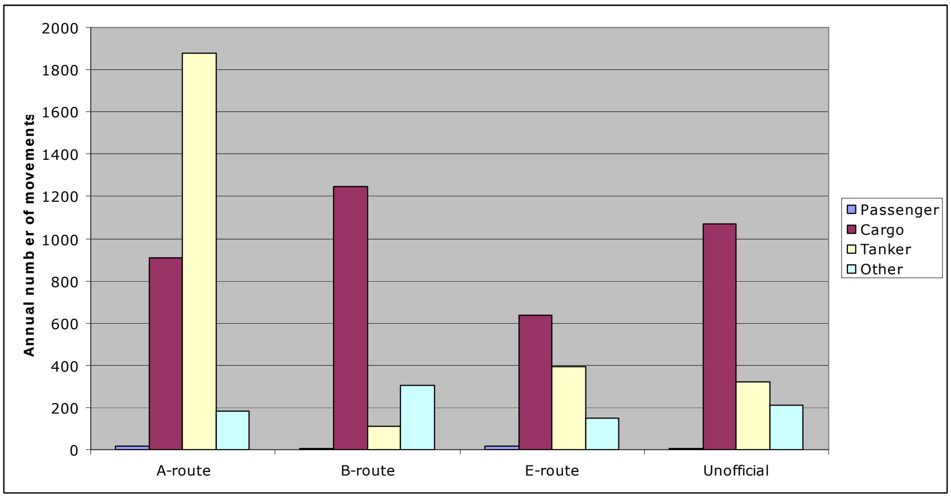


Figure 9-8. Chart with ship type distributions.

9.2.3 Transverse distribution

In ship collision modelling it is common practise to model transverse ship traffic distribution by a mix between a normal distribution and a uniform distribution. This is based on the assumption that most ships try to follow the official route as close as possible and are thus normally distributed across the route. Aside from this, there are certain ships that follow the main direction of the route, but at a more or less random distance to the centre of the route. These ships are described by the uniform distribution.

These assumptions, however, do not fully describe the behaviour of the traffic on routes A, B and E, because these routes all consist of a northbound and a south bound lane. This means that aside from keeping to the centre of the lane, ships also try to stay clear of the on coming traffic in the opposite lane. Therefore, the traffic is not distributed symmetrically across the route, but is rather skewed as illustrated in Figure 9-9.

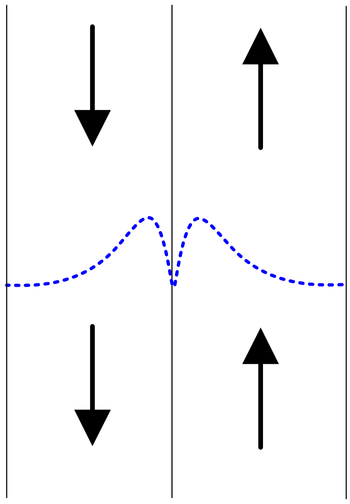


Figure 9-9. Ship traffic in north- and southbound lanes try to stay clear of the traffic in the opposite direction, which makes the traffic pattern skewed.

The normal distribution is innately symmetric, which makes it unsuitable for describing this specific traffic pattern. For this reason it has been chosen to use a lognormal distribution with cutoff, rather than the usual normal distribution. The difference between the normal- and lognormal distribution with cutoff is shown in Figure 9-10. The skewness of route B, SE is very pronounced and the lognormal distribution captures this far better than a normal distribution.

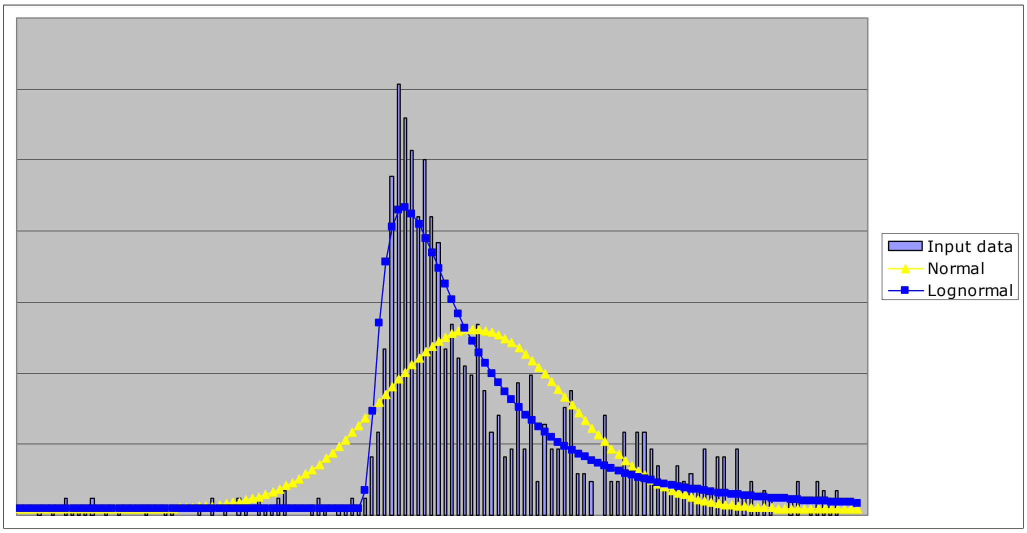


Figure 9-10. Difference between normal and lognormal approximation to the ship traffic in route B, SE. The skewness of route B, SE is very pronounced and the lognormal distribution captures this far better than a normal distribution.

The transverse distribution of the ship traffic is thus described by

$$F(x) = (1-\alpha)\cdot Lognormal(x,\mu,\sigma) + \alpha \cdot Uniform(x,a,b) \qquad (9\text{-}1)$$

where

α	The ratio of ships following a uniform distribution.
$Lognormal(x,\mu,\sigma)$	Lognormal distribution with parameters μ and σ.
$Uniform(x,a,b)$	Uniform distribution with lower boundary a and upper boundary b.
x	Transverse distance variable.

Parameters for the transverse distribution

The specific parameter values describing each route are found by fitting the function F(x) to the AIS data registered across a number of report lines. For the A-route the results obtained through this procedure are depicted in Figure 9-11 and Figure 9-12. The parameters describing each route is given in Table 9-3.

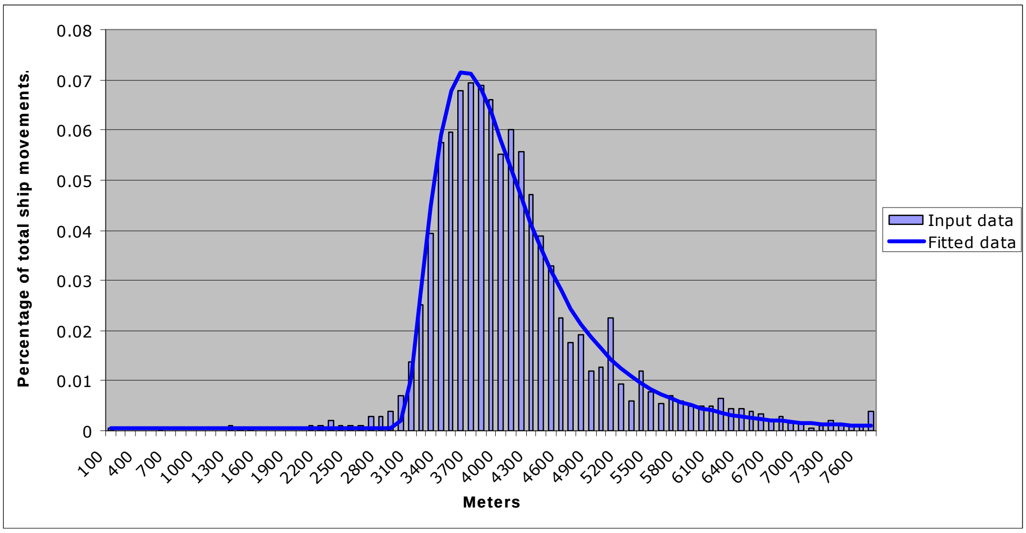


Figure 9-11. Transverse distribution and fitted data for A, NE.

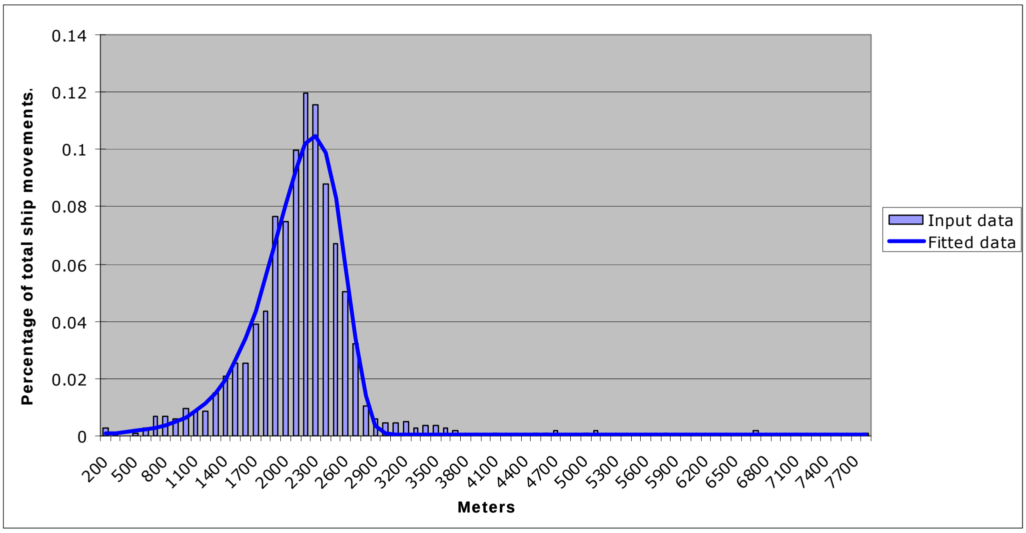


Figure 9-12. Transverse distribution and fitted data for A, SW.

Table 9-3. Statistical parameters describing the A-, B- and E-route.

Route	μ	σ	α	a	b
A-route NE	7.00	0.58	0.04	2800	4900
A-route SW	7.05	0.38	0.03	4533	3167
B-route, NW	7.81	0.30	0.20	2572	10127
B-route, SE	7.25	0.88	0.11	2066	10633
E-route NE	6.77	0.59	0.09	3843	3455
E-route SW	6.66	0.79	0.11	3607	3693

9.3 Ferry traffic

There are two ferries operating in the area

- The ferry between Anholt and Grenå (M/F Anholt)
- The ferry between Varberg (Sweden) and Grenå (Stena Nautica)

In Figure 9-13 M/F Anholt is depicted to the left, while Stena Nautica is shown to the right. The characteristics for the two ferries are shown in Table 9-4.

Figure 9-13 Left. M/F Anholt from www.ferry-site.dk. Right: Stena Nautica from www.stenaline.dk.

Table 9-4 Ferry characteristics.

Ferry name	Annual number of passages	MMSI / IMO number	Length [m]	Width [m]	Operating speed [km/hour]	Number of engines
MF Anholt	500	219002731 / 9263368	48	12	22	2
Stena Nautica	1200	265859000 / 8317954	135	24	34	2

The movements of the ferries are depicted in Figure 9-14. The sailing pattern of the Grenå/Varberg ferry is such that it has approximately 300 annual movements north of Anholt and 900 south of Anholt.

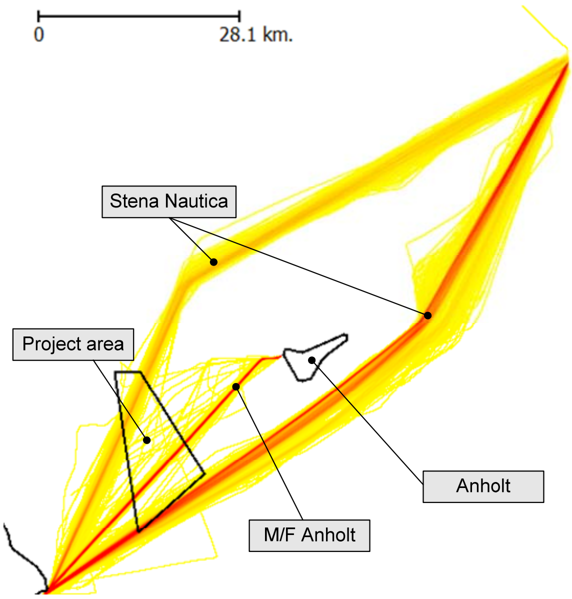


Figure 9-14. Ferry sailing pattern.

It has not yet been decided whether it will be possible for the ferries to pass through the project area after the construction of the wind farm. Based on notification from Danish Energy Agency the basis of the analysis is that both ferries will pass south of the project area. It is further assumed that the distance to the project area is 1 kilometre as depicted in Figure 9-15.

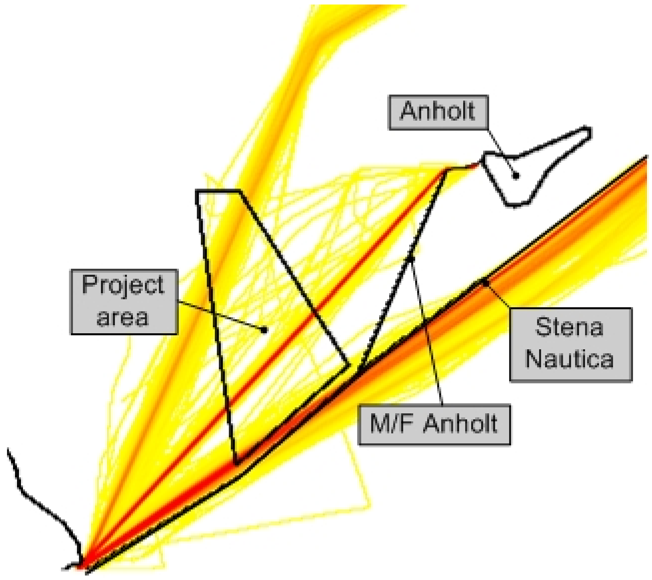


Figure 9-15. Assumed future sailing pattern of the ferries.

As discussed earlier, the Grenå-Varberg has approximately one third of its movements going north of Anholt. The choice between north and south movement is made based on the weather and wind conditions, so it is likely that the ferry will continue this pattern. From a risk point of view a path north of Anholt is less critical than the southern path. This is because the ferry sails closer to the wind farm for longer when sailing south of the investigation area. To be conservative all movements are therefore taken south of Anholt when estimating the collision frequencies.

9.4 Fishing vessels

The proposed wind farm location is located in ICES square 42G1. On the basis of VMS data (Vessel Monitoring System) fishery from vessels larger than 15 m. can be charted, see Figure 9-16. The activity of larger fishing vessel operating in the area can be characterised as very limited. In the south western corner of the investigation area there is a small amount of trawling activity and very limited fishing with Danish seine can also occur throughout the area. The lack of trawling and seine activity is mostly due to unfavourable bottom conditions.

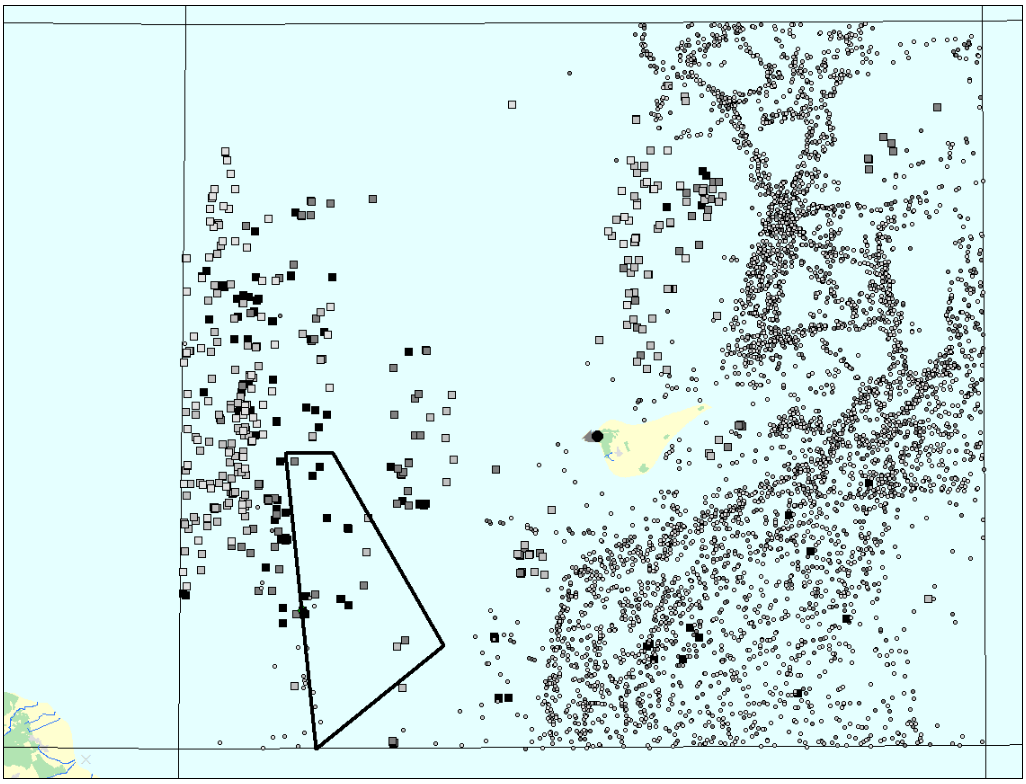


Figure 9-16 VMS data of fishing vessels larger than 15 m. for 2005-2008 in ICES square 42G1. Trawl: circles, Net: square, Danish seine: circle with dot, /16/.

