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Project Manager:
Björn Forsman
bjorn.forsman@sspa.se
+46 730729059

Authors:
Björn Forsman
Nelly Forsman

Nord Stream 2 AG

Baarerstrasse 52
6300 Zug

Switzerland

Detailed Maritime Assessment of North-Western pipeline routeing in Danish EEZ

Nord Stream 2 AG is currently investigating NS2 routeing options outside Danish territorial waters and this study specifically addresses routeing options north and west of Bornholm within Danish EEZ. SSPA has previously, as preparatory activity for this report, conducted a basic risk identification including traffic analysis and basic routeing alignment studies, which form the foundation of this report, that presents a detailed assessment including risk assessment, risk control options, and conclusions.

The risk assessment is based on an event tree model for delayed emergency anchoring. Quantification of risk figures is prepared by a combination of statistics, calculations and, consultations.

SSPA Sweden AB

Joakim Lundman
Vice President

SSPA Sweden AB

Björn Forsman
Project Manager
Maritime Consulting

Summary and recommendations

Nord Stream 2 AG is currently investigating NSP2 routeing options outside Danish territorial waters in the area north and west of Bornholm, within the Danish EEZ. The study initially comprised a basic sea traffic analysis, a basic pipeline routing alignment assessment, and this report presents a quantitative risk assessment including detailed analysis and evaluation of identified risks and optional route alignments. Combined with output reported from a previously conducted risk identification workshop, the structure of the study includes the components of a Formal Safety Assessment in applicable parts.

The study primarily addresses indirect risks to ship traffic and other maritime activities, triggered by the presence of the NSP2 pipelines and by activities during the construction and operational phase. Direct risks related to ship-ship collisions are analysed in other separate studies, (Saipem, 2018), (G.M., 2018), and (Ramboll, 2018) .

The comparative assessment of routeing options shows that minimisation of the duration of interaction between third-party ship traffic and construction vessels, is a relevant risk reducing route alignment criterion for the construction phase. The proposed NSP2 routeing in the TSS separation zone is found to be favourable from a collision point of view. The routeing across the precautionary area may generate complex interaction with turning traffic and merging ship flows, but may also offer somewhat wider areas for third-party vessels to pass aside the exclusion zone around the pipe-lay vessel. The size and shape of the exclusion zone is not yet finally decided, and it is considered relevant to further examine what would be an optimum size and shape.

The presented AIS analysis shows that successful anchoring in the separation zone is possible. However, the AIS analysis shows that the separation zone is not considered particularly attractive for emergency anchoring of drifting vessels.

The event tree model applied, shows that potential delay of emergency anchoring caused by the presence of pipelines in the separation zone, only generates a negligible contribution of indirect collision risks compared with other direct ship-ship collision risks. Regarding third-party risks to the public, the risk contribution potentially caused by delayed emergency anchoring is consequently also well below the established level of broadly acceptable risks. No complementary risk reduction measures specifically addressing this issue are elaborated or proposed by the study.

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Abbreviations

NSP1	The existing Nord Stream pipeline Project
NSP2	The planned new Nord Stream 2 pipeline Project
AIS	Automatic Identification System, compulsory ship transponder system
DP	Dynamic Position keeping system for ships by thruster propulsors
EIA	Environmental Impact Assessment
EEZ	Exclusive Economic Zone
FSA	Formal Safety Assessment – Risk assessment methodology by IMO
TW	Territorial water, here mainly referring to Danish TW border
TSS	Traffic Separation Scheme Traffic separation zone between traffic lanes in different directions. Precautionary area - a routeing measure comprising an area within defined limits where ships must navigate with particular caution.
ITZ	Inshore Traffic Zone – zones between the coast and the TSS. Traffic separation line – border line between traffic lane and ITZ
DW	Deep Water route, here referring to the DW 25 m route N Bornholm.
N, E, S, W	Cardinal directions – North, East, South, and West Frequently used in combinations like; NE for north eastern or north east, SW for south western, NW for north western, SE for south eastern.
IMO	International Maritime Organization of the United Nations, UN
nm	Nautical mile, 1 nm = 1 852 m

Protection zone - Regulative measure in Denmark imposing a zone of anchoring and fishing zone prohibition of 200 m width along each side of a subsea pipeline or cable, (BEK_939, 1992)

1 Introduction

1.1 Background

Nord Stream 2 AG is a new company, handling a new project but uses the experience from the existing Nord Stream pipeline Project (NSP1). The new project comprises an additional set of two natural gas pipelines. The aim of the Nord Stream 2 pipeline Project (NSP2) is to increase the total gas transfer capacity. Based on comprehensive route selection studies and consultation processes carried out, it has previously been found that the new pipelines preferably should be in parallel with the existing Nord Stream pipelines, E and S of Bornholm. A new amendment to the Danish Continental Shelf Act has, however, called for a revisit and refinement of routeing options in the Danish EEZ, N and W of Bornholm.

1.2 Objective

The objective of this study is to provide NSP2 AG with objective and pertinent background data and a reference document to complement EIA and Permit Application documents, with recommended NSP2 pipeline route alignment for routeing options N and W of Bornholm in Danish EEZ. The principle assessment criterion is maritime safety during the construction phase and during the long-term operational phase of the pipeline. Potential maritime safety risks imposed to third-party[1] ships by the construction works or by the presence and operation of the planned NSP2 pipeline, are identified and analysed.

Initially a preparatory comparative qualitative risk assessment was performed on a number of pipeline routeing options addressing identified risks for the construction phase as well as for the operational phase. This assessment report includes detailed assessment including risk assessment, risk control options, and conclusions.

1.3 Scope and limitations

The study is primarily addressing indirect risks to the ship traffic and other maritime activities triggered by the presence of the NSP2 pipelines and by activities during the construction and operational phase. The geographical area of analysis is restricted to areas N, W, and S of Bornholm where the investigated NSP2 route options diverge from the existing NSP1 pipeline route, and in particular to three separate route sections indicated by A, B and C in

[1] Any commercial ship excluding the pipe-lay vessel and other vessels involved in the NSP2 construction, supply and, monitoring works.