The three main harbours in the vicinity of the proposed wind farm are Anholt, Bønnerup and Grenå. The number of fishing vessels resident to these harbours is given in Table 9-5. The number of fishing vessels has decreased significantly in the last years and there is a large majority of smaller vessels in all three harbours. Based on registrations of local fishermen it has also been established that the activity of smaller vessels within the project area is much larger than the activity of larger vessels, /16/.

The sailing pattern of fishing vessels is far more random than that of larger vessels as they do not follow official transit routes. In fact fishing vessels will try to stay clear of official routes in order to avoid being run down by or collide with much larger vessels.

Table 9-5 Number of fishing ships resident at Bønnerup, Grenå and Anholt from 1999-2008 /16/.

Harbour	Length	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Anholt	< 10 m	3	2	1	1	2	2	2	2	2	2
	10-15 m	1	1	1	1	1					
	> 15 m										
	Total	**4**	**3**	**2**	**2**	**3**	**2**	**2**	**2**	**2**	**2**
Grenå	< 10 m	44	40	29	28	27	24	24	26	26	21
	10-15 m	16	18	16	13	11	9	8	11	10	7
	> 15 m	10	8	8	8	9	8	8	5	5	4
	Total	**70**	**66**	**53**	**49**	**47**	**41**	**40**	**42**	**41**	**32**
Bønnerup	< 10 m	33	32	31	30	30	26	25	27	27	24
	10-15 m	10	11	9	9	8	6	6	4	4	4
	> 15 m	6	6	9	9	10	9	8	7	5	5
	Total	**49**	**49**	**49**	**48**	**48**	**41**	**39**	**38**	**36**	**33**

9.5 Leisure crafts

Kattegat is popular amongst leisure sailors and there are a number of marinas along the coast of Djursland, Jutland as well as one on Anholt. In many marinas the facilities are adapted to leisure sailors passing through as well as the sailors who are using the marinas on a year-round basis.

The busiest routes in terms of pleasure boating relevant to this project are located along the coast of Djursland from the south of Jutland and Germany, via Grenaa to Anholt. There is also traffic from the north of Jutland, Norway and Sweden crossing the Kattegat and travelling south following the "Læsø Rende" to Anholt. In addition boats travel to Anholt from Limfjorden, Mariager Fjord, Randers Fjord and Bønnerup, /17/.

As with fishing vessels the sailing pattern of leisure crafts is quite random. Leisure crafts will tend to stay closer to land and stay clear of official routes not to be run down by larger vessels. The wind farm could however act as a point of interest and attract leisure sailors.

Table 9-6 Capacity for leisure crafts in Anholt, Grenå and Bønnerup harbour.

Harbour	Capacity of berthage for leisure craft
Anholt	300
Grenå	350
Bønnerup	225

9.6 Assumed transit route layout

As described in Section 7 the Danish Maritime Authorities are currently working on changing the layout of existing transit routes in Denmark. The official location of new routes has not yet been made public and new routes will not be in effect until 2013 at the earliest. Through communication with the Danish Maritime Authorities it has been established that both the B- and E-routes are expected to be terminated and that a new transit route will be introduced 3 miles west of the project area.

Regarding the current B- and E- route certain ships could choose to follow the old routes for a period of time even after the routes have been discontinued. This is particularly relevant for the B- route as a path north of the wind farm will represent the shortest route between Øresund and Limfjorden. How much traffic will pass north of the wind farm will depend on what alternatives are given in the new layout of transit routes. The discussed scenario is less probable for the E- route as the new route, which is expected to be introduced, gives a good alternative to the E-route.

To mitigate the issue of traffic on the B-route measures should be taken at an early stage to insure that the park is communicated to navigators and clearly marked. Specifically safety zones during construction should be designed with maritime safety in mind and simplified in order to avoid confusion. This is discussed further in Section 13 and Section 14.

If the discussed issue is addressed as early as during construction then navigators will be familiar with the existence and location of the wind farm by the time operation start. Furthermore the wind farm will be clearly visible on radars, which decreases the risk of ships accidently entering the wind farm area. For these reasons only official transit routes will be included in the frequency modelling. The official transit routes are the A-route and the expected future route (EFR).

9.6.1 Traffic load on the EFR-route

In Figure 9-17 the locations of current route and the ERF-route are depicted. The EFR route runs parallel to the project area and has a bend towards the west north of the project area.

When the B- and E route is removed from sea charts the current traffic will have to find new ways of crossing Kattegat and this will give a certain traffic load on the EFR route. The issue of continued traffic on discontinued routes is discussed above. This section discusses what sort of maximum load can be expected on the EFR route, based on the current traffic.

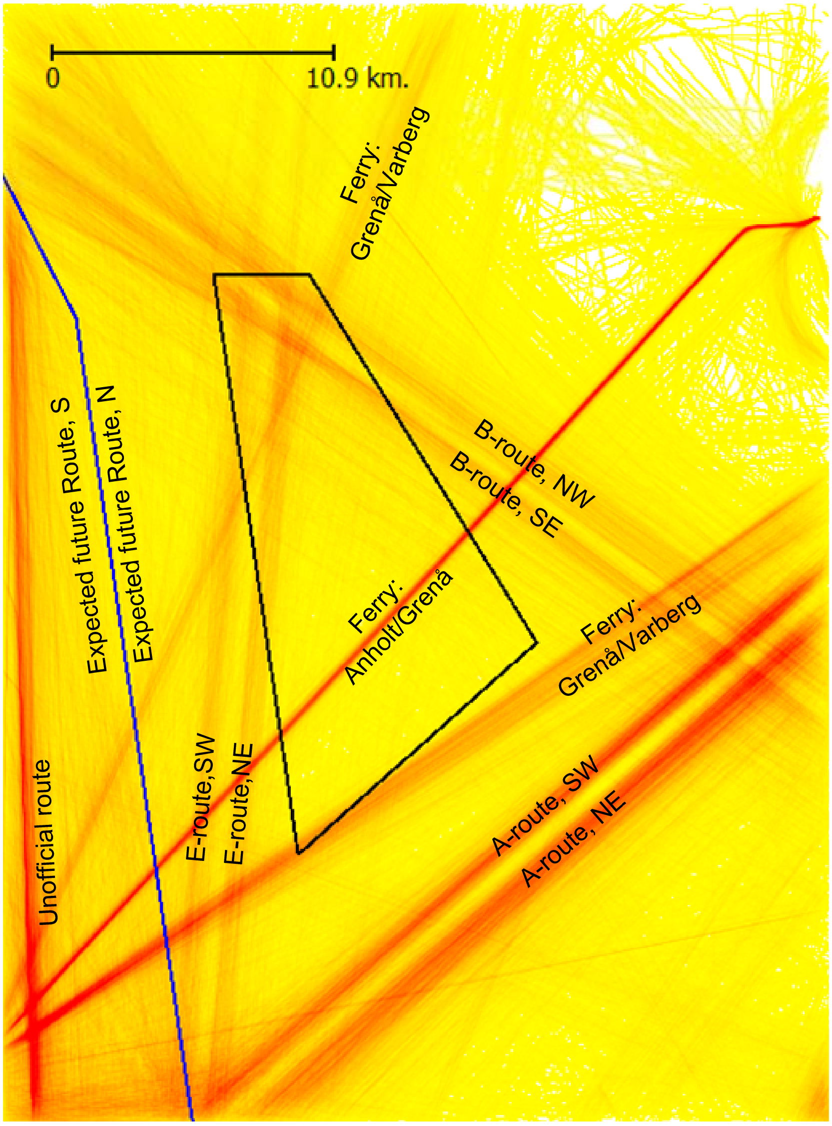


Figure 9-17. Location of the EFR route and the unofficial ship traffic route.

As can be seen in Figure 9-17 the paths of the E-route and the EFR route are very similar. It is therefore considered very likely, that the traffic from the E-route will be transferred to the EFR route, after the E-route has been terminated.

The traffic currently crossing the Kattegat using the B-route will have to travel north of Anholt or south of Hesselø, when the B-route is discontinued if they follow official transit routes. A path south of Hesselø will also take ships through the EFR route. As a conservative approach, it is assumed, that all the ship traffic on the B-route will pass through the EFR route.

West of the EFR route, there is an unofficial ship traffic lane. An unofficial lane is unmarked in sea charts, but ships, which know the area well, choose to sail here anyway. After the introduction of the new route, these ships might choose to follow the official route instead, as the two have very similar paths. This will bring the ships closer to the park, and as a conservative approach all ship traffic currently on the unofficial route is moved to the EFR route in the calculations.

With these conservative assumptions the EFR route will carry traffic form the unofficial route, the B-route and the E-route, and this traffic load will form the basis of the collision frequency analysis. The annual number of movements on the EFR-route is given in Table 9-7 and the length and width classes are illustrated in Figure 9-18 and Figure 9-19.

Table 9-7. Annual number of movements on the EFR-route.

Route	Annual number of movements
EFR, NW	2150
EFR, SE	2500

Table 9-8. Ship type distribution for the EFR-route.

Ship type	Percentage of total ship movements
Passenger	1%
Cargo	66%
Tanker	19%
Other	15%

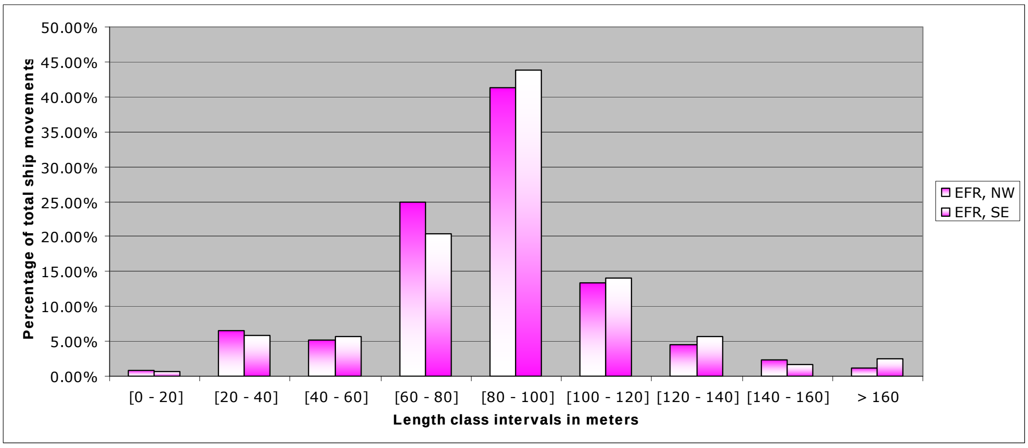


Figure 9-18. Length class distribution for the EFR-route.

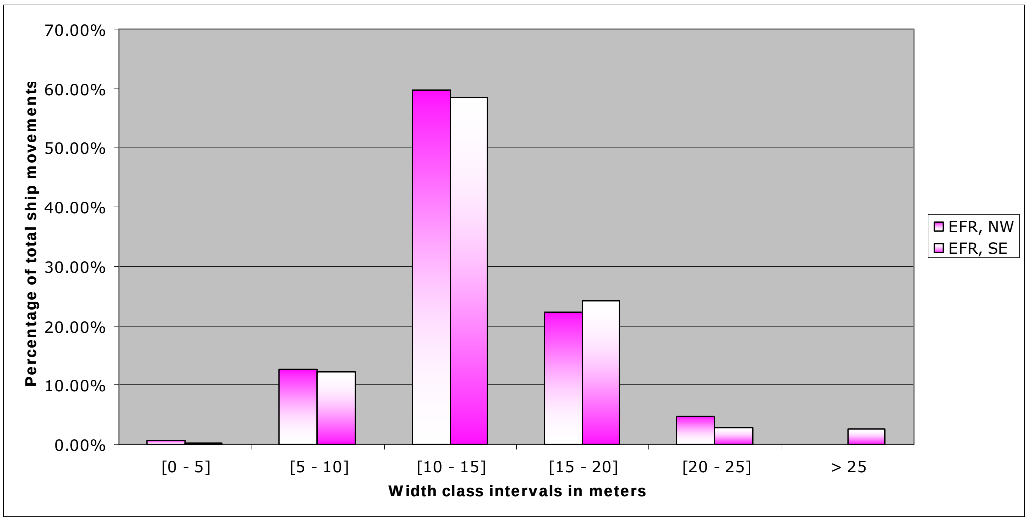


Figure 9-19. Width class distribution for the EFR-route.

9.6.2 Transverse distribution

Since the EFR route is not yet in effect the set of transverse parameters can not be found by fitting observed data. The set of transverse parameters which have been chosen for the EFR route is discussed in this section.

The specific transverse distribution on a route is mostly dependent on the size of the ship traffic and the proximity to obstacles. Generally larger ships tend to follow the route more accurately, than smaller ones and obstacles, such as areas of shallow water, also have a narrowing effect on the transverse distribution of ship traffic.

The ship dimension on the B-, E- and unofficial route, which constitute the traffic on the EFR route, is quite homogeneous in terms of dimension. This is seen in Figure 9-5 where most ships on all routes are between 60 and 120 meters in length and there is very little ship traffic above that level. The path of the current E-route and the EFR routes are very similar, so the transverse distribution parameters of the E-route will be used when modelling the EFR route. This is considered conservative as the introduction of an obstacle in form of the wind farm will probably compress the transverse distribution more than is the case on the E-route. The fit obtained for the transverse distribution on the E-route is depicted in Figure 9-20 and Figure 9-21 and the transverse parameters are given in Table 9-3.

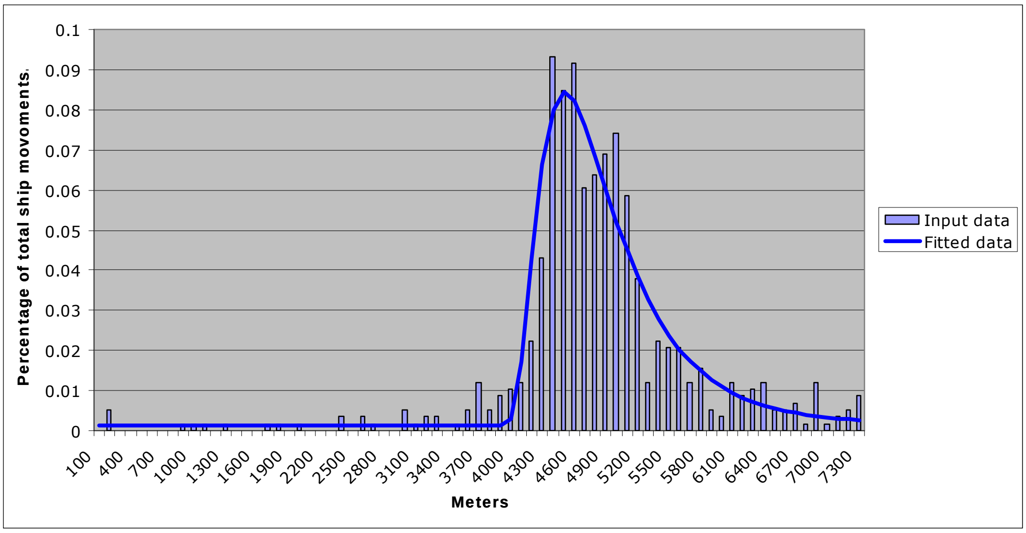


Figure 9-20. Input data and fitted data for E, NE.

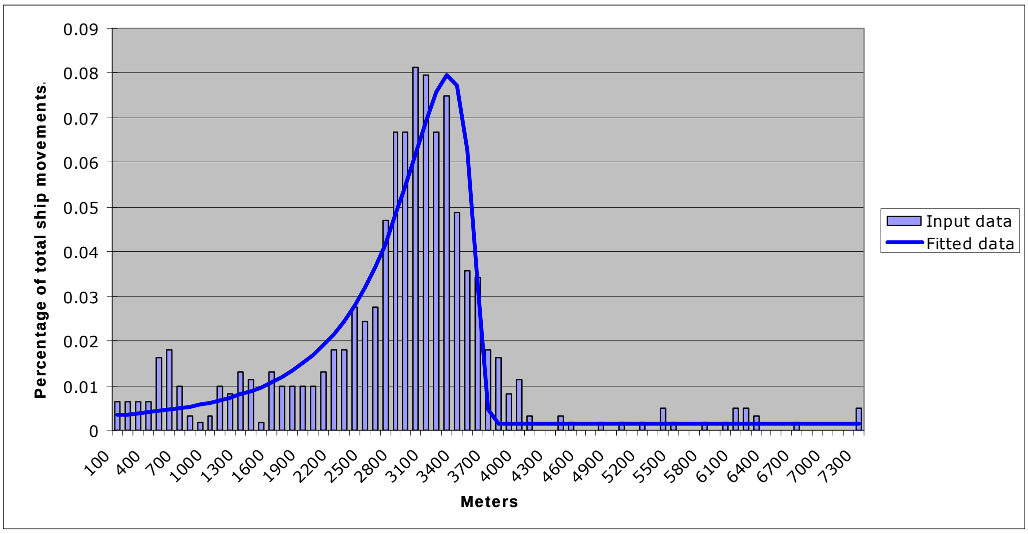


Figure 9-21. Input data and fitted data for E, SW

10. Frequency analysis

The collision frequency analysis is carried out by identifying critical situations, denoted collision scenarios, where a ship-turbine collision can occur. A model is then developed for each scenario and an estimate of the frequency of collision as a result of the specific critical situation is computed. Information regarding wind farm layout, wind and ship traffic is used as input to the model to yield an estimate of the annual ship-turbine collision frequency.

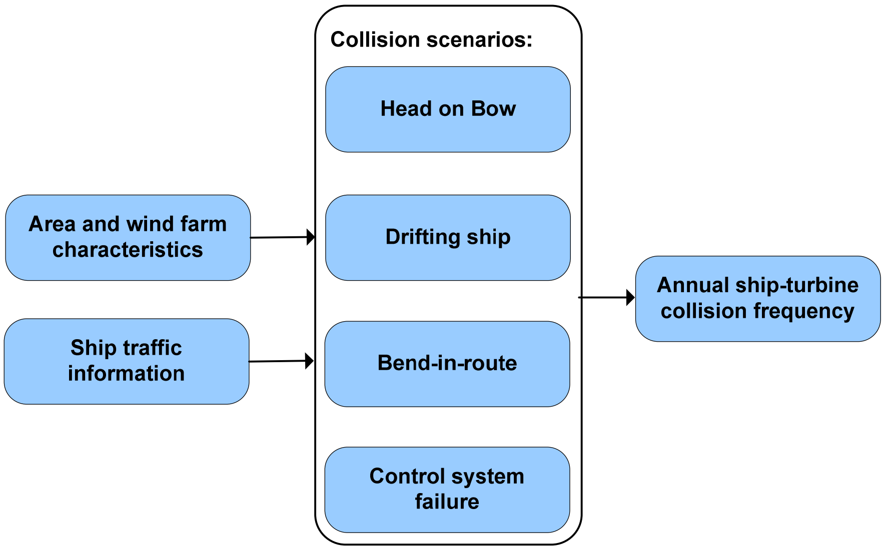


Figure 10-1. Methodology for collision frequency analysis.

If a critical situation arises and a vessel enters the project area, then a collision will not necessarily take place. The radii of the turbine foundations are only 2.5 to 12.5 meters and the distance between the turbines is expected to be minimum 500 m. The distance between the turbines is mainly governed by power production considerations, such as minimisation of wake effects etc. Due to the large distance between the turbines the probability of vessels sailing right through the farm is larger than one might first expect. If this was ignored in the model the obtained estimate would be far too conservative. In this analysis the turbines are instead modelled as individual objects which allow a certain amount of traffic to pass through the project area without the occurrence of a collision.

Another complication of having multiple objects is that front turbines can block a vessels trajectory towards back turbines, the so-called shadow effect. If this was ignored in the modelling the obtained risk estimate would be far too conservative. In this analysis the shadow effect is handled from detailed geometrical considerations.

In case of a collision event it is of course possible, that a ship could strike more than one turbine. Modelling of collision dynamics and ship trajectories after impact is however outside the scope of the report. This means that the model estimates the frequency of any ship-turbine collision event, but not how often a collision will result in damage to more than one turbine.

The collision frequency computations take the following scenarios into account:

- Head on bow (HOB) collision occur when a vessel is directly on collision course towards a turbine and no evasive actions are carried out. This collision type is also referred to as a collision due to human error.

- Drifting ship collision can occur when a vessel suffers a propulsion machinery failure and drifts towards a turbine.

- Bend-in-route collision is a result of vessels failing to make a turn when a route has a bend and subsequently collides with an obstacle.

- Control system (steering) failure resulting in circular motion due to the rudder being fixed in a left or right position and potentially leading to a collision.

The four models are described in details in the following sections.

10.1 Head on bow

The head on bow (HOB) collision occurs when a ship due to human failure continues its course along the shipping routes directly into a turbine.

There are two assumptions which have to be satisfied in order for a HOB collision to occur:

- The ship has to be on collision course. I.e. the direction of travel is directly towards a turbine. Such ships will be referred to as a "collision candidates"

- A collision candidate must hold its course and not perform any evasive actions. The probability of sustaining a collision course is denoted "the probability of a human error", $P_{Human\ Error}$.

A model is developed, which takes into account the number of ship passages on each route, the ship size distribution, the layout of the wind farm, the shadow effect and the probability of human error.

Human error

The causes for human error can be the following

- Absence from bridge

- Present but distracted
- Present but incapacitated due to accident or illness
- Present but asleep from fatigue
- Present but incapacitated from alcohol
- Ineffective radar use (bad visibility only)

The probability that a human error, $P_{Human\ Error}$, occurs is set to $2 \cdot 10^{-4}$ in accordance with /5/. It is assumed that the $P_{Human\ Error}$ is independent of the position of the ship and that failure is sustained until collision.

Collision candidates and shadow effect

The collision candidates are determined from the geometric relationship between the route and the turbines. The HOB collision scenario and the shadow effect are illustrated in Figure 10-2.

The distribution of the ships across the sailing route is a weighted sum of a log-normal and a uniform distribution. The width of the area where a ship is on HOB collision course is equal to the diameter of the turbine, plus the width of the vessel. This means that the light grey region illustrates the probability of a ship being on collision course with the front turbine. For the back turbine however, the width of the critical area has been restricted, due to the fact that the front turbine is blocking it.

The probability of a ship in ship class i being on collision course with the turbine j is denoted $P_{i,j}$. This number is obtained by integrating the ship traffic distribution given by Equation (9-1) over the area illustrated in Figure 10-2.

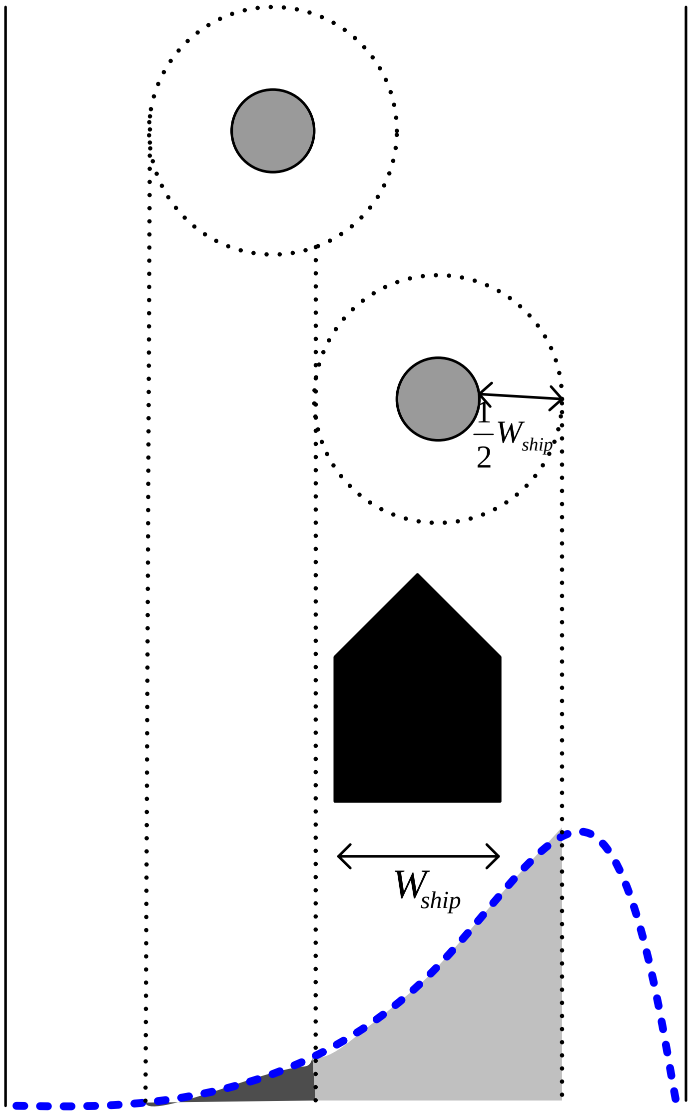


Figure 10-2. Shadow effect for the HOB collision scenario.

HOB collision frequency

The frequency of the HOB collision can now be computed using the information regarding the collision candidates, the probability of human failure and the number of passages of each ship class.

The frequency model applied is

$$f_{HOB} = P_{Human\ Error} \sum_{i}^{I} \sum_{j}^{J} N_i \cdot P_{i,j}$$

where

f_{HOB}	Frequency of Head on Bow collisions.
I	Number of ship classes.
J	Number of turbines.
N_i	Number of ships in ship class i.
$P_{i,j}$	The probability that a ship in ship class i is on collision course with turbine j.
$P_{Human\ Error}$	The probability of human error.

10.2 Drifting ship

In case of failure in the propulsion machinery the ship will start to drift, which will introduce a risk of collision if the drifting direction is towards the wind farm. If a ship is to collide with a turbine, then the following conditions must be satisfied:

- The ship has to be on collision course, i.e. the wind is moving the ship directly towards a turbine. Such ships will again be referred to as "collision candidates"
- A collision candidate must hold its course and not perform any evasive actions until the point of impact. The evasive actions considered are a mending of the propulsion equipment or successful anchoring.

As a simplification drifting ships are assumed to follow a straight path in the direction of the drifting forces and the drift velocity applied for all ships is 1 knot or 1.852 km/hour. It is also assumed that a drifting ship will collide sideways with a turbine.

In order to compute the drifting ship collision frequency the following measures must be determined:

- Drift direction
- Frequency of failure in the propulsion machinery
- Drift duration

- The probability of successful anchoring
- The collision candidates
- The number of passages for each ship class on the route

Failure in propulsion machinery

No statistical data have been identified for how often the propulsion machinery on a ship fails and the ship potentially may start to drift. However, according to general ship engineering judgement, the propulsion machinery on a ship is assumed to fail approximately once during a year in service. Assuming that an average ship has 270 effective days at sea the failure frequency per hour is

$$f_{Machine\ failure} = 1.5 \cdot 10^{-4} \text{ failures per sailing hour}$$

The above number is applied for all types of ships on the A- and EFR- route regardless of time of year.

The MF Anholt and Stena Nautica both have two propulsion engines and are thus expected to have a lower failure rate than single engine vessels. In /3/ a frequency of $1.35 \cdot 10^{-5}$ failures per sailing hour is proposed for a multiple propulsion machine vessel. This approximately corresponds to one failure per 10 years and this number is applied in the drifting ship calculations for the ferries.

Drift duration

When a failure of propulsion machinery occurs and the error is detected the person responsible for maintenance will initiate repairing the machinery and in most cases be able to fix it within a certain timeframe. The model applied in this study is a generally applied one, when modelling drifting ships.

The probability of having repaired the failure on the propulsion machinery, $P_{repair}(t)$, is given by a truncated cumulative distribution function of the Weibull distribution:

$$P_{repair}(t) = \frac{1 - \exp(-0.83 \cdot (2.4 \cdot t)^{0.5})}{1 - \exp(-0.83 \cdot 24 \cdot t^{0.5})}$$

where t is given in hours and the cut-off appears after 10 hours, indicating that it is assumed that all ships have repaired a failure within 10 hours.

The probability that a ship is still drifting at time t is then given by

$$P_{Drift\ time}(t) = 1 - P_{repair}(t) .$$

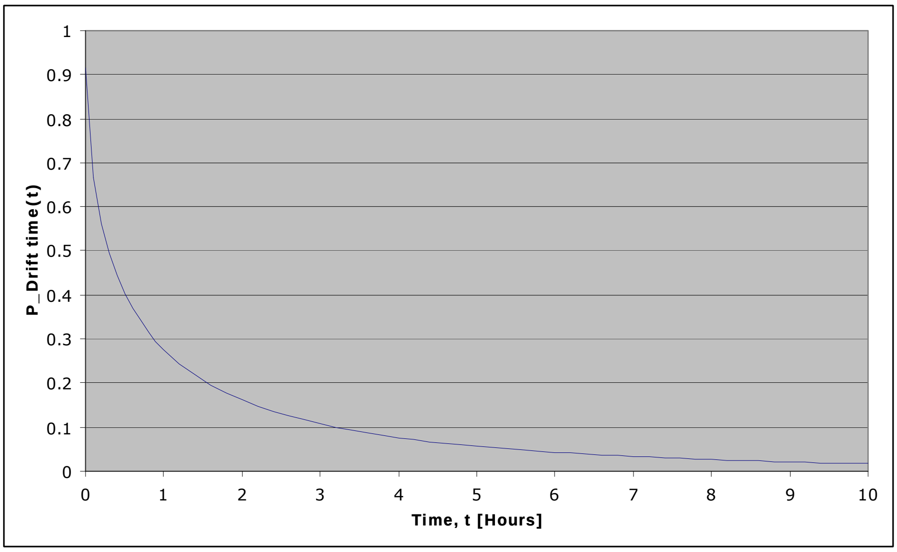


Figure 10-3. The probability of drifting as a function of time.

Probability of successful anchoring

When a ship starts to drift towards the wind farm the crew has the option of performing an emergency anchoring in order to end the drifting trajectory. The probability of successful anchoring, P_{anchor}, depends on the anchoring conditions. The usual estimate of the anchor probability of 0.7 will be applied in this analysis, since the actual water depths allow for anchoring.

Collision candidates and shadow effect

To determine the collision candidates the routes are represented by a number of equidistant points distributed along the densest part of the route. The densest part of the route is computed from the statistical description of the route given in Section 9.2.3. The distance between the points is denoted d, so the time it takes a ship to sail between two points is given by $\frac{d}{v_i}$, where v_i is the velocity of the ship. This in turn means that the probability that a ship breaks down between two points is given by $f_{Machine\ failure} \frac{d}{v_i}$. In all calculations the value of d is set to 250 meters.

It is assumed that the prevailing factor for the drift direction distribution is the wind and that the ship will drift along a straight line. It is further assumed that a drifting ship will collide sideways with the turbine.

Based on these assumptions the probability that a ship will drift towards a specific turbine can be determined from the distance between the turbine and drift point, the length of the ship and the radius of the turbine. The idea is illustrated in Figure 10-4, and it is obvious that if the ship starts to drift closer to the turbine the probability of being on collision course will increase.

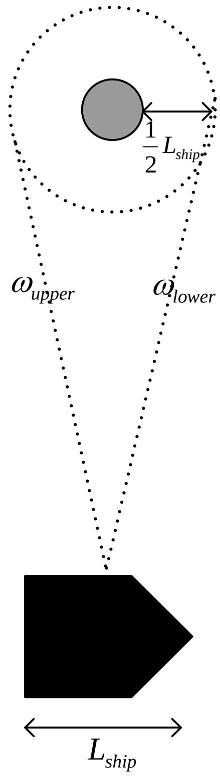


Figure 10-4. The probability that a ship will drift towards a specific turbine depends on the angle spanned by ω_{lower} and ω_{upper}.