Figure 1 below. Section B is essentially defined by the NE and SW limits of the centre section of the Bornholmsgat TSS. In NW, section B is defined by the EEZ border between Sweden and Denmark and in SE by the Danish territorial water (TW) border.

Direct risks to the pipeline imposed by the operation of third-party ship traffic, such as dropped objects, dropped anchors, dragging of anchors and sinking ships, are not within the scope of this study.

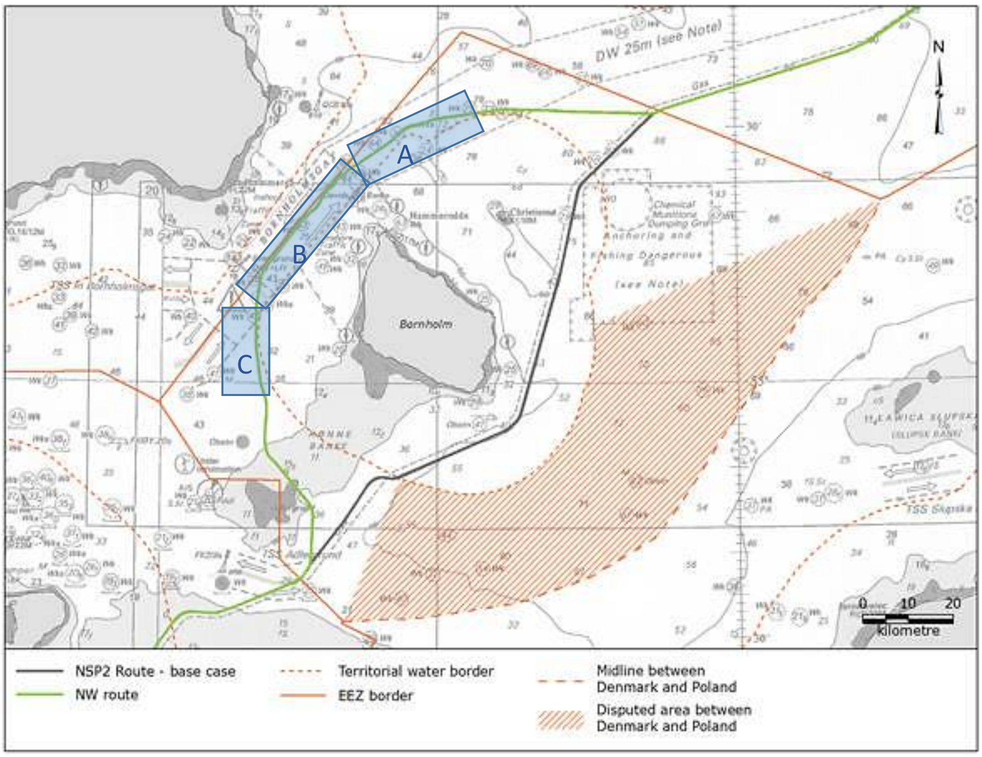

Figure 1. The originally proposed base case route alignment of the NSP2 pipeline in parallel with the existing pipeline (black line) and the new proposed NSP2 route alignment (green) N and W of Bornholm in the Danish EEZ.

1.4 Methodology

Results of the previous study from 2015-2016, (SSPA, 2016) of potential indirect navigational risks has been reviewed as well as previously conducted hazard identification session 2017, reported in (RNO300EN-00, 2017).

Initially, preparatory activities comprised a basic sea traffic analysis, a basic pipeline routing alignment assessment, and risk identification that form the foundation of this report, which comprises a quantitative risk assessment including detailed analysis and evaluation of identified risks and optional route alignments. Together these components form a maritime risk analysis, outlined in accordance with the IMO Formal Safety Assessment (FSA) methodology in applicable parts.

2 Risk assessment – Construction phase

The hazard identification workshop (RNO300EN-00, 2017) identified seven different potential collision scenarios where third-party ships may be involved during the construction phase. Most of these were related to the interaction and collision with the stationary pipe-lay vessel (moving at speed < 0.1 knots) and its exclusion zone and other involved construction vessels. The radius of the exclusion zone was originally indicated up to 1 nm, but later considerations indicate that a radius of 0.5 nm is sufficient. Collision scenarios between third-party vessels caused by reduced passage and manoeuvring space as well as collisions with pipe haul vessels, were also identified. The initial step of this study covered a qualitative comparison of a number of pipeline routeing options in three different sections (cf. Figure 1) along the route N and W of Bornholm, with respect to the seven identified collision and interaction scenarios. From the comparative assessment of optional routeing, it was found that minimisation of the duration of interaction between third-party ship traffic and construction vessels operating near the pipe-lay vessel and its exclusion zone, was a relevant risk reducing route alignment criterion.

Based on this criterion and the various identified hazards, the pipeline routeing option in the TSS separation zone, was recommended for section B along the Bornholmsgat TSS. A potential alignment along (but outside) the Danish TW border at the SE side of the NE-going traffic lane of the TSS, would cause significantly more interaction. The routeing in the separation zone implies that the main NE heading traffic flow must be crossed twice. Routeing options with perpendicular crossing of the main ship traffic lanes would geometrically minimize duration and number of potential lane crossing conflicts, but it was also found that variation of crossing angles and bending radii, only would have minor influence on the identified potential collision risks. Technical construction aspects on cable crossings and pipeline bending radii may therefore be determinant for detailed alignment of the traffic lane crossings.

Regarding the routeing across the TSS precautionary area as proposed in the EIA and Permit Application, it was found that this may generate somewhat more complex interaction between third-party traffic and the crossing pipe-lay vessel, than a perpendicular crossing in the SE area of the traffic lane. In the precautionary area, some of the third-party traffic is turning and traffic flow from two directions are merging. On the other hand, the route across the precautionary area may offer somewhat more space for third-party vessels to pass aside the exclusion zone encircling the advancing pipe-lay vessel. Figure 2 and Figure 3 below graphically indicate that the proposed routeing across the precautionary area may allow somewhat wider passage width aside of a possible circular exclusion zone than the indicated routing options (red line and dotted blue line) crossing the NE going one-directional TSS lane.

In the figures exclusion zones with a radius of 1.0 nm respective 0.5 nm is indicated to illustrate the impact on the available passage width for third-part vessels for subsequent pipe-lay vessel positions along two route alignment options.

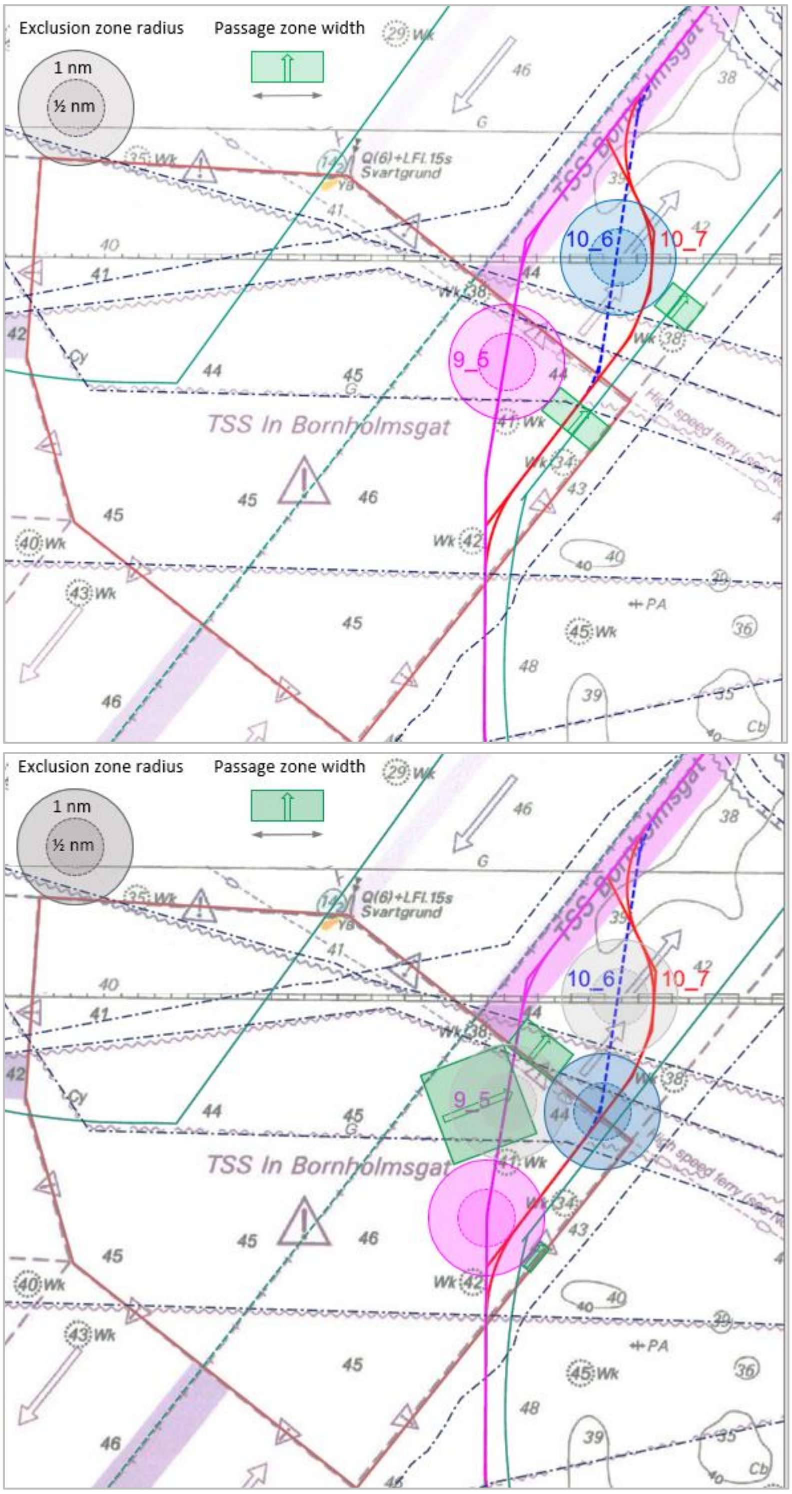

Figure 2. Comparison of available passage width outside a 1 nm radius pipe-lay vessel exclusion zone for two route alignment options; 9_5 (proposed NSP2 NW route) across the precautionary area and 10_6 with an angular crossing of the NE going traffic lane. An optional exclusion zone with 0.5 nm radius is indicating by dotted circle. Top; N position, exclusion zones touching the separation zone and Below; Mid position. Both indicating wider green passage width for routeing option 9_5 than for 10_6.