It has been assumed that the main drift direction is determined by the wind, so the probability of a ship in ship class i , drifting from point k is on collision course with turbine j is

$$P_{i,j,k} = \int_{\omega_{lower}}^{\omega_{upper}} Wind(180-\theta)\ d\theta$$

where ω_{lower} and ω_{upper} is determined from the geometric relationship between the drift point, ship and turbine.

The shadow effect is included if a turbine is blocked by other turbines closer to the drift point. This is illustrated in Figure 10-5 and Figure 10-6.

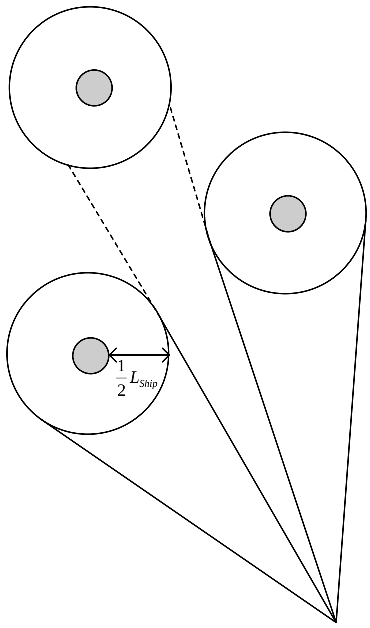


Figure 10-5. Because of the shadow effect, the angle span of the back turbine is narrowed as the two front turbines are blocking it.

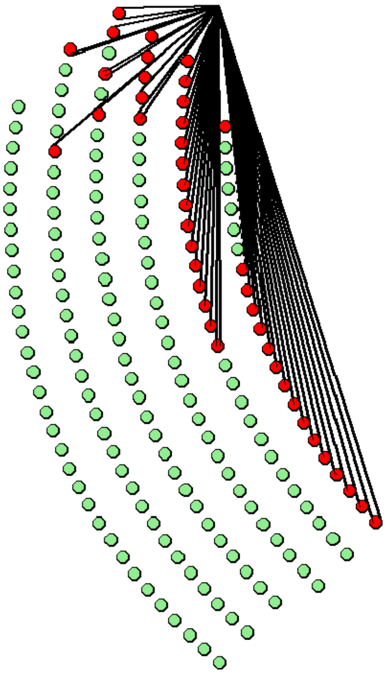


Figure 10-6. The shadow effect means that only the red turbines can get a straight hit by a ship drifting in a straight line from the point of origin. Notice that the turbine radii have been strongly exaggerated for the sake of clarity. In actuality it is mostly the length of the ship, which makes the shadow effect a significant factor.

Drifting ship collision frequency

The frequency of the drifting ship collisions can now be computed using the information regarding the collision candidates, the probability of succesfull anchoring, the frequency of machine failure, the expected drift time and the number of passages for each ship class. The frequency model applied is

$$f_{Drifting\ ship} = (1 - P_{Anchor}) \cdot \sum_{i}^{I} f_{Machine\ failure} \frac{d}{v_i} \sum_{j}^{J} \sum_{k}^{K} P_{Drift\ time} \cdot N_i \cdot P_{i,j,k}$$

where

$f_{Drifting\ ship}$ Frequency of drifting ship collisions.

P_{Anchor} The probability of successful anchoring.

I Number of ship classes.

$f_{Machine\ failure}$ Frequency of failure in propulsion machinery.

d Distance between discretization points.

v_i Average speed of ships in ship class i .

J Number of turbines.

K Number of discretization points on route.

$P_{Drift\ time}$ The probability that a ship drifting from point k will drift long enough to reach turbine j .

N_i Number of ships in ship class i .

$P_{i,j,k}$ The probability that a ship in ship class i , drifting from point k is on collision course with turbine j .

10.3 Bend-in-route

The bend-in-route scenario is relevant if there is a bend in a route close to an obstacle and vessels are on collision course before the bend. All vessels which, due to human error, do not make the turn can collide with the obstacle if no evasive actions are performed. In order for a collision to occur the distance to the obstacle must therefore be less than the distance cowered by the ship in the time it takes to detect the error.

It is assumed that the failure to follow the route correctly is always detected within one hour and evasive actions are then performed. If the average speed of vessels is 25 km/hour, then the obstacle must be within 25 km of the bend in the route in order for a collision to occur.

Present day traffic

There are three bends in the route, which could potentially be critical to the wind farm. These bends and the possible collision courses are marked in Figure 10-7. It is clear from the figure that the distance between bends and turbines is more than 25 km. for all bends and only a fraction of the ship traffic is actually on collision course with the project area. The bend-in-route scenario is therefore not considered critical since the contribution to the ship-turbine collision frequency is minimal.

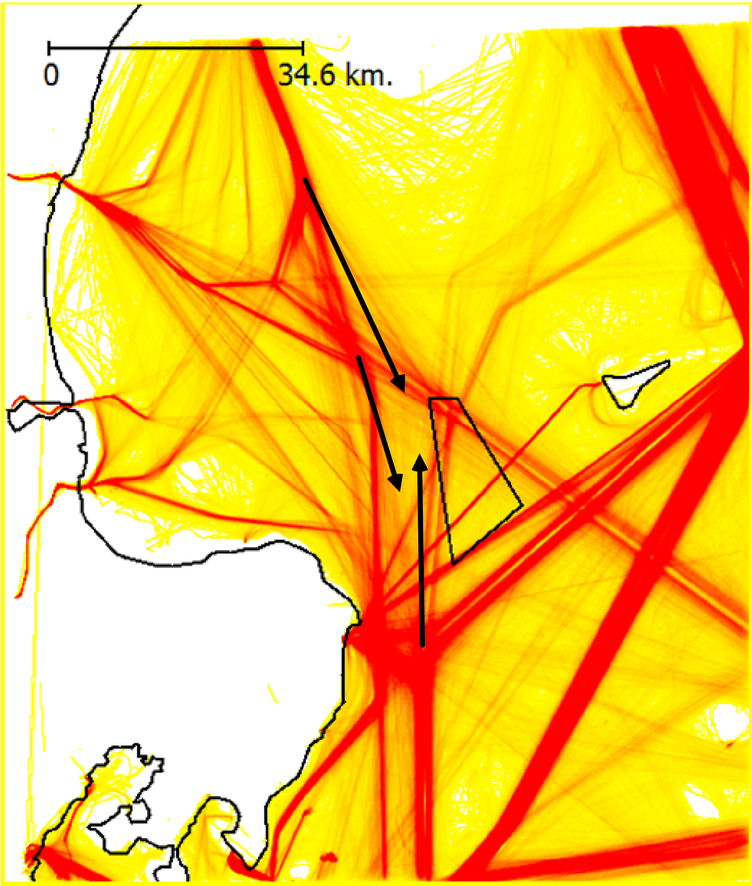


Figure 10-7. There are three bends in routes close to the project area. The distance between bends and the wind farm, however, is large, so the bends pose a minimal risk.

Bend in the EFR

As can be seen from Figure 9-17 the EFR-route has a bend quite close to the project area. The distance between the bend and the project area is only 15 km, so the bend in route scenario will be investigated for southbound traffic on the EFR-route.

For a ship to strike a turbine as a result of a bend in the route the ship has to miss the turn and fail to detect the error until the point of collision. The missed turn is a result of human error so the causation factor applied is the same as in Section 10.1. The geometrical probability of collision for this scenario is the same in the head on bow scenario (see Section 10.1). In /12/ it is proposed to model the annual frequency at which a ship does not detect that it has failed to make a correct turn by

$$P_{\text{Error not detected}} = e^{-\lambda \cdot \frac{d}{v}}$$

where λ is the check frequency of the navigator (checks per hour), d is the distance between missed turning point and obstacle (km) and v is the velocity of the vessel. This description is applied in the present project. The check frequency is set to 30 checks per hour and the average velocity is assume to be 25 km/hour.

With this setup the following frequency model is applied

$$f_{BIR} = P_{Human\ Error} \sum_{i}^{I} \sum_{j}^{J} N_i \cdot P_{i,j} \cdot P_{\text{Error not detected}}$$

where

f_{BIR}	Frequency of bend in route collisions.
I	Number of ship classes.
J	Number of turbines.
N_i	Number of ships in ship class i.
$P_{i,j}$	The probability that a ship in ship class i is on collision course with turbine j.
$P_{Human\ Error}$	The probability of human error.
$P_{\text{Error not detected}}$	The probability that the failure to make the correct turn is not detected before collision.

10.4 Control system failure

The final scenario which is included in the analysis is a control system failure collision. In case of failure in the control system the rudder will be locked in a certain position and the ship will initiate a clockwise or anti-clockwise circular motion. It is assumed that such a failure will result in the rudder placed in one of the two outer positions. If the trajectory of the circular motion is intersecting the project area a collision can occur.

The radius of the circular motion is influenced by the length of the ship, the width and the ship type. In general the radius is from 2 to 5 times the length of the ship.

The control system failure collision frequency can be obtained from the frequency of control system failure and the probability of a ship having a control system failure while passing the park.

Frequency of control system failure

According to an American survey described in /4/ the frequency of control system failure is estimated to 0.41 failures pr. ship pr. year. Assuming that the effective number of sailing days is equal to 270 the frequency for failure in the control system is given by

$$f_{control\ system\ failure} = 6.3 \cdot 10^{-5} \text{ failures per sailing hour}$$

This measure is applied for all kind of ship types/classes and is considered to be constant for the whole period a ship is in service.

As the ship can turn either port or starboard, the probability that a ship will suffer a control system failure, which can lead to a collision, is $\frac{1}{2} f_{control\ system\ failure}$.

Collision candidates

For a ship to collide with a turbine it must suffer a control system failure while passing the project area, as illustrated in Figure 10-8. The time it takes a ship to pass the project area is given by $\frac{L_{Park}}{v_i}$, where L_{Park} is the length of the side of the project area, which is parallel to the route, and v_i is the average speed of the ship class.

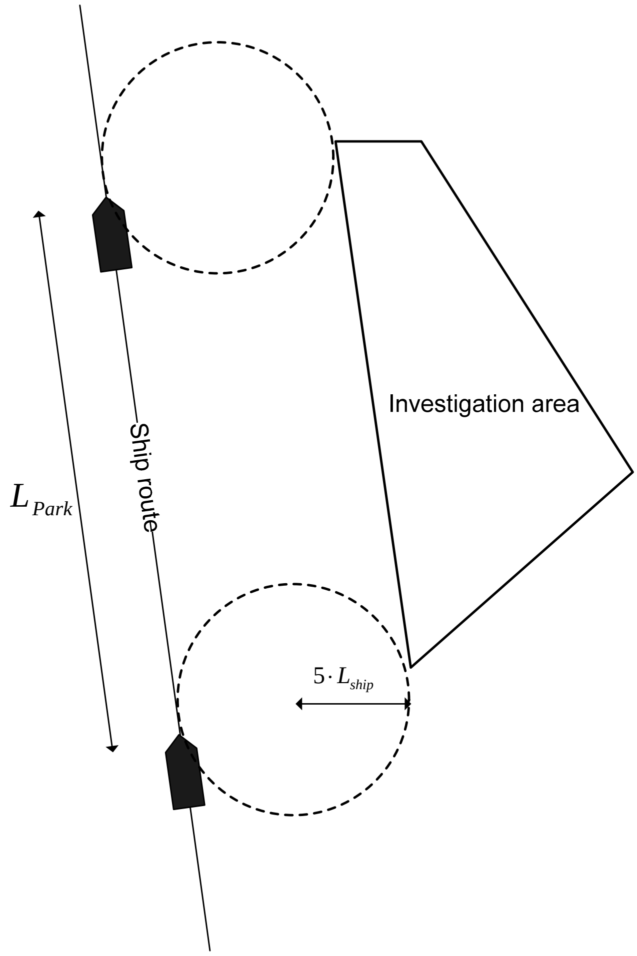


Figure 10-8. For a ship to collide with a turbine as a result of control system failure it must suffer the failure while traversing the distance L_{Park}.

The diameter of the circular motion is much smaller than the distance from the centre of the route to the project area. This means that only a fraction of the traffic on the route is close enough to actually intersect the project area in case of control system failure, as illustrated in Figure 10-9. The probability that a ship is within a critical distance of the project area is denoted P_i. This number is obtained by integrating the ship traffic distribution given by Equation (9-1) over the area illustrated in Figure 10-9.

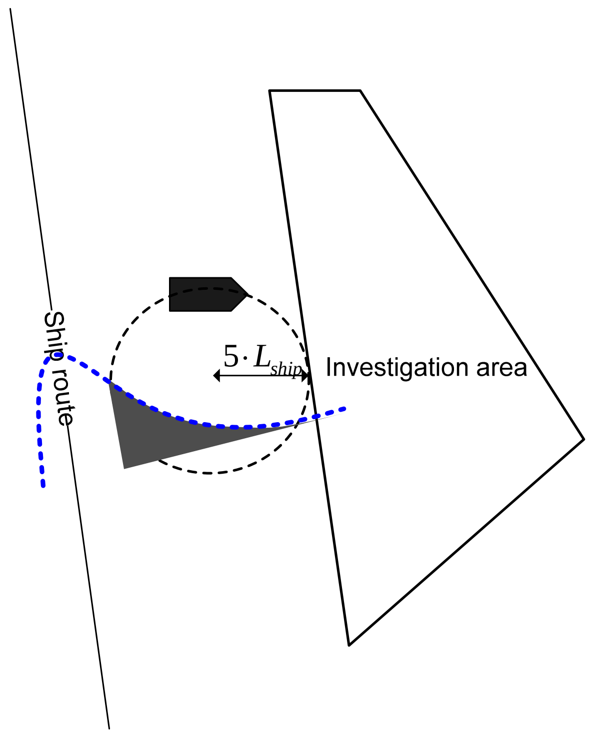


Figure 10-9. Not all ship traffic is close enough to intersect the project area in case of control system failure.

Control system failure collision frequency

The frequency of collisions caused by control system failure can now be computed using the information regarding the collision candidates, the frequency of control system failure, the critical distance that ship sail parallel to the wind farm and the number of passages for each ship class.

The frequency model applied is

$$f_{Control\ system\ collision} = \frac{1}{2} f_{control\ system\ failure} \cdot \sum_{i}^{I} P_i \cdot N_i \cdot \frac{L_{Park}}{v_i}$$

where

$f_{Control\ system\ collision}$ Frequency of collisions as a result of control system failure [per year].

$f_{Control\ system\ failure}$ Frequency of control system failure [per year].

P_i Probability of a ship in length class i being a collision candidate.

N_i Number of ships in ship class i.

L_{Park} Length of the side of the farm which is parallel to the route [m].

v_i Average velocity of ships in ship class i [km/hour].

10.5 Transformer station

As discussed in Section 8.6.3, the design basis for the transformer station is up to 60 by 60 meters. As a conservative approach the station is modelled by a circular zone completely containing that area, see Figure 10-10. The transformer station is assumed to be positioned at (632210; 6274468) which is the centre of the 100 by 100 meter area indicated in Figure 8-7. It can also be seen from Figure 8-7 that the transformer station is far more exposed to then ERF route, than the A-route. Only the EFR route is therefore considered relevant when estimating collision frequencies to the transformer station.

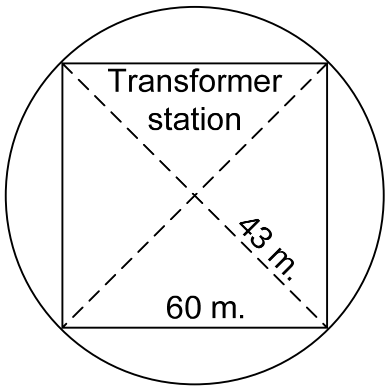


Figure 10-10 The transformer station is modelled by a circular zone completely containing the station.

10.6 Results

The frequency model presented in Section 10.1 to Section 10.4 is used to obtain the results for the following scenarios:

- Head on bow (Section 10.1).
- Drifting ship (Section 10.2).

- Bend in route (Section 10.3).
- Control system (steering) failure (Section 10.4).

In Section 9.4 the location and traffic load on the EFR route was discussed and a conservative future scenario was that the traffic currently on the B-, E- and unofficial route would all be transferred to the EFR route west of the project area. The A-route would remain the same, but the ferry routes would pass south of the project area as described in section 9.3.

10.6.1 Ferry traffic

Some of the basic assumptions and model parameters are different for the ferries than for the additional traffic.

The bend in route scenario is not relevant as the ferries are never on collision course with the park before a bend.

The drifting ship scenario is modelled the same way as with the regular traffic. It is again noted, that the MF Anholt and Stena Nautica both have two propulsion engines and are thus expected to have a lower propulsion failure rate than single engine vessels. A frequency of $1.35 \cdot 10^{-5}$ failures per sailing hour is therefore applied in the drifting ship calculations for the ferries.