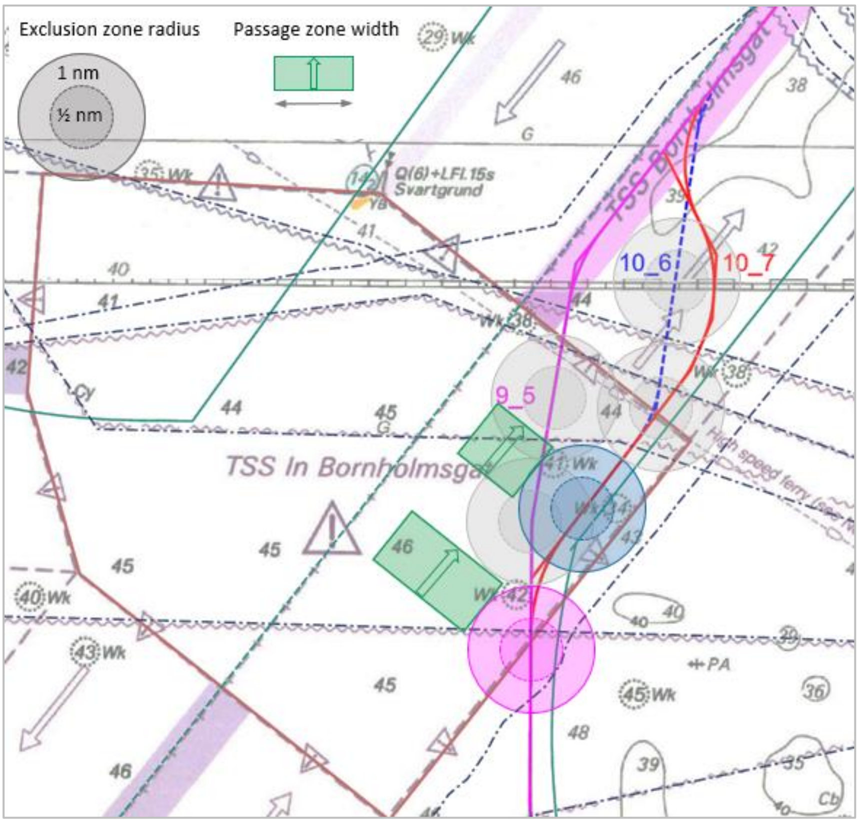

Figure 3. Comparison of availabe passage width outside a possible 1 nm radius pipe-lay vessel exclusion zone for two route alignement options; 9_5 (proposed NSP2 NW route) across the precautionary area and 10_6 with an angular crossing of the NE going traffic lane. Position S of the previous mid positions also indicating somewhat wider green passage width for routeing option 9_5 (pink line and circle) than for 10_6 (blue line and circle). An optional exclusion zone with 0.5 nm radius is indicated by a dotted circle. It would allow 0.5 nm more passage width.

In addition to this qualitative comparative risk assessment of route alignment options, a quantitative calculation of expected additional collision risks for third-party vessels, caused by the presence and operation of the pipe-lay vessel and other work vessels, has been conducted and reported in (G.M., 2018). The report concludes that the temporarily additional risk contribution generated by the presence and transit of construction vessels and associated collision risk with third-party vessels, is very low compared with the current normal collision frequency in the area.

3 Risk assessment – Operational phase

For the operational phase, the initial phase of the study briefly described potential collision scenarios related to operation of regular survey and maintenance vessels as well as potential hazards and accident scenarios related to fishing vessels engaged in bottom trawling. Both these aspects have been subject to separate analyses and reported in other documents (Saipem, 2018). Risks related to fishing activities and bottom trawling are primarily related to the safety and integrity of the pipeline and not considered as maritime safety issues.

Other pipeline risks associated with normal shipping operations, e.g. unintentional dropping or dragging of anchors, are primarily governed by the number of third-party ship crossings of the pipeline route. The proposed pipeline route crosses the main NE going traffic lane twice, and thus the detailed alignment, its crossing angles, and total length is not crucial.

No conflicting aspects between risk minimisation routeing criteria addressing the construction phase and corresponding criteria for the operational phase have been identified. Very few ship crossings of the separation zone are registered and the NSP2 pipeline route section located in the central separation zone of the Bornholmsgat TSS, is thus well protected from any potential risk associated with crossing ship tracks.

3.1 Indirect maritime safety risks

In the risk identification phase, delayed emergency anchoring and subsequent potential accident risks were identified as the main safety issue for the operational phase of the investigated proposal for routing alignment of the NSP2. In contrast to the direct collision risk with survey or maintenance vessels, and risks related to the integrity of the pipeline, potential delay of emergency anchoring is considered as an indirect potential maritime safety risk to third-party vessels, generated by the presence of the pipeline.

Aspects and hazards related to potential delay of emergency anchoring have in the past been highlighted by maritime administrations and regulating bodies in application processes on sub sea cables and pipelines located close to important shipping routes. In some cases the need for so called buffer zones has been claimed in order to ensure that areas for potential emergency anchoring are available outside the main traffic lanes. Such buffer zones are primarily relevant in areas close to particularly sensitive shallow bank areas, coastlines, or offshore wind farms.

The proposed routeing of the pipeline in the separation zone does not restrict the possibilities for emergency anchoring outside the traffic lanes of the TSS. If an engine failure, blackout, and drifting event occurs in one of the one-directional lanes of the Bornholmsgat TSS, the preferred evasive manoeuvre would most likely be a starboard turn into the adjacent Inshore Traffic Zone (ITZ).

Thereby interference with other traffic while trying to regain propulsion would be prevented. In case the propulsion failure occurs in wind conditions generating a drift direction to the portside, towards the traffic separation zone, this zone may possibly be considered favourable for emergency anchoring. Emergency anchoring may then prevent collision risks and interference with dense traffic in the opposite lane as well as preventing grounding or stranding risks in the ITZ outside the lanes.

Emergency anchoring by drifting vessels having encountered a blackout, may be considered by ship captains in order to arrest or reduce the drift speed of the ship. In particular for pipeline route sections located within the 1 500 m wide central traffic separation zone of TSS Bornholmsgat (section B), the question whether this zone is attractive for emergency anchoring is relevant.

3.2 AIS-analysis for identification of drifting and anchoring events in the Bornholmsgat

3.2.1 Registered events with drifting vessels

In order to identify if the separation zone is considered attractive for emergency anchoring, a dedicated AIS-analysis was conducted to identify historical anchoring events in the TSS and to provide a quantitative estimation of the probability for emergency anchoring or dragging of anchors across the pipeline route.

Analysed AIS-data cover all commercial ship traffic in the Bornholmsgat TSS area (categories; cargo, passenger and, tanker vessels classified as shiptype number 40-89) from the period 2014 to 2017.

In this analysis, ships assumed to have experienced a blackout event with loss of propulsion, are identified by the following criteria:

- Vessel speed over ground (SOG) < 2 knots (but > 0.3 knots)
- Difference between course over ground (COG) and heading ≥ 30 degrees (in order to exclude ships intentionally heading at very low speed)
- Duration of the above two conditions > 10 minutes (but < 3 days).

A total of 75 events with drifting vessels are identified by these criteria and, thus an annual average of 19 drifting events with lost propulsion per year is considered a representative frequency estimation in this area.

Many of the identified drifting vessels show a track diverging from the main direction of the traffic lane and some also show an end point at a fixed position, indication a location of anchoring followed by later restart and regain of original heading.

Figure 4 below gives an indicative view of the tracks generated by the identified 75 drifting vessel events within the investigated area.

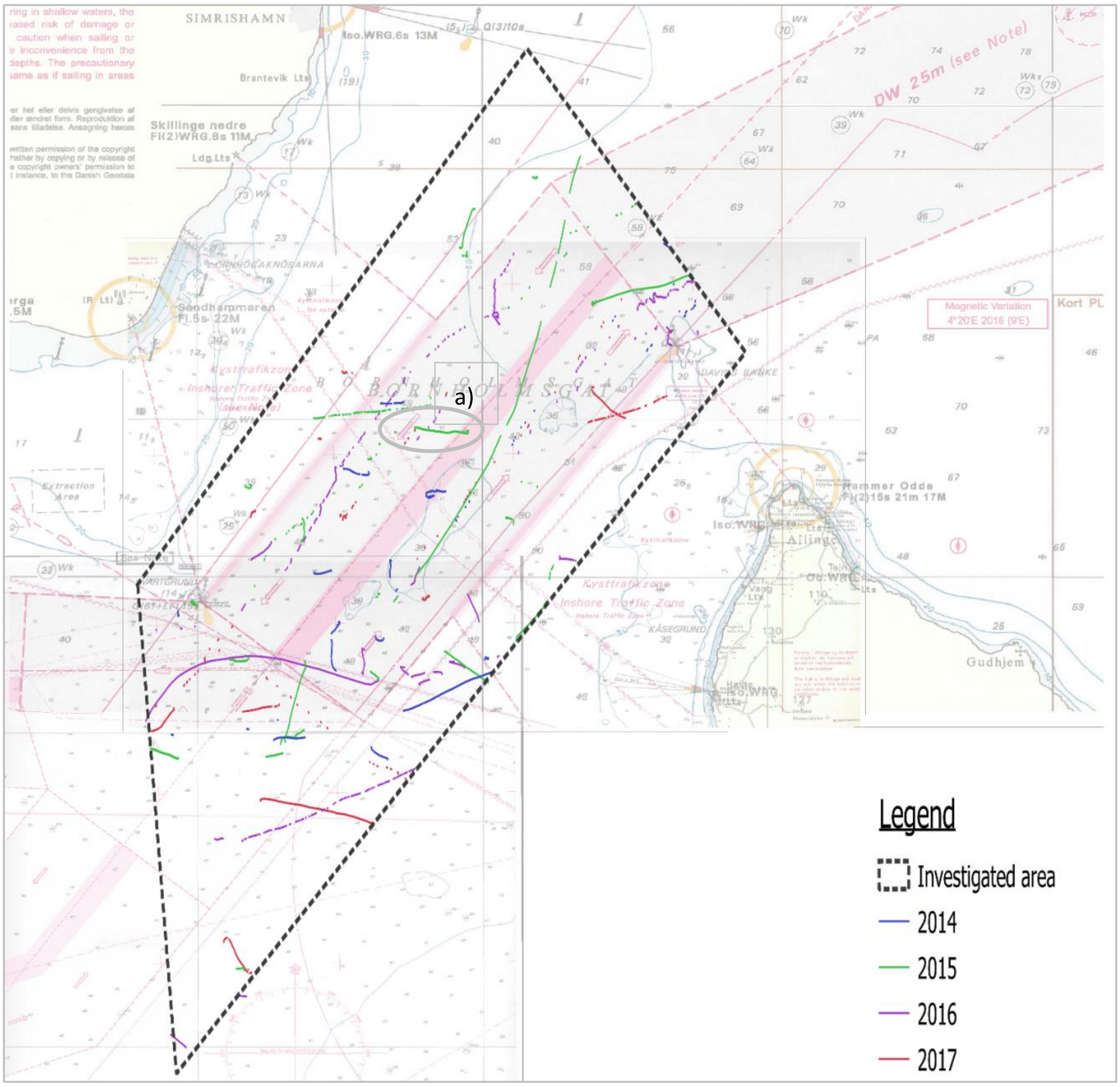

Figure 4. Recorded tracks of drifting vessels from 2014–2017 in the Bornholmsgat area. The track marked a) represent one identified anchoring event registered in the separation zone.

Most of the tracks start and end within the same traffic lane, but a few indicates drifting across the separation zone and the track, marked a) illustrates one identified event where the drifting vessels enter the separation zone and drops anchor.

A close up of the recorded track (marked a) in Figure 4) of the drifting vessel dropping its anchor in the separation zone, is shown in Figure 5 below. It represents a cargo vessel with length L 99.6 m and breadth B 15.5 m constructed in 2010, drifting eastwards from the SW going lane into the separation zone, on 15 July 2015. It anchored in the separation zone, inside the Danish side of the EEZ. It stayed anchored in this position for about 5 h before it regained its SW heading at normal speed.

Figure 5. Recorded track of a vessel drifting into the TSS separation zone, anchoring and later regaining its original SW heading.

The AIS analysis shows that successful anchoring is possible, but it does not clearly confirm that the separation zone is considered particularly attractive for emergency anchoring of drifting vessels. The single recorded anchoring event is not statistically significant but the separation zone may occasionally provide an emergency anchoring area preventing interaction and collision risks with traffic in the original lane as well as in the lane with traffic in opposite direction.

3.2.2 Statistical calculation of blackout with loss of propulsion and drifting events.

The recorded number of drifting vessels within the two traffic lanes of the TSS includes about two-thirds of the total number of recorded drifting vessels for the area marked in Figure 4. With a total traffic flow averaging 44 000 passages of the TSS (with an average passage time of 1h 20 minutes (@12 knots), the recorded 19 drifting events correspond to a statistical frequency of blackout events with loss of propulsion (excluding the one's recovered by "self-repair" within the first 10 minutes) of 2.0 x 10^{-4} per ship hour. The indicated frequency is in accordance with figures used in other risk analyses but slightly higher than the figures e.g. used as default input figures in the IWRAP calculation tool (about 1 x 10^{-4} per ship hour). The indicated figure from the Bornholmsgat AIS-recordings is considered reasonable taking into account that some of the registered drifting events may be intentional.