Assessing the collision frequencies for the head on bow and steering error is also a bit different than for the regular traffic, as the ferries will travel relatively close to the wind farm. As discussed earlier passing close to an object means that the transverse distribution will change considerably and become skew rather than symmetric. This is illustrated in Figure 10-11, Figure 10-12 and Figure 10-13. The transverse distribution of the Varberg ferry is depicted both as it approaches Grenå and as it passes close to Anholt. It can be seen from Figure 10-12, that when the Ferry is free of all obstacles the transverse distribution is a relatively wide, symmetrical distribution. In Figure 10-13 the transverse distribution as the ferry passes Anholt is given. The distribution here is skew and very steep towards Anholt. There is no movements left of the 1400 meter mark on the report line. The reason for this is that ferry personnel are very familiar with the area and experienced in traversing the specific ferry route.

The same change in sailing pattern will probably happen once the wind farm is constructed. The head on bow and control system failure frequencies for the ferries are therefore computed by use of the symmetrical transverse distribution and multiplied by a factor of 0.01 to account for the narrowing effect. This means that the amount of times where the ferry strays significantly from the central path in Figure 10-12 and Figure 10-14 is reduced by a factor of 100.

The transverse distribution of the MF Anholt is depicted in Figure 10-14 and statistical parameters describing the transverse distribution of the ferries are given in Table 10-1.

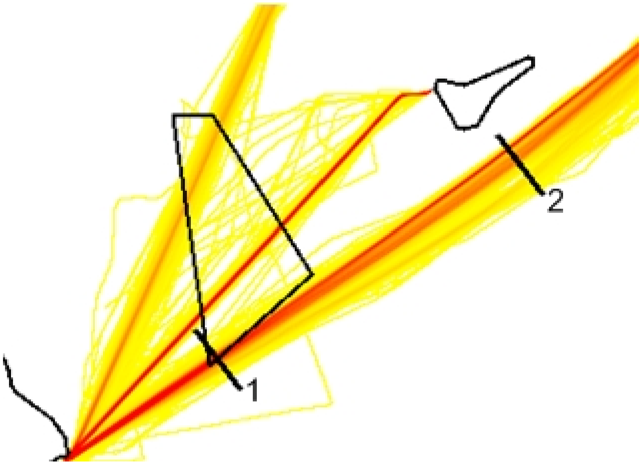


Figure 10-11 Report lines used for analysing transverse distribution of movements of the Grenå-Varberg ferry.

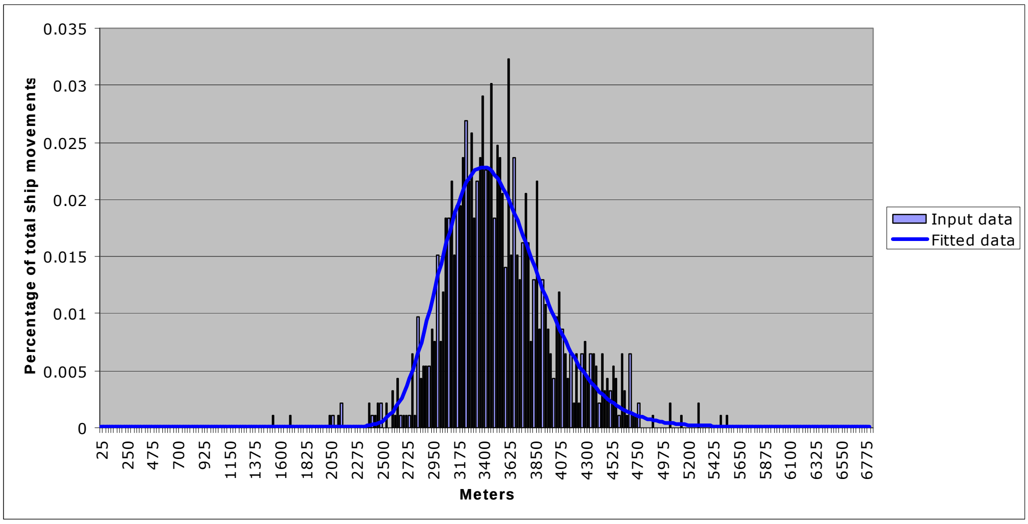


Figure 10-12 Transverse distribution for the Varberg-Grenå ferry as it approaches Grenå. The distribution is obtained for report line 1 in Figure 10-11.

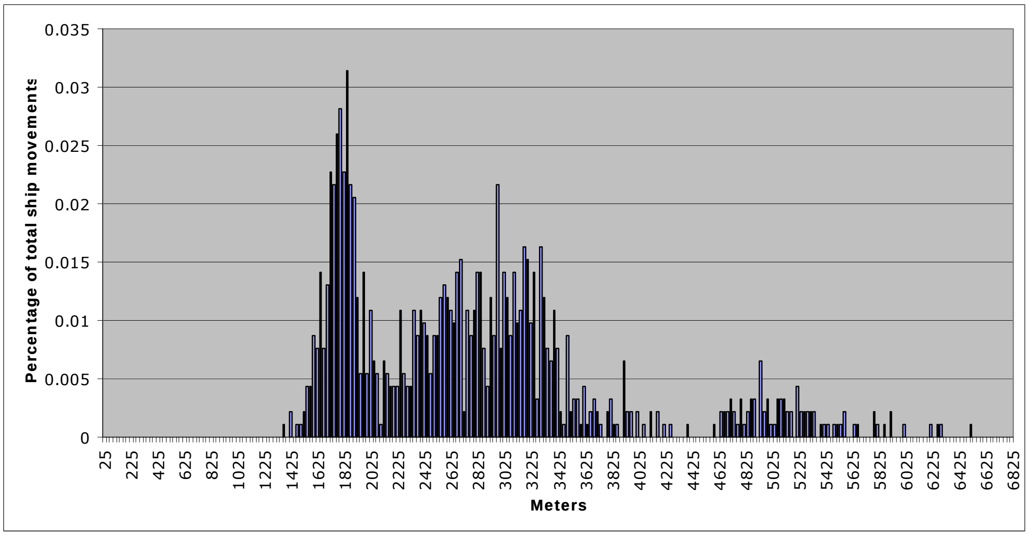


Figure 10-13 Transverse distribution for the Varberg-Grenå ferry as it passes Anholt. The distribution is obtained for report line 2 in Figure 10-11.

Table 10-1. Statistical parameters describing the ferries.

Route	μ	σ	α	a	b
Varberg-Grenå	7.69	0.12	0.02	2103	4722
Anholt-Grenå	7.77	0.05	0.04	2365	3009

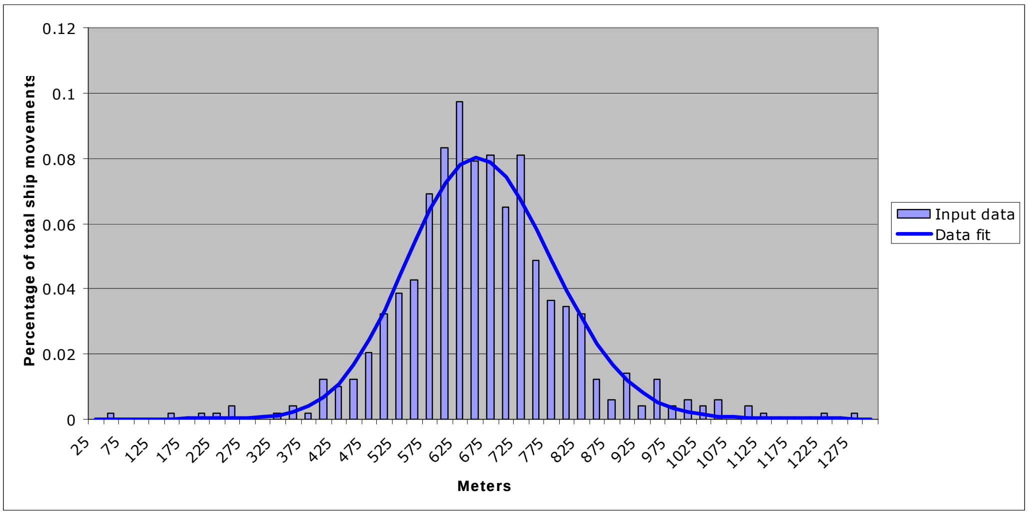


Figure 10-14 Transverse distribution of the MF Anholt.

10.6.2 Combined results

The collision frequencies have been estimated for the two turbine layouts, namely Radials 2.3 and Arcs 2.3 (Figure 8-6). The results related to the current ship traffic are presented in Appendix 16.1.

For the layout Radials 2.3 the results are given in Table 10-2 and Table 10-3. The return period of ship-turbine collision summarised over all routes and scenarios is 172 years.

Table 10-2. Estimated annual collision frequencies for the turbine layout Radials 2.3.

Route	Head on Bow	Drifting ship	Control sy-stem failure	Bend in route	Total
A-Route, turbines	2.02E-08	8.13E-04	3.11E-06	NA	8.16E-04
EFR, turbines	1.01E-04	4.54E-03	3.93E-05	5.36E-08	4.68E-03
EFR, transformer	2.95E-05	9.04E-05	9.68E-08	7.69E-10	1.20E-04
Varberg-Grenå	4.53E-06	7.09E-05	9.86E-05	NA	1.74E-04
Anholt-Grenå	1.17E-06	2.26E-05	1.21E-06	NA	2.50E-05
Total	1.36E-04	5.54E-03	1.42E-04	5.44E-08	5.82E-03

Table 10-3. Estimated collision return period for turbine layout Radials 2.3.

Route	Head on Bow	Drifting ship	Control sy-stem failure	Bend in route	Total
A-Route, turbines	49,504,950	1,230	321,543	NA	1,225
EFR, turbines	9,901	220	25,445	18,656,716	214
EFR, transformer	33,898	11,062	10,330,579	1,300,390,117	8,334
Varberg-Grenå	220,701	14,107	10,145	NA	5748
Anholt-Grenå	853,018	44,153	827,471	NA	39,953
Total	7,341	181	7,028	18,392,834	172

The largest contribution to the ship-turbine collision frequency is from drifting ships. A drifting ship collision where the ship originated from EFR is five times more likely than a ship drifting from the A-route. There are a number of reasons for this:

- The distance between the route and the project area is the same for both routes, but the EFR is down wind from the turbines, which increases the risk of collision.
- Turbines are spread out along the western border of the project area parallel to the EFR. This means that passing ships are exposed to the wind farm for longer time on the EFR than on the A-route.
- It has been estimated that there will be about 30% more ships on the EFR route than on the A-route.

The estimated collision frequencies and return period for the layout Arcs 2.3 are given in Table 10-4 and Table 10-5. Considering the A-route the collision frequencies are almost the same for both layouts, because they both consist of six rows of turbines. The total return period for a collision is 217 years, which is higher than the number found for Radials 2.3. The main reason is that drifting ships from the EFR route have to drift longer to collide with a turbine, which reduces the frequency of collision. For both layouts the ferry routes have the smallest contribution to the total collision frequency.

For both layouts the collision return periods fall into the ALARP area of between 50 and 300 years where further analysis of consequences and mitigating measures are needed in accordance with the criteria described in Section 6.

Table 10-4. Estimated annual collision frequencies for the turbine layout Arcs 2.3.

Route	Head on Bow	Drifting ship	Control system failure	Bend in route	Total
A-Route, turbines	1.93E-08	9.03E-04	3.11E-06	NA	9.06E-04
EFR, turbines	9.64E-05	3.23E-03	3.93E-05	4.33E-08	3.37E-03
EFR, transformer	2.95E-05	9.04E-05	9.68E-08	7.69E-10	1.20E-04
Varberg-Grenå	4.99E-06	7.66E-05	9.86E-05	NA	1.80E-04
Anholt-Grenå	1.36E-06	2.95E-05	1.21E-06	NA	3.21E-05
Total	1.32E-04	4.33E-03	1.42E-04	4.41E-08	4.60E-03

Table 10-5. Estimated collision return period for the turbine layout Arcs 2.3.

Route	Head on Bow	Drifting ship	Control system failure	Bend in route	Total
A-Route, turbines	51,813,472	1,107	321,543	NA	1,104
EFR, turbines	10,373	310	25,445	23,094,688	297
EFR, transformer	33,898	11,062	10,330,579	1,300,390,117	8,334
Varberg-Grenå	200,235	13,047	10,145	NA	5,549
Anholt-Grenå	734,596	33,843	827,471	NA	31,135
Total	7,560	231	7,028	22,691,688	217

10.7 Sensitivity analysis

In order to assess the sensitivity of the results presented in Section 10.6 the effect of larger turbine radius is analysed. Furthermore, since the drifting ship scenario contributes the most to the total collision frequency, the significance of the drifting speed is assessed in details.

10.7.1 Turbine radius

In the ship-turbine collision frequency model presented in section 10.1 to 10.4 it is assumed that the radius of the turbine is 2.5 meters. In order to assess the importance of this parameter the ship collision frequency results are obtained for a turbine radius of 5 m. for A-route and EFR, since these routes contributes the most the total ship-turbine collision frequency.

In Table 10-6 and Table 10-8 ship-turbine collision return periods are shown for the two wind farm layouts for the A-route and EFR. Comparing the results with the results in Table 10-3 and Table 10-5 for the radius 2.5 meters case the increase in collision frequencies can be computed. The results are given in Table 10-7 and Table 10-9. The collision frequencies will depend not only on the size of the turbine, but also on the length and width of the involved ships. This is why the increase in head on bow frequencies is larger than the increase in drifting ship frequencies as the first collision scenario involves the width of the ship, but the second scenario involves the length of the ship.

The total increase in collision frequencies is less than 5%.

The scenario control system failure has not been included, because the turbine radius is not a parameter in the control system failure model. The bend in route scenario is not included because the contribution to the total collision frequency is very small.

Table 10-6. Estimated collision return period for the turbine layout Radials 2.3, with radius 5.

Route	Head on Bow	Drifting ship	Total
A-route	44,843,049	1,214	1,214
EFR	9,009	211	207

Table 10-7. Increase in collision frequencies when radius in increased from 2.5 m to 5 m for the turbine layout Radials 2.3.

Route	Head on Bow	Drifting ship	Total
A-route	10.40%	1.35%	1.35%
EFR	9.90%	4.19%	4.31%

Table 10-8. Estimated collision returnperiod for the turbine layout Arcs 2.3, with radius 5.

Route	Head on Bow	Drifting ship	Total
A-route	45,871,560	1,095	1,095
EFR	8,772	298	288

Table 10-9. Increase in collision frequencies when radius in increased from 2.5 m to 5 m for the turbine layout Arcs 2.3.

Route	Head on Bow	Drifting ship	Total
A-route	12.95%	1.11%	1.11%
EFR	18.26%	4.02%	4.44%

10.7.2 **Drift speed**

In the drifting ship collision scenario presented in section 10.2 it is assumed that the ship is drifting with a velocity of 1 knot. By varying the assumed drifting speed the collision frequency will change. For the current analysis only the A-route and EFR is used, since they contribute the most the total collision frequency.

The annual collision frequency is computed for drifting velocity of 0.5 knot, 1 knot (base case) and 2 knots. In Table 10-10 the results are shown for the radials 2.3 layout and a turbine radius of 2.5 m. It can be observed that the higher drifting speed the higher ship-turbine collision frequency, which means that the ships drifting from a longer distance will be able to collide with the turbines. For the A-route the collision frequency increases by a factor 3.26 when applying 2 knots in stead of 1 knot, while for the ERF the collision frequency increases by 2.39. If a drifting speed of 2 knots is applied the total return period would be approximately 69 years, which is still in the ALARP region according to criterion in section 6.

Table 10-10. Estimated annual collision frequency for drift speed equal to 0.5, 1 and 2 knots. The layout used for the calculations is Radials 2.3 with a turbine radius of 2.5.

Route	0.5 knots	1 knot	2 knots
A-route	1.31E-04	8.13E-04	2.65E-03
EFR	1.07E-03	4.54E-03	1.08E-02

11. Consequence analysis

In section 10 the frequency of ship collision with a turbine in the wind farm was assessed. In order to obtain the risk (frequency · consequence) the consequences must be determined.

In the event of a ship colliding with a turbine it could either lead to a severe damage of the turbine and/or the ship. It may also be the case that the ship barely touches the turbine resulting in a less severe or insignificant damage. Figure 11-1 illustrates three categories of consequences which can occur.