3.3 Risk modelling of potential accidents caused by delayed emergency anchoring

The purpose of the risk modelling is to illustrate if probabilities of stranding or collision accidents due to delayed emergency anchoring is influenced by the presence of a pipeline in the separation zone. An event tree model is applied to describe potential casual chains and accidental outcome. Probability figures for each sequential step are estimated to allow quantitative risk calculation

3.3.1 Event tree structure

In order to analyse and quantify if, and how, the future potential presence of the NSP2 pipeline in the separation zone might influence the probability of ship collisions between drifting ships and ships heading in the traffic lane of opposite direction, an event tree model was designed in Excel and applied for comparative calculations. The event tree structure is schematically illustrated in Figure 6 below.

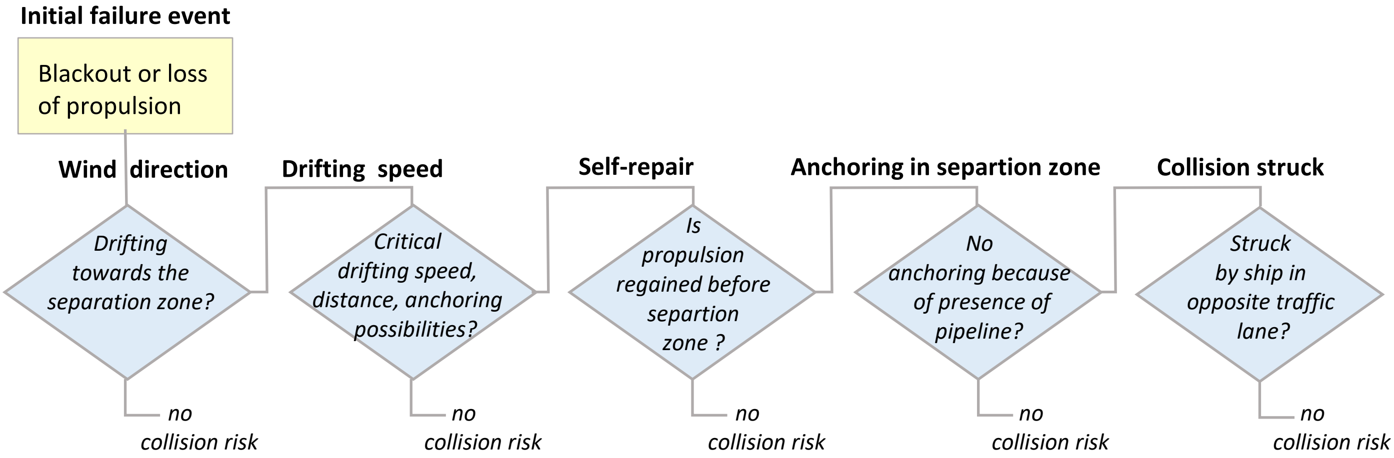

Figure 6. Schematic illustration of the event tree model.

3.3.2 Event tree – quantitative calculations

Two tree models have been applied; one for vessels encountering a blackout event in the SW going lane and one for vessels in the NE going lane. Quantitative input figures for the event tree model have been derived and estimated from various sources, briefly described below.

Initial failure event
Numerical input for ship traffic characterisation was derived from recorded AIS statistics. The registered number of NE-going vessels is somewhat lower (20 512)

than the one registered for the SE going lane (22 620). In order not to underestimate the potential accidents caused by the presence of the pipeline, the value 2.0 x 10^{-4} per ship hour, was used to calculate the expected annual number of drifting vessels in the shipping lanes. With a recorded average speed of 13 knots, the expected annual number of drifting vessels is 5.1 and 5.7 for the NE going lane and the SW going lane, respectively.

Wind direction

Wind statistics from the area (Utklippan south of Karlskrona), compiled by SMHI, (SMHI, 2018) were utilised to estimate the probability of drifting direction towards the separation zone. From positions in immediate proximity of the separation zone, a ± 90 degree range of wind directions around NW, would generate drift from the SW going lane into the separation zone and correspondingly for SO wind directions and vessels in the NE going lane. From positions in the central part of the lane, where most vessels are operating, as well as from positions close to the end points of the lanes, the range of possible wind directions towards the separation zone is more narrow. Recorded wind statistics are divided into 16 directions and for each of the lanes, 7/16 of the recorded directions were defined as critical directions. This wide range contributes making the calculations conservative.

Wind speed

The wind speed influences the drifting speed and thereby also the drifting time required to reach the separation zone. Depending on the type and size, different ships will show different drifting behaviour, but a maximum drifting speed for a tanker has in previous studies for NSP2 (SSPA, 2016) been calculated to 1.7 knots for a tanker and 2.1 knots for container vessel at a wind speed of 23 m/s. In wind speeds representing the registered average the wind speed in the area (6.9 m/s), drifting speed in the order of 0.6 – 0.7 knots are considered more likely. The minimum drifting time from the centre of one of the traffic lanes to the separation zone would be 2 h, and taking into account non-perpendicular drift directions an average drifting time of 3 h is considered representative.

The probability for successful anchoring is also dependent on the drifting speed and thereby also indirectly influenced by the wind speed. At a drift speed around 1 knot, anchoring is normally successful but at 2 knots, the probability of failure may be in the order of 50%.

Based on the considerations on wind speed and drifting conditions towards the separation zone, a critical wind speed limit of 5 m/s was identified for vessel likely to drift into the separation zone. At wind speed below 5 m/s the drifting behaviour is less predictable, with drift speed below 0.4 knots and drifting time longer than 5 h to reach the separation zone.

Self-repair

When a failure of the propulsion system is detected, the crew will immediately start remedy and repair efforts to regain control of the vessel. In most cases the repair is conducted quick and manoeuvring control is regained in due time to prevent grounding or collision risks and emergency anchoring is not applied. According to (Rasmussen, 2012) the probability of having repaired the blackout is given by a cumulative distribution as a function of time. This distribution could be estimated with a Weibull function with k=0,5 and λ=0,605. This function means that in half of the blackout events, control is regained within about 15 minutes and within 3 h, only about 10% are expected to still be out of propulsion.

Based on considerations on the AIS recording of drifting events as well as the on the suggested and previously applied statistical distribution functions of expected self-repair time, a conservative self-repair probability was estimated.

Anchoring in separation zone
For the fraction of drifting vessels entering the separation zone, their captains will consider the possibility of anchoring in the separation zone in order to prevent the risk of being struck by other ship if drifting continues in the lane of opposite direction. The potential presence of the NSP2 pipeline might influence their decision and input probability figures differ from the case representing the present situation without pipeline and a future situation with the pipeline present.

The width of the pipeline route including its 200 m protection zone along each side, is about 500 m and the total width of the separation zone is 1 500 m. Provided that the captain has accurate position data on the pipeline protection zone and the ship, it cannot be totally ruled out that dropping anchor leeward of the pipelines inside the separation zone, may be considered feasible. More likely, anchoring within the separation zone would be avoided in case the pipeline is present. Also in the case without the pipeline, some drifting vessels will fail to anchor and continue drifting into the opposite lane and thereby being exposed to collision risk of being struck by vessels transiting the one-directional lane.

For the sake of this assessment, a conservative approach is applied by assuming all vessels will successfully anchor in case there is no pipeline present and that 90% of the drifting vessels will avoid anchoring in, or close to the separation zone in case the pipeline is present.

Ship collision - drifting vessel being struck
The drifting vessels are unable to manoeuvre or observe the give way rules normally applicable for the traffic flow approaching from the starboard side. If the drifting vessels are identified by the other ship traffic it is relatively easy to predict its drifting route and to avoid close encounters or collision events. Emergency power supply for navigation, communication and lights should be in operation within 30 minutes from a blackout according to SOLAS regulations.

There is no empirical statistics available on collision frequency of drifting ships, and thereby no established model for calculation of collision probability. For this event tree model the software IWRAP Mk2 ver. 3.0 has been utilised for the estimation of collision risks. The tool is developed within the Danish Technical University (DTU) and in cooperation with Danish Maritime Authority (DMA) and GateHouse, and it is recommended by IALA[2]. First, the present traffic within the two one-directional traffic lanes of the Bornholmsgat TSS was modelled by the use of AIS-statistics recorded in 2017 and analysed in terms of expected collisions. The calculated expected collision frequency is very low and includes only collisions associated with overtaking events. In order to quantify the expected impact of potential vessels drifting across the separation zone and continue drifting across the opposite traffic lane, a crossing route leg representing the drifting vessels was introduced. The modelled traffic flow of this additional route leg was represented by the number of drifting vessels at the end of the event tree model. Its lateral distribution was very wide, representing a stochastic distribution of crossing routes of drifting vessels and its average speed around 1 knot.

With the drifting vessels introduced, the IWRAP calculations present a number of additional expected collisions characterised as crossing, bending or merging collisions. The IWRAP model and its default causation factors are designed to represent collision and grounding probability of powered ships and grounding probability of drifting ships, but collision events where powered ships are striking drifting ships are not specifically addressed. The derived number of expected additional collisions due to the presence of the pipeline in the separation zone may, however, be considered as a reasonable figure. Taking into account all the conservative aspects, most likely overestimating the number of drifting vessels entering and drifting across the opposite lane, the uncertainty associated with the IWRAP calculation is not considered to contradict the conservative approach.

The areal plot from the IWRAP calculation in Figure 7 below, shows an example where a crossing route leg is introduced in the NE going traffic lane.

[2] IALA, a non-profit, international technical association for marine aids to navigation authorities and other stakeholders.

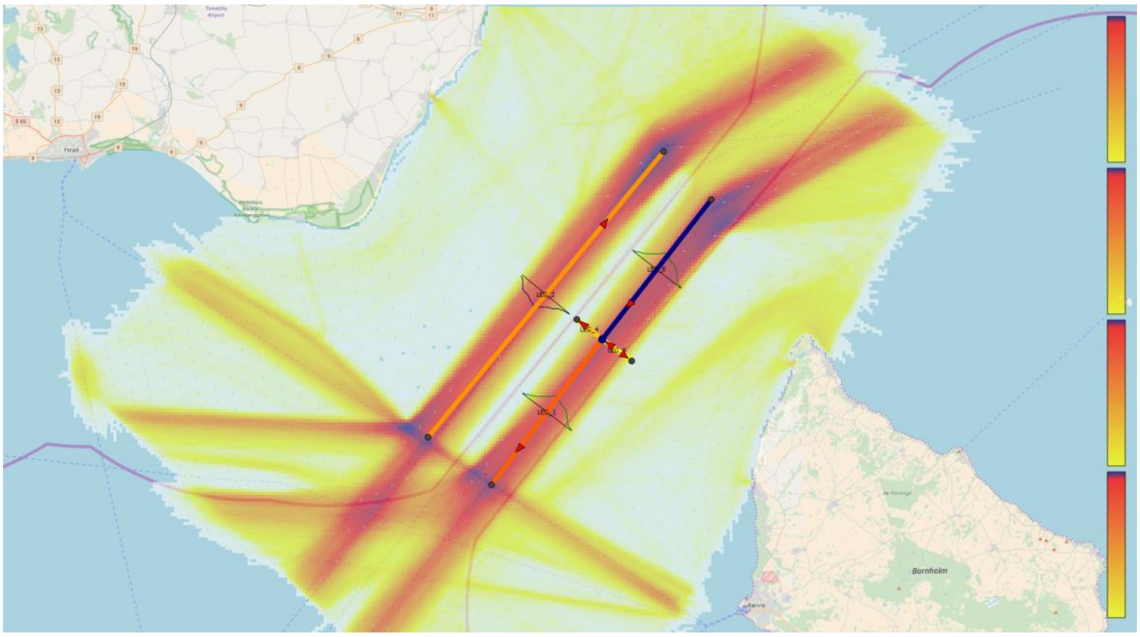

Figure 7. IWRAP traffic density plot on the Bornholmsgat TSS with an example of a crossing route leg introduced. Dark purple colour indicates the areas with the highest traffic density and yellow represents less dense traffic. The separation zone is white, indicating very few ship crossings between the main lanes.