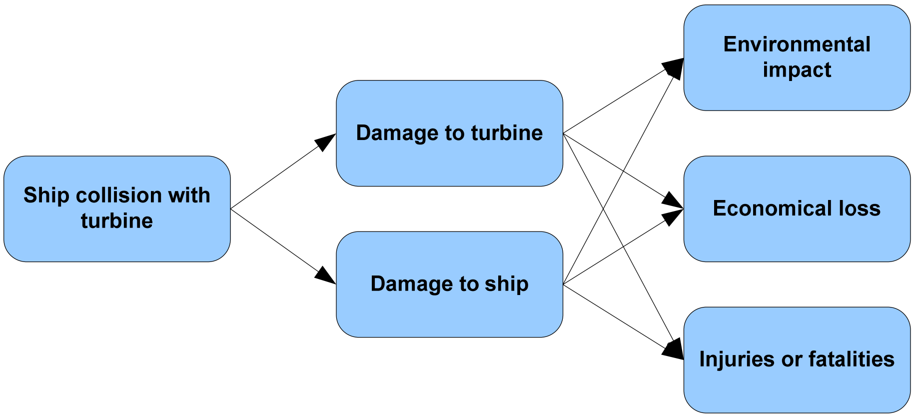


Figure 11-1 Severe consequences related to a ship colliding with a turbine.

Damage of the turbine could lead to one or more of the following:

- Environmental impact:
    - Discharge of chemicals and/or lubrication oil from the turbine.
- Economical loss:
    - Loss of power production from turbine. Depending on the electrical grid layout of the farm and the emergency procedures, the farm may still produce power from the remaining turbines not affected by the loss of the collided turbine. Damage to the transformer station would lead to a significantly longer downtime (several months) of the whole power production of the farm.
    - Loss of property in terms of the turbine
    - Loss of reputation

- Injuries or fatalities:
    - Injuries or fatalities of the maintenance crew present at the turbine

Damage to the ship could lead to one or more of the following:

- Environmental impact:
    - Discharge of oil spill, chemicals etc. from the ship
- Economical loss:
    - Costs of repairing damaged ship, cost of not being able to utilise the ship due to repair time
    - Loss of reputation
- Injuries or fatalities:
    - Injuries or fatalities of ship crew and passengers

In the following only consequences related to the environment and human safety are considered. The economic consequences are as such not related to the safety of the ships.

It is assumed that the environmental impact from a ship colliding with a turbine is mainly due to an oil spill from the ship. Discharge of various chemicals or lubrication oils from the turbine is of very limited amount and is therefore considered negligible compared to the amount of oil discharged from a ship. Injuries and fatalities to maintenance crew is not part of the risk assessment to 3rd party personnel and are therefore not addressed. Therefore, only consequences related to damages to ship is assessed in the following.

11.1 Environmental impact

Environmental impact can result from the turbine collapsing onto the ship or from bottom rupture of the ship. Each scenario is discussed below and the risk is determent by use of event trees. Event trees are given in Appendix 16.3.

11.1.1 Falling turbine

Passenger ships and cargo ships bunker fuel can be discharged if the fuel tank is penetrated by the turbine. The fuel tank is normally located close to the engine room in the stern of the ship. The same accounts for the tanker ship, but they also have a number of oil tanks, typically 6 to 12 tanks depending on the size of the ship.

Using the consequence ranking in section 6 it is assumed that for passenger ships and cargo ships a bunker spill will be a *significant* consequence, while for tanker ships the spill will either be *significant* (80%) or *severe* (20%).

Table 11-1 Consequence ranking for falling turbine distributed on ship types.

	Minor	Significant	Severe	Major
Passenger/Cargo	0	100%	0	0
Tanker	0	80%	20%	0

The probability of a collision leading to a spill, P_{spill}, is obtained by the use of event trees where the following assumptions are applied:

- As described in /1/ the turbine structure will probably fail in case of collision with a larger ship and if the collision scenario is a drifting ship, then the turbine will in most cases fall away from the ship and into the water. For the collision scenario drifting ship the probability of the turbine falling onto the ship is therefore set to 0.25.
  A direct impact can result from the collision scenarios head on bow, control system failure or bend in route. A direct impact will be more forceful than a drifting ship collision and the probability of the turbine falling on to the ship is therefore set to 0.75.

- It is assessed that there is a 0.1 probability that the impact from the falling turbine will result in damage to fuel tanks (all type of ships) or oil tanks (only applicable to tankers).

Table 11-2 Probability that the turbine falls on to the deck of the ship for the different cillision scenarios.

	Drifting ship	Head on bow, control system failure and bend in route
Turbine falls onto ship	0.25	0.75
Turbine falls away from ship	0.75	0.25

11.1.2 Bottom rupture from slicing

If the turbine foundation is a GBS structure, then a sharp edge on the GBS base can cause tearing of the hull if the ship slides along the edge (see Figure 11-2).

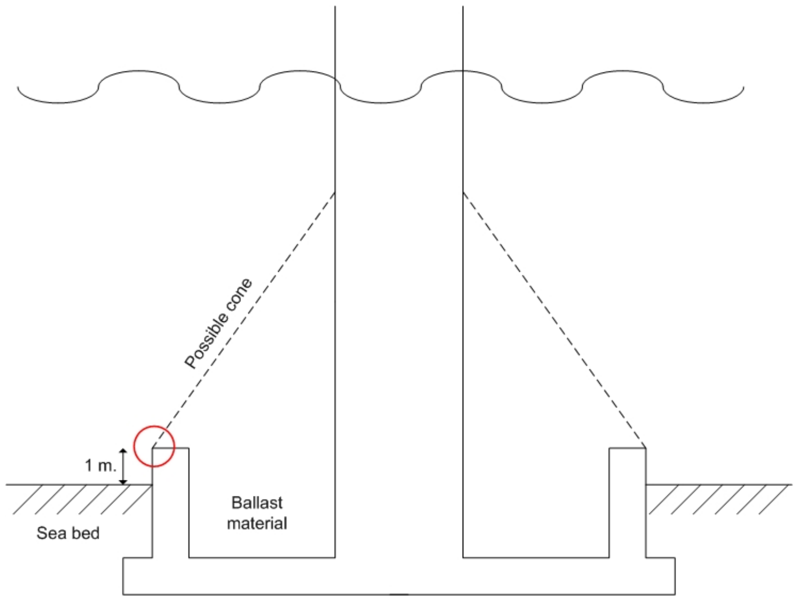


Figure 11-2 Illustration of GBS foundation. The red circle marks the critical edge.

For bottom slicing to occur the involved ship must have a large enough draught for the ship hull to come into contact with the foundation base. The draught which makes this possible is called critical draught.

The probability of bottom rupture from slicing leading to a spill, P_{spill}, is obtained by the use of event trees where the following assumptions are applied:

- The collision type must be a direct hit in order for the ship to keep sliding along the edge. Direct hits can result from head on bow, control system failure and bend in route collisions.
- The ship must have critical draught.
- It is assessed that if the ship does have critical draught, then there is a 0.5 probability that the collision will result in severe damage to fuel tanks (all type of ships) or oil tanks (only applicable to tankers).

The consequence ranking in case of bottom rupture from slicing is given in Table 11-3.

Table 11-3 Consequence ranking for bottom rupture from slicing distributed on ship types.

	Minor	**Significant**	**Severe**	**Major**
Passenger/Cargo	0	80%	20%	0
Tanker	0	33%	33%	33%

Critical draught

To analyse what is a critical draught certain assumptions has to be made on the dimensions of the GBS foundation. In the present analysis it is assumed, that the critical edge on the foundation will rise at most 1 m. above the sea bed. This is based on that the GBS foundation base will be three meters high and imbedded at least two meters.

The depth in the project area is depicted in Figure 11-3 and varies between 14 and 20 meters. Generally the depth is larger in the southern part of the area, and south of the dotted line the minimum depth is 15.5 meters.

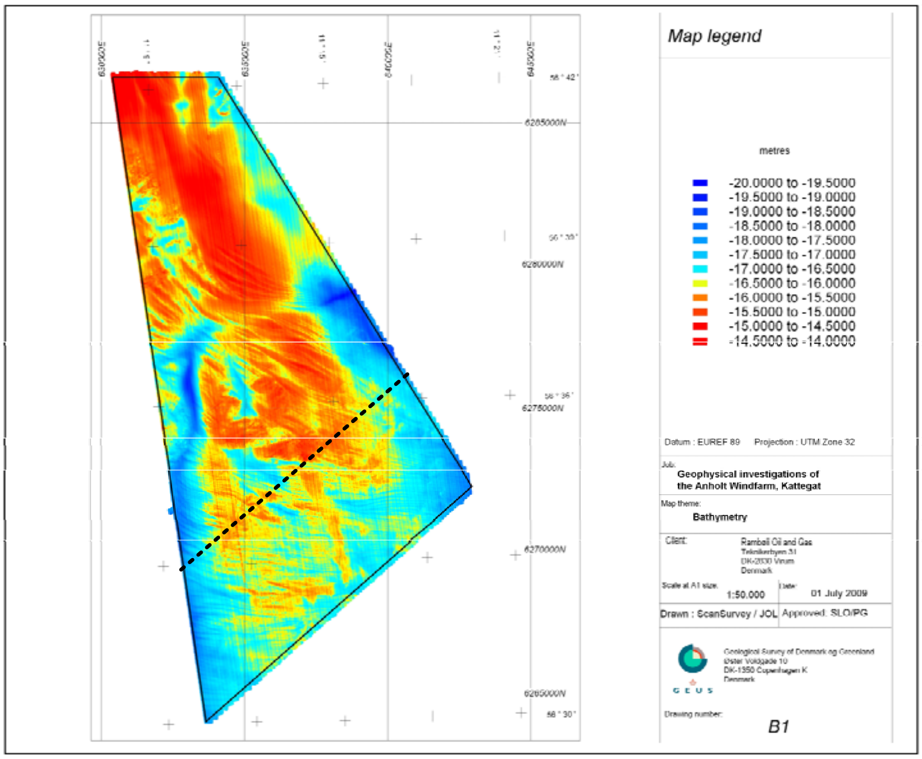


Figure 11-3. Bathymetry.

Since the minimum water depth is 14 meters and the GBS base is assumed to rise 1 meter, the draught of ships must be larger than 13 meters for the ship and base to collide. The draught of a ship will depend on the specific load, that is the cargo and fuel on board. Draught is included in the information supplied by AIS data, but it is a rather error-proven parameter. The draught information is supplied manually by the navigators and is therefore only updated sporadically during travel.

The draught for the ships on the A-route and the EFR route as derived from the AIS-data available is summarised in Table 11-4. As can be seen from the last row, there is a large amount of data degeneration. Almost 40 % of the observations are unreliable, as the draught is either missing, less than 1 meter or larger than 17 meters. The limit of 17 meters has been chosen because this is the minimum water depth on the A route.

Table 11-4. Draught of the ships registered on the A- and EFR route. Corrupted data constitutes registrations where draught is missing, less than 1 meter or larger than 17 meters.

Draught [m.]	A –route	EFR route
< 12	52.48%	60.77%
12-13	4.27%	0.00%
13-14	1.74%	0.00%
14-15	2.43%	0.00%
15-17	0.00%	0.00%
Corrupted data	39.08%	39.23%

If it is assumed, that the corrupted data is distributed the same way as the available data, then it is observed, that no ships registered on the EFR route has a draught larger than 12 meters. This means that the scenario of collision between ship and GBS base is highly unlikely, as all registered draughts are clear of the critical limit.

For the A-route only 4 % of the registrations have a draught larger than 13 meters and the minimum water depth in a 5 kilometre zone parallel to the A-route (south of the dotted line in Figure 11-3) is 15.5 meters.

Based on the above discussion, the probability of the ship having critical draught is set to 0 for the EFR route and 0.1 for the A-route.

11.1.3 Overview of event tree probability

The probability of minor, significant, severe and catastrophic impact is determined by use of event and these are given in Appendix 16.3. These probabilities will depend on the type of collision (drifting ship or direct impact), type of ship (tanker or passenger/cargo) and route (the probability of critical draught is 0 for the EFR-route and 0.1 for the A-route). An overview is given in Table 11-5.

Table 11-5 Summary of probabilities determined by event trees.

Scenario	Minor	Significant	Severe	Catastrophic
Drifting ship, tanker, both routes	0.975	0.020	0.005	0.00
Drifting ship, passenger/cargo, both routes	0.975	0.025	0.00	0.00
Direct impact, tanker, A-route	0.86	0.078	0.038	0.024
Direct impact, passenger/cargo, A route	0.86	0.13	0.015	0.00
Direct impact, tanker, EFR-route	0.925	0.060	0.015	0.00
Direct impact, passenger/cargo, EFR-route	0.925	0.075	0.00	0.00

Finally it is noted, that in case of both the turbine falling onto the ship and the ship having critical draught the probability of significant damage to the ship is set to 80% and the consequence ranking in Table 11-3 is used for that scenario.

11.2 Loss of life

In order to determine the individual risk for the most exposed person the probability of fatality, $P_{fatality}$, given a collision must be determined. $P_{fatality}$ depends on the type of collision and the type of vessels. In the following cargo/tanker ships and passenger ships are considered.

The consequences relating to loss of lives are

- Consequences from high voltage
- Consequences from falling turbine
- Consequences from contact with blades

11.2.1 Consequences from high voltage

The wind turbines will be connected by 33 kV submarine cables, which will be embedded not less than 1 meter into the sea bottom. The 33 kV cables will connect the wind turbines in groups to the transformer platform. There will be up to 20 cable connections from the platform to the wind turbines and possibly one cable connection to Anholt, /7/.

In case of collision there is a risk of contact between high voltage cables and vessels. It is however assessed that such contact could lead to loss of property, but it is very unlikely, that it will lead to loss of lives.

In order for accidental contact with high voltage to be fatal, the current has to pass through part of the body. If the vessel is made of a non-conductive material such as wood, then the vessel will act as an insulator and there will be no flow of current through vessel or passengers. Contact between wood and high voltage cables could however result in creation of sparks and fire.

If the vessel is made of a conductive material such as iron, then the vessel will act as an extension of the wire and the electrical potential of vessel and passenger will be raised to the level of the high voltage cable. This however is not harmful as passengers can stand on the vessels same way as birds can sit on high voltage wires.

For current to pass through a passenger the cable and passenger have to be in direct contact. Such a situation would be fatal, but the scenario is highly unlikely.

11.2.2 Consequences from falling turbine and contact with blades

Before a collision leads to loss of life onboard the colliding ship a number of events must happen.

1. If the ship is on collision course due to a non-human failure it must be expected that emergency procedures are initiated in order to avoid fatalities in case of a collision and the turbine falling onto the ship.

2. The turbine must fall onto the ship.

3. If the turbine does not fall onto the ship there is still a risk of loss of life from ship contact with blades.

4. The most exposed person must be on deck.

Based on the above considerations $P_{fatality}$ is determined using event trees for the different collision scenarios and type of ship. The following assumptions have been applied:

- For a ship colliding due to non-human failure (drifting ship and control system failure scenario) the emergency procedure will be successful in 90% of the cases. For HOB and bend in route collision scenario it will not be possible to initiate any emergency procedures.

- The probability of the turbine falling onto the ship is 0.25 for a drifting ship collision and 0.75 for head on bow, control system failure or bend in route collision. The reasons for this are discussed in Section 11.1.1.

- For cargo/tanker ships the probability that the most exposed person would on deck at time of collision is 0.05, while for passenger ships the probability is 0.033. This number is based on a 50-50 rotation scheme for cargo and tanker ships and a 3 person rotating scheme for passenger ships and a 10% chance that the most exposed person is on deck.

- If the turbine does not fall over, there is still a 10% that the most exposed person is killed from ship contact with blades. This is only included for collision due to non-human failure. If the ship is on collision course due to non human failure it is assumed that the most exposed person will be able to get out of reach of the blades.

Event trees are given Appendix 16.4 and a summary of the probability of fatality for each collision scenario is given in Table 11-6.

Table 11-6 Probability of fatality for cargo/tanker ships and passenger ships for each collision scenario.

Type of vessel	Head on Bow and bend in route	Drifting ship	Control system failure
Passenger	5.00E-02	8.33E-04	2.50E-03
Cargo/tanker	6.25E-02	1.25E-03	3.75E-03

12. Risk evaluation and comparison with acceptance criteria

In order to evaluate the risk to crew/passengers onboard the ships in terms of loss of life due to a ship-turbine collision and the risk of impact on the environment from oil spill, the frequency of the event and the consequence must be combined. In section 10 the frequency of ship-turbine collisions were assessed and the resulting consequences were described in section 11. In the following the results will be combined to yield the risk and compared to the risk acceptance criteria presented in section 6.

The consequences of ship collision to the transformer station are considered comparable to the consequences of ship collision with a turbine in terms of environmental impact and loss of life. Furthermore the frequency of collision to the platform contributes less than 3% to the total collision frequency, so an increase in consequences in case of collision to the transformer station will not contribute significantly to the overall risk. For these reasons the frequency contribution of the transformer station is included in the general risk evaluation for the turbines.

12.1 Loss of life

The loss of life is determined as Individual Risk (IR) and is taken to be the risk of fatality and is computed for the most exposed individual on a tanker/cargo ship and passenger ship according to:

$$IR_{shiptype} = \sum_{i=1}^{4} F_{collision,i} \cdot P_{fatality,i}$$

where

$F_{collision,i}$	Collision frequency for a given ship for collision scenario *i*. This number also contains the fraction of time a person is exposed to that risk
$P_{fatality}$	Resulting probability of fatality for collision scenario *i*

Since the collision frequency per ship is higher for the EFR it is assumed that the most exposed person for cargo/tanker is travelling on this route and is onboard a ship which travels back and forth on the route once a month, i.e. 24 crossings per year. For the passenger ships the most exposed person is located on the ferry between Varberg and Grenå since the collision frequency is higher compared to the Anholt-Grenå ferry.

In Table 12-1 the results are shown for the radials 2.3 and arcs 2.3 wind farm layout. The IR for a passenger ships and a crew on a cargo/tanker ship are below the broadly acceptable fatality risk boundary for both layouts when evaluated against the acceptance criterion in section 6. Also the individual risk estimates are much below the maximum tolerable fatality risk per year, which is set to 10^{-3}.

Table 12-1 IR for most exposed person on cargo/tanker and passenger ship for the two wind farm layouts.

Ship type	Radials 2.3	Arcs 2.3
Cargo/Tanker	6.26E-08	5.27E-08
Passenger	5.32E-07	5.60E-07

12.2 Environmental impact

The risk of environmental impact is assessed in terms of risk of oil spill. The risk is determined from the frequency of oil spill and the resulting consequences. A risk matrix is then used to determine if the risk is acceptable, in the ALARP region or not acceptable. The risk matrix introduced in section 6 is applied.

The hull can be penetrated if the ship has critical draught and if the turbine falls onto the ship, there is a risk of damage leading to discharge of bunker fuel or oil tanks (only applicable to tankers). Since the consequence class *minor* does not result in impact on the environment, section 6, it is excluded in the following.

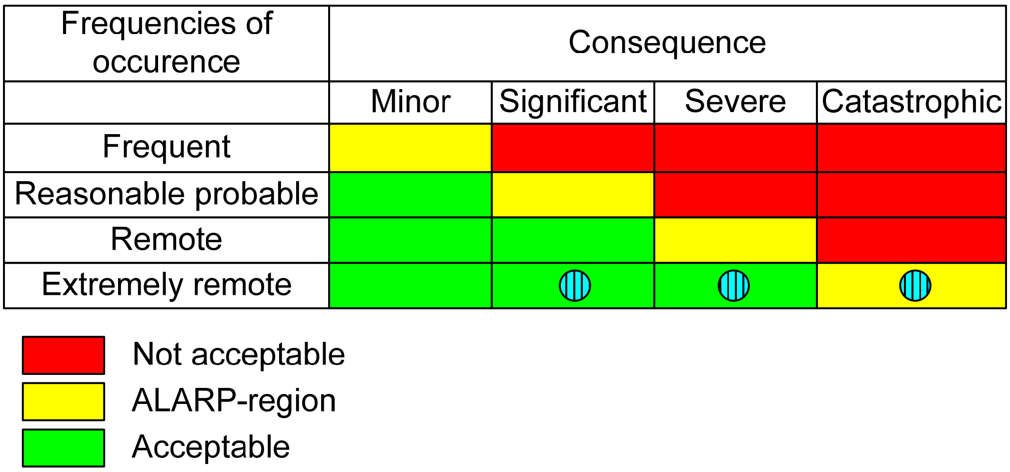


Figure 12-1 Risk matrix. Evaluation of environmental risk.

In Figure 12-1 the risk of significant, severe and catastrophic impact is plotted in the risk matrix. For significant and severe impact the risk is in the acceptable region.

For the consequence class catastrophic the risk is in the ALARP region. The risk acceptance criteria in section 6 dictates that any return period larger than 500 years for catastrophic consequences must be put in the ALARP region. The estimated return period of catastrophic impact however is 21 million years (Table 12-3), which is

42.000 more than the minimum return period, which is considered ALARP. It is therefore assessed, that the risk is acceptable.

The main reason why the estimated return period for catastrophic impact is so low is that the scenario can only happen as a result of bottom slicing. Further more an important parameter of bottom slicing is the height of the critical edge. In the present analysis it was assumed, that the critical edge would only rise 1 m. above the sea bed. This assumption entailed that less than 5% of the registered draughts in the AIS data was considered critical.

If the chosen solution for the foundation type has sharp edges rising higher than 1 m. then the present analysis will not be applicable. It is then left to the nominated developer to show that the chosen solution is collision friendly. The demand for collision friendly design is primarily requested for the most exposed rows of turbines. The most exposed turbines are the first row parallel to the A- and EFR-routes.

Table 12-2 Frequencies of minor, significant, severe and catastrophic impact.

	Minor	Significant	Severe	Catastrophic	Total
Radials	5.66E-03	1.52E-04	7.54E-06	4.77E-08	5.82E-03
Arcs	4.48E-03	1.22E-04	6.56E-06	4.76E-08	4.60E-03

Table 12-3 Return periods of minor, significant, severe and catastrophic impact.

	Minor	Significant	Severe	Catastrophic	Total
Radials	177	6.582	132.709	20.983.146	172
Arcs	223	8.168	152.414	20.989.181	217

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12.3 Transformer station

The return period for collision with the transformer station has been estimated to 8300 years corresponding to a frequency of $1.20 \cdot 10^{-4}$. This is acceptable compared to the general industry standard of $5 \cdot 10^{-4}$ (return period of 2000 years). This means that the usual safety precautions regarding marking and safety zone described in Section 8.6.3 are considered sufficient and no demand for additional mitigating measures are put forward.

13. Recommendations

The overall risk relating to environmental impact and loss of life have been evaluated and found acceptable. The main reasons for this are, that the area between Djursland and Anholt, where the wind farm is proposed, is not too heavily trafficked. Furthermore, there is a distance of three nautical miles to all future official transit routes which significantly increases the ship traffic safety. Based on this the following recommendations on how to increase ship traffic safety during the operational phase of the Anholt Offshore Wind Farm are given

- Continuation of 500 m safety zone around wind farm area or parts here of (see below). The safety zone should be marked in accordance with the requirements of the DaMSA and kept in place until the new layout of official transit routes has been effectuated.

- The wind farm area should be clearly marked in sea charts and updated sea charts should be available to the public as early as possible.

- Establishment of communication line to the wind farm surveillance centre (see below).

- Installation of aids to navigation, such as AIS-transponders, Radar Beacon (RACON), navigation lights and foghorns on key turbines (see below).

- Preparing emergency plans and training of personnel on ferries to handle critical situations.

- Emergency response plans / procedures should be in place.

It is judged that a permanent real time surveillance system of the ship traffic in the wind farm area is not relevant due to the limited ship traffic in the area compared to other areas where VTS has been implemented. It is also assessed that because the risk is generally acceptable there is no need for permanent standby vessels.

The wind farm will be added to sea charts through announcements in EfS and through chart corrections from the NSC. It is the responsibility of the navigator of the ship to make sure that sea charts are updated with the latest corrections and information.

Continuation of safety zone
During the construction and commissioning phases of the wind farm a rolling safety zone of 500 meters will be established to protect the project vessels and personnel, and the safety of third parties. The extent of the safety zone at any one time will be dependent on the locations of construction activity. However the safety zone may include the entire construction area or a rolling safety zone may be selected.

It is intended that third parties will be excluded from any safety zone during the construction period, and that the zone(s) will be marked in accordance with the requirements from the DaMSA. The temporary markings will include yellow light buoys with an effective reach of at least 2 nautical miles. All buoys will further be equipped with yellow cross sign, radar reflector and reflector strips.

It is recommended that the project area or parts here of should be declared a safety zone not only during the construction and commissioning phase, but until the new layout of official transit routes has been effectuated. This is not expected to happen until 2013 at the earliest.

The recommendation is given on the basis of the analysis in Appendix 16.1 where it is found that the coexistence of the wind farm and the current B- and E- route would result in collision return periods of just 10 years. The critical area is the northern part of the investigation area where the B- and E-routes intersect each other inside the project area. If the safety zone is terminated while the B- and E-route still function as primary transit routes further analysis of how to increase traffic safety in that situation is needed.

If a safety zone is maintained until 2013 navigators will be familiar with the existence and location of the wind farm. This will have a large effect on the over all traffic pattern when the safety zone is terminated.

Establishment of communication line

In the event of a ship having course towards the wind farm due to technical failure (drifting ships and control system failure collision scenario) it would be advantageous if the personnel on bridge could get in contact with the control centre operating the wind farm. If the control centre were aware of the critical situation they could initiate emergency procedures to minimise the consequences of a collision, such as turn of the power production from the turbines and yaw the blades in a direction resulting in the lowest risk to the ship. Furthermore, mobilisation of relevant emergency personnel could be initiated. This should be a part of the emergency response plan for the wind farm.

In the case where there is sufficient time for the officer of the watch (OOW) to contact the coast station via the VHF band, the coast station should provide the OOW with information on how to get in contact with the wind farm operator. In order to increase the awareness of the communication line to the ships travelling in the area on a regular basis, the wind farm operator could inform about the communication line to be used in emergency situations and how it is used.

Installation of aids to navigation.

In order to increase the visibility of the wind farm from a navigational point of view it is recommended to implement AIS transponders, RACON and navigational lights on key turbines. Which turbines can be considered key will depend on the specific layout and extend of the park, however corner turbines and turbines close to the A- and EFR route should be marked. Also turbines in the northern part of the investigation area, where the B-route intersects, should be emphasised. This is because a certain amount of traffic is expected on this route, as discussed in Section 9.6.

14. Risk during construction phase

During the construction phase of the wind farm there will be a number of vessels performing different tasks. The specific type of construction vessel will be selected by the nominated developer, but typical vessels used during the construction phase are jack-up barge, floating barge, construction barge, cable lay vessel and work boats, /7/. The construction work will therefore impact the ship traffic in the vicinity of the project area.

The task of conducting a risk analysis of the construction phase should be appointed to the entrepreneur. This is because many of the key parameters in the risk evaluation will depend on the construction technique of the entrepreneur. Such parameters include which harbour building materials is shipped from and building materials could also be shipped directly from the production site. Further more different construction vessels will be on site for different periods of time and thus have varying impacts on the regular ship traffic.

A request for a risk analysis of the construction phase will be put forward by the DMA when the project has been concretised.

It is recommended that the following hazards relating to the construction phase are investigated in the risk analysis:

- Risk of ship-ship collisions as construction vessels intersect official transit routes.
- Risk of ship-ship collision between commercial vessel and construction vessel operating within the project area.

Another important issue is how to handle the two transit routes currently intersecting the investigation area. Early and clear indication that the routes will be discontinued will significantly increase maritime safety during the construction phase and also extend to the operational phase.

It is recommended that the following risk reducing measures are evaluated in a risk analysis of the construction phase:

- Termination of the B- and E-route as early as possible.
- The extent of the safety zone/construction area should be constructed with maritime safety in mind. The amount of modifications should be minimised in order to avoid confusion among navigators.
- Introduction of standby vessels.

- Establishment of navigation coordination centre.
- Issuing Notice to Mariners well in advance of the construction activities.
- Broadcasting of regular NAVTEX and VHF radio warnings in order to increase the awareness for the ships traffic travelling in the area.
- Creation of emergency response plan in case of accident.

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16. Appendices

16.1 Frequency analysis of present day traffic

The frequency analysis presented in the main document has also been conducted on the present day transit route layout, with the B- and E-route intersecting the project area. Only the scenarios head on bow and drifting ship were included in the analysis and the turbine radius is 2.5 meters. The results are presented in Table 16-1 and Table 16-2.

As can be seen from Figure 8-6 the layout Radials 2.3 has a large number of turbines in the area where the B- and E-route intersect. The most critical lanes are as expected B, SE and E, NE.

A return period of ship-turbine collision is of the order 10 years regardless of the specific layout. This is far below the acceptable limit of 50 years, so if the wind farm should coexist with the current B- and E-route it is expected that there would be an unacceptable number of ship-turbine collisions.

Table 16-1. Estimated collision frequencies and return periods for the present day transit route layout and the turbine layout Radials 2.3.

Route	HOB frequency	HOB return period	DS frequency	DS return period
A-route NE		NA	4.22E-04	2,370
A-route SW	2.02E-08	50,000,000	3.92E-04	2,550
B-route NW	1.63E-02	61	1.33E-03	749
B-route SE	3.70E-02	27	2.57E-03	388
E-route NE	5.18E-02	19	3.80E-03	263
E-route SW	2.76E-02	36	3.44E-03	290
Total	1.33E-01	8	1.20E-02	84

Table 16-2. Estimated collision frequencies and return periods for the present day transit route layout and the turbine layout Arcs 2.3.

Route	HOB frequency	HOB return period	DS frequency	DS return period
A-route NE		NA	4.60E-04	2,170
A-route SW	1.93E-08	51,800,000	4.43E-04	2,260
B-route NW	7.76E-03	129	7.71E-04	1,300
B-route SE	3.07E-02	33	1.61E-03	620
E-route NE	3.33E-02	30	2.54E-03	393
E-route SW	2.45E-03	408	1.90E-03	526
Total	7.43E-02	13	7.73E-03	129

16.2 Ship class distribution tables

Table 16-3. Width class distribution for the A-route.

Ship width classes [m.]	A-route NE	A-route SW
[0 - 5]	0.05 %	0.00 %
[5 – 10]	1.09 %	0.87 %
[10 - 15]	3.77 %	3.91 %
[15 – 20]	3.44 %	5.21 %
[20 - 25]	9.08 %	8.51 %
[25 – 30]	41.99 %	19.44 %
[30 - 35]	23.51 %	23.18 %
[35 – 40]	1.42 %	2.86 %
[40 – 45]	13.23 %	33.25 %
[45 – 50]	0.98 %	2.43 %
> 50	1.42 %	0.35 %

Table 16-4. Length class distribution for the A-route.

Ship length classes [m.]	A-route NE	A-route SW
[0 – 20]	0.05 %	0.00%
[20 – 40]	0.77 %	0.69%
[40 – 60]	0.22 %	0.43%
[60 – 80]	0.77 %	0.17%
[80 – 100]	2.24 %	2.60%
[100 – 120]	2.79 %	3.56%
[120 – 140]	2.57 %	3.82%
[140 – 160]	4.43 %	5.90%
[160 – 180]	16.13 %	9.46%
[180 – 200]	41.72 %	21.44%
[200 – 220]	3.61 %	2.78%
[220 – 240]	11.48 %	13.72%
[240 – 260]	11.54 %	31.51%
> 260	1.69 %	3.91%

Table 16-5. Width class distribution for traffic routes comprising the traffic load on the EFR route.

Ship width classes [m.]	B-route NW	B-route SE	E-route NE	E-route SW	Unofficial NW	Unofficial SE
[0 - 5]	0.62 %	0.23 %	0.69 %	0.33 %	0.42%	0.22%
[5 – 10]	18.95 %	19.58 %	7.27 %	6.69 %	9.92%	8.62%
[10 – 15]	65.59 %	59.44 %	50.17 %	49.76 %	60.62%	63.05%
[15 – 20]	13.47 %	16.43 %	28.03 %	32.46 %	27.76%	25.53%
[20 – 25]	0.87 %	3.15 %	10.55 %	4.89 %	0.28%	1.01%

[25 – 30]	0.37 %	0.58 %	1.38 %	2.77 %	0.85%	1.23%
[30 – 35]	0.12 %	0.58 %	1.56 %	1.79 %	0.14%	0.22%
[35 – 40]	0.00 %	0.00 %	0.00 %	0.16 %	0.00%	0.00%
[40 – 45]	0.00 %	0.00 %	0.17 %	1.14 %	0.00%	0.11%
[45 – 50]	0.00 %	0.00 %	0.00 %	0.00 %	0.00%	0.00%
> 50	0.00 %	0.00 %	0.17 %	0.00 %	0.00%	0.00%

Table 16-6. Length class distribution for traffic routes comprising the traffic load on the EFR route.

Ship length classes [m.]	B-route NW	B-route SE	E-route NE	E-route SW	Unofficial NW	Unofficial SE
[0 – 20]	1.36%	0.70%	0.69%	0.81%	0.56%	0.34%
[20 – 40]	9.89%	8.38%	2.08%	3.73%	6.50%	4.69%
[40 – 60]	7.17%	8.27%	4.33%	2.92%	3.53%	5.03%
[60 – 80]	29.05%	21.42%	14.01%	16.40%	28.95%	22.01%
[80 – 100]	37.33%	37.83%	37.20%	34.58%	49.01%	55.75%
[100 – 120]	12.86%	16.76%	19.20%	17.37%	9.18%	9.16%
[120 – 140]	1.61%	3.49%	11.94%	14.45%	1.69%	1.68%
[140 – 160]	0.49%	2.10%	7.44%	3.08%	0.14%	0.45%
[160 – 180]	0.00%	0.12%	1.21%	2.60%	0.14%	0.11%
[180 – 200]	0.00%	0.70%	1.21%	2.60%	0.14%	0.56%
[200 – 220]	0.12%	0.00%	0.17%	0.16%	0.00%	0.00%
[220 – 240]	0.12%	0.23%	0.52%	0.49%	0.14%	0.11%
[240 – 260]	0.00%	0.00%	0.00%	0.81%	0.00%	0.11%
> 260	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 16-7. Width class distribution for the EFR-route.

Ship width classes [m.]	EFR-route, NE	EFR-route SW
[0 - 5]	0.58%	0.25%
[5 – 10]	12.66%	12.13%
[10 - 15]	59.64%	58.44%
[15 – 20]	22.34%	24.09%
[20 - 25]	3.36%	2.80%
[25 – 30]	0.81%	1.40%
[30 - 35]	0.53%	0.76%
[35 – 40]	0.00%	0.04%
[40 – 45]	0.05%	0.34%
[45 – 50]	0.00%	0.00%
> 50	0.05%	0.00%

Table 16-8. Length class distribution for the EFR-route.

Ship length classes [m.]	EFR-route NE	EFR-route SW
[0 – 20]	0.91%	0.59%

[20 – 40]	6.59%	5.78%
[40 – 60]	5.16%	5.65%
[60 – 80]	24.87%	20.34%
[80 – 100]	41.24%	43.76%
[100 – 120]	13.37%	14.05%
[120 – 140]	4.49%	5.65%
[140 – 160]	2.29%	1.73%
[160 – 180]	0.38%	0.76%
[180 – 200]	0.38%	1.14%
[200 – 220]	0.10%	0.04%
[220 – 240]	0.24%	0.25%
[240 – 260]	0.00%	0.25%
> 260	0.00%	0.00%

16.3 Event trees for environmental impact

Table 16-9 Event tree for passenger/cargo ship and drifting ship collision, both routes.

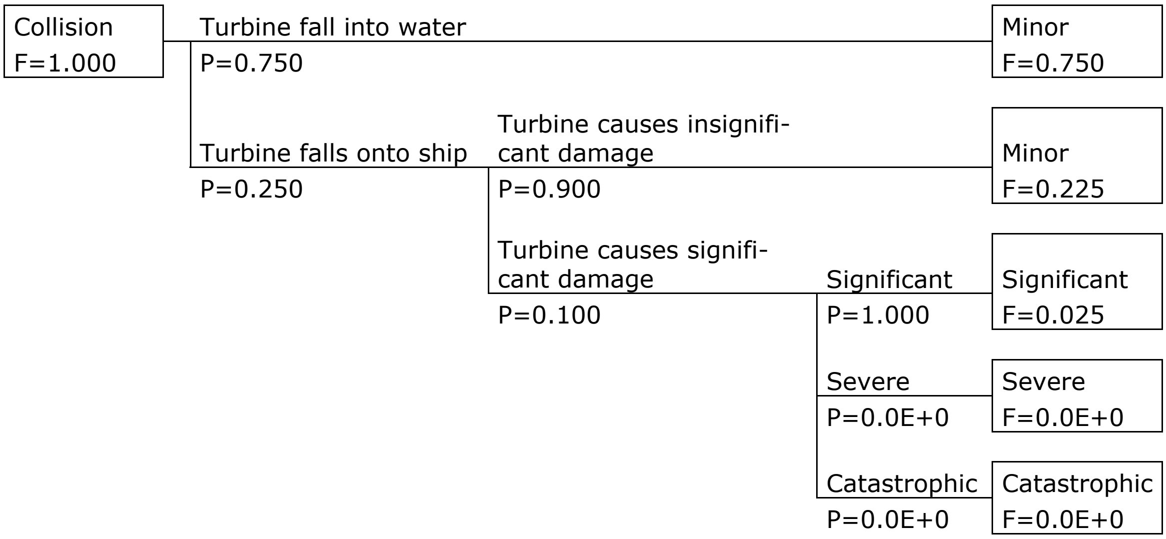

Table 16-10 Event tree for tanker and drifting ship scenario, both routes.

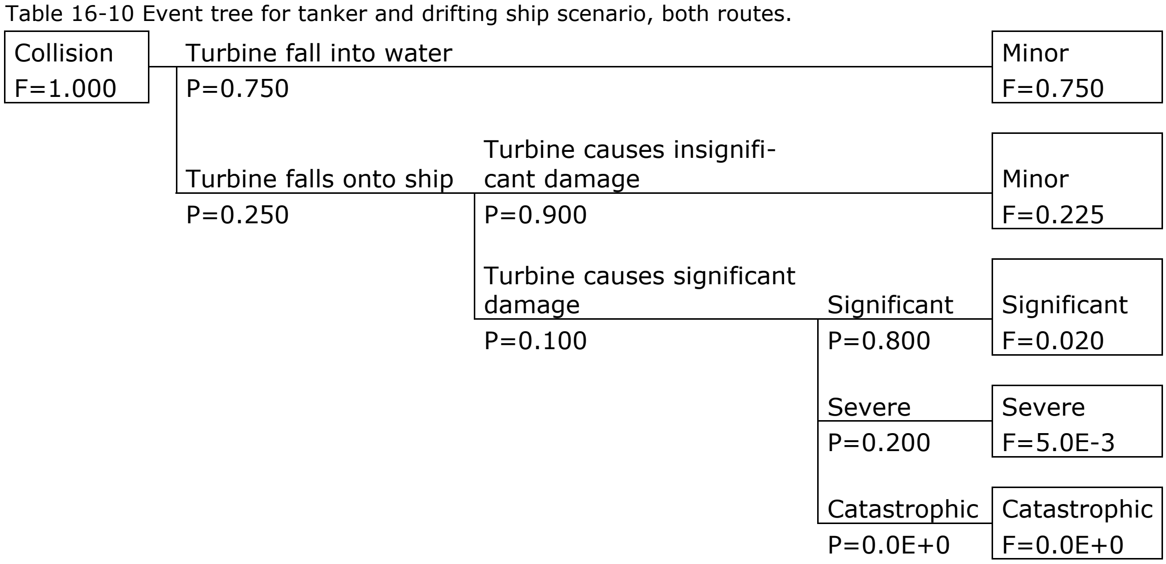

Table 16-11 Event tree for passenger/cargo ship and direct impact, EFR route.

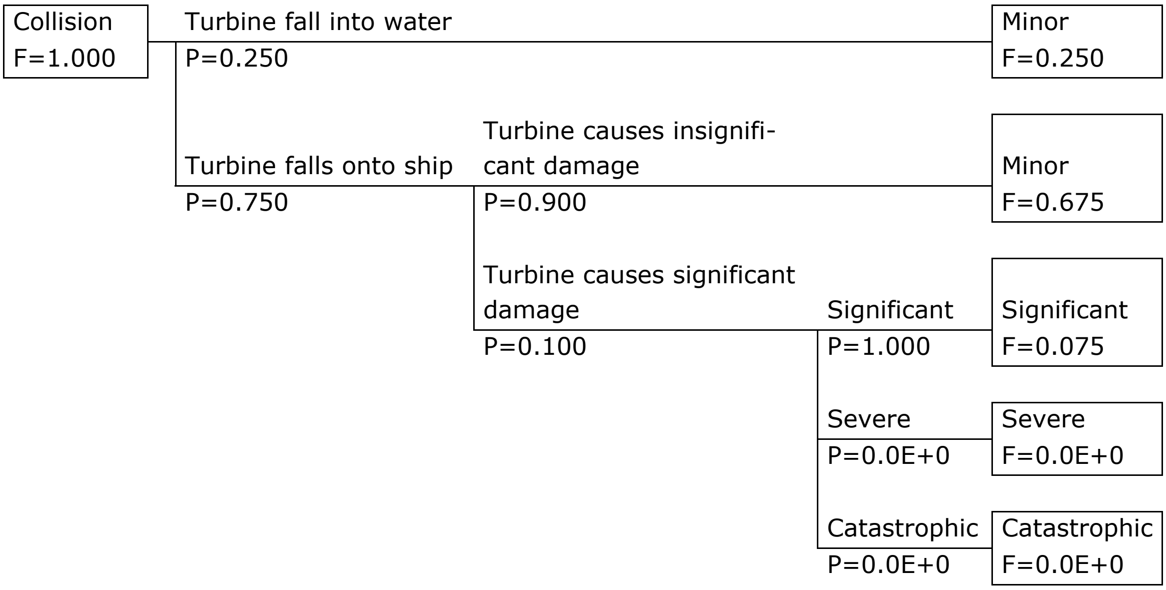

Table 16-12 Event tree for tanker and direct impact, EFR route.

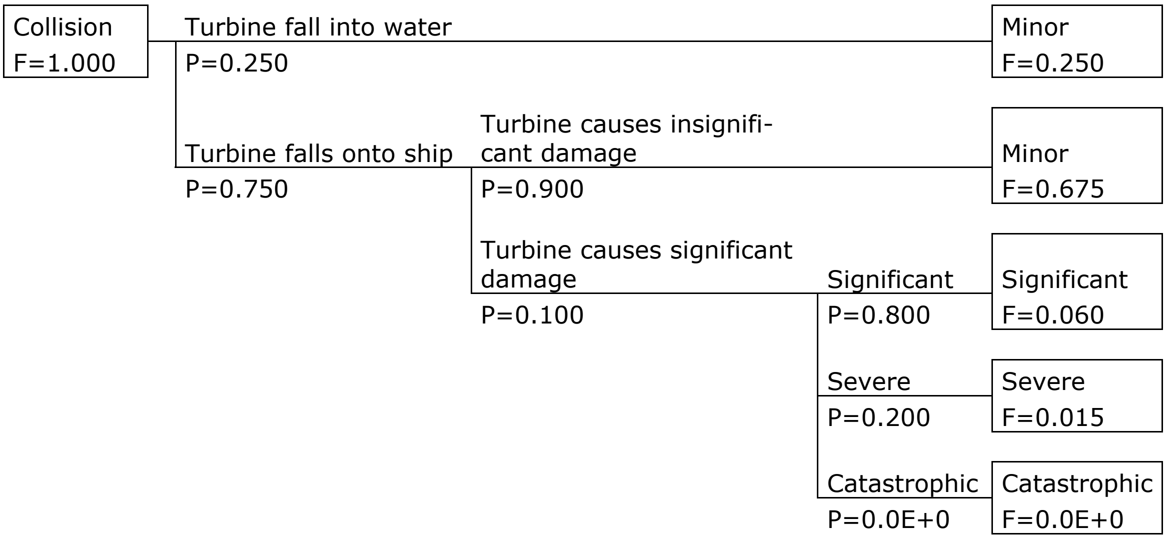

Table 16-13 Event tree for passenger/cargo ship and direct impact, A route.

Collision F=1.000	Not onto ship, not critical draught P=0.225			Minor F=0.225
	Onto ship, not critical draught P=0.675	Turbine causes insignificant damage P=0.900		Minor F=0.608
		Turbine causes significant damage P=0.100	Significant P=1.000	Significant F=0.068
			Severe P=0.0E+0	Severe F=0.0E+0
			Catastrophic P=0.0E+0	Catastrophic F=0.0E+0
	Not onto ship, critical draught P=0.025	Edge causes insignificant damage P=0.500		Minor F=0.013
		Edge causes significant damage P=0.500	Significant P=0.800	Significant F=1.0E-2
			Severe P=0.200	Severe F=2.5E-3
			Catastrophic P=0.0E+0	Catastrophic F=0.0E+0
	Onto ship and critical draught P=0.075	Turbine and edge causes insignicicant damage P=0.200		Minor F=0.015
		Turbine and edge causes significant damage P=0.800	Significant P=0.800	Significant F=0.048
			Severe P=0.200	Severe F=0.012
			Catastrophic P=0.0E+0	Catastrophic F=0.0E+0

Table 16-14 Event for tanker and direct impact, A route.

Initiating event	Event 1	Event 2	Event 3	Outcome
Collision F=1.000	Not onto ship, not critical draught P=0.225			Minor F=0.225
	Onto ship, not critical draught P=0.675	Turbine causes insignificant damage P=0.900		Minor F=0.608
		Turbine causes significant damage P=0.100	Significant P=0.800	Significant F=0.054
			Severe P=0.200	Severe F=0.014
			Catastrophic P=0.0E+0	Catastrophic F=0.0E+0
	Not onto ship, critical draught P=0.025	Edge causes insignificant damage P=0.500		Minor F=0.013
		Edge causes significant damage P=0.500	Significant P=0.333	Significant F=4.2E-3
			Severe P=0.333	Severe F=4.2E-3
			Catastrophic P=0.333	Catastrophic F=4.2E-3
	Onto ship and critical draught P=0.075	Turbine and edge causes insignificant damage P=0.200		Minor F=0.015
		Turbine and edge causes significant damage P=0.800	Significant P=0.333	Significant F=0.020
			Severe P=0.333	Severe F=0.020
			Catastrophic P=0.333	Catastrophic F=0.020

16.4 Event trees for loss of life

Table 16-15 Event tree for drifting ship collision of passenger ships.

Collision F=1.000	Emergency procedures successful P=0.900			No fatality F=0.900
	Emergency procedures not successful P=0.100	Turbine falls into water P=0.750		No fatality F=0.075
		Turbine falls onto ship P=0.250	Most exposed person on deck P=0.033	Fatality F=8.3E-4
			Most exposed person not on deck P=0.967	No fatality F=0.024

Table 16-16 Event tree for drifting ship collision of tanker/cargo ship.

Collision F=1.000	Emergency procedures successful P=0.900			No fatality F=0.900
	Emergency procedures not successful P=0.100	Turbine falls into water P=0.750		No fatality F=0.075
		Turbine falls onto ship P=0.250	Most exposed person on deck P=0.050	Fatality F=1.3E-3
			Most exposed person not on deck P=0.950	No fatality F=0.024

Table 16-17 Event tree for head on bow and bend in route collision of passenger ships.

Collision F=1.000	Turbine falls into water P=0.250	Fatality from ship contact with blades P=0.100	Fatality F=0.025
		No contact with blades P=0.900	No fatality F=0.225
	Turbine falls onto ship P=0.750	Most exposed person on deck P=0.033	Fatality F=0.025
		Most exposed person not on deck P=0.967	No fatality F=0.725

Table 16-18 Event tree for head on bow and bend in route collision of tanker/cargo ship.

Collision F=1.000	Turbine falls into water P=0.250	Fatality from ship contact with blades P=0.100	Fatality F=0.025
		No contact with blades P=0.900	No fatality F=0.225
	Turbine falls onto ship P=0.750	Most exposed person on deck P=0.050	Fatality F=0.038
		Most exposed person not on deck P=0.950	No fatality F=0.713

Table 16-19 Event tree for control system failure collision of passenger ship.

Collision F=1.000	Emergency procedures successful P=0.900			No fatality F=0.900
	Emergency procedures not successful P=0.100	Turbine falls into water P=0.250		No fatality F=0.025
		Turbine falls onto ship P=0.750	Most exposed person on deck P=0.033	Fatality F=2.5E-3
			Most exposed person not on deck P=0.967	No fatality F=0.073

Table 16-20 Event tree for control system failure collision of tanker/cargo ship.

Collision F=1.000	Emergency procedures successful P=0.900			No fatality F=0.900
	Emergency procedures not successful P=0.100	Turbine falls into water P=0.250		No fatality F=0.025
		Turbine falls onto ship P=0.750	Most exposed person on deck P=0.050	Fatality F=3.8E-3
			Most exposed person not on deck P=0.950	No fatality F=0.071