3.3.3 Output from the event tree

Based on sea traffic registered in 2017, comparative calculations with the event tree model, expected collision figures for the situation without and with the pipeline in the separation zone, are shown in Table 1 below.

Table 1. Results from comparative collision calculations from the event tree model.

Collision risk in the Bornholmsgat TSS	***Collisions per year***	***Years between collisions***
Present situation without pipeline in the separation zone. *Expected collisions caused by overtaking events within the two one-directional lanes of the Bornholmsgat TSS*	*0.00217*	*461*
Future situation with pipeline in the separation zone. *Expected additional collisions caused by drifting vessel avoiding emergency anchoring in the separation zone and being struck by vessels in the opposite traffic lane.*	*1.36×10^{-6}*	*735 000*
Expected collisions caused by overtaking events and striking of drifting vessel caused by delayed emergency anchoring	*0.00217136*	*461*

The output of the event tree model indicates that if drifting ships are prevented from emergency anchoring in the separation zone due to the presence of the pipeline, collision probability in the lanes may increase by less than 1‰.

In the ship-ship collision report (Ramboll, 2018), it is estimated that increment represented by the collision frequency involving third-party vessels and work vessels along the Danish pipeline sector is 5.26×10^{-4} per year during the construction phase. This contribution is considered to be “very limited”. Corresponding contribution from the entire pipeline route in the Baltic Sea is indicated to represent less than 0.1‰ of the average number of annual ship collisions in the Baltic Sea.

The estimated additional frequency contribution from delayed emergency anchoring in the operational phase shown in Table 1, is significantly smaller than the contribution from the construction phase in the Danish sector. Its contribution can thus be considered insignificant compared with other collision risks in the area.

3.4 Drifting vessels and potential emergency anchoring in the precautionary area

The presented event tree model is primarily designed to represent the situation for the NSP2 pipeline section located in the TSS separation zone. For the precautionary area with crossing and merging traffic lanes, the expected ship collision probability is higher than in the one-directional separation lanes. For navigators the NSP2 routeing through the precautionary area introduces an additional factor to observe in an area with dense and complex traffic, but no specific influence on navigational safety during the operational phase, is identified.

Anchoring conditions are influenced by the pipeline routeing, but in case of blackout events with loss of propulsion or close encounter situations with imminent collision hazards, emergency anchoring is not considered a relevant measure to prevent collisions in this area. Hence, the presence of the pipeline in the precautionary area does not influence the expected collision frequency of drifting vessels nor of powered ones. Neither are the possibilities for emergency anchoring of drifting vessels in the precautionary area in order to prevent grounding or stranding accidents, influenced by the presence of the pipeline. There is enough of space and areas with attractive water depth for anchoring and low traffic intensity, in and adjacent to the precautionary area to ensure safe anchoring.

4 Risk Control Options – RCO

The quantitative analysis of identified potential risk associated with delayed emergency anchoring, indicates that its additional contribution to collision risk is significantly smaller than the risk contribution represented by the ship-ship collisions in the construction phase in the Danish sector. With respect to third-party risk to the public, the ship-ship collision contribution from the construction phase (G.M., 2018), does not generate risks exceeding established limits considered "broadly acceptable", and thus the potential risk associated with delayed emergency anchoring, neither will generate individual risk exceeding this level. Corresponding group risk (societal risk) in the construction phase, is also shown to be within acceptable limits and consequently the estimated risk contribution from delayed emergency anchoring does not call for any specific risk reduction measures or introduction dedicated risk control options.

Nevertheless risk control and emergency preparedness are essential and a number of measures and preparations are included in the planning phase. Examples of areas and measures to be included are briefly described below. More detailed information is found in technical documentation and emergency plans.

4.1 Construction phase

4.1.1 Spill response and preparedness

In particular during the construction phase the collision risk contribution imposed by the operation of work vessels and handling of fuel and provisions, require a well prepared and equipped organisation for any potential oil spill. All engaged contractors must fulfil the NSP2 requirements for Tier 1 response and comply with Shipboard Oil Pollution Emergency Plan (SOPEP) regulations. For larger spills, Nord Stream 2 AG is responsible for dealing with Tier 2 and Tier 3 spills, and therefore has an oil spill contingency plan (OSCP) in place.

4.1.2 Information and communication

Another important area where experience from the construction phase of NSP1 have generated extensive knowledge to be applied also in NSP2, is related to distribution of information and communication with contactors as well as third-party vessel. The measures are particularly focussing issues on distribution of information, communication, vessel traffic monitoring and prevention of hazardous interaction conflicts with third-party vessel traffic.

4.2 Operational phase

4.2.1 Regular pipeline inspection and monitoring

In order to prevent and minimise pipeline damage, gas leakage accidents and complicated repair operations, routines for regular inspection and monitoring of the pipeline conditions will be implemented. Automatic emergency shutdown and redundant control systems will be installed.

4.2.2 Information and regulations

In order to prevent any type of maritime incidents and potential damage to the pipeline, it is important to ensure accurate and clear information on the pipeline route as well as regulations on protection zone etc.

4.2.3 Regular traffic monitoring and analyses

The past years of operation of the NSP1 pipeline show a good safety record and a low frequency of incidents and hazardous events. Modern AIS technique and sea traffic management offers a wide range of proactive monitoring and analysis methods by which potentially hazardous conditions or situations may be identified and rectified in due time before and incident is manifest.

4.2.4 Emergency towing capacity

With regard to potential grounding or stranding risks for drifting vessels, it is shown that future potential presence of the NSP2 pipeline in the separation zone, will not influence the probability or conditions for successful emergency anchoring in order to prevent grounding or stranding along the coast of Bornholm or the Swedish coast on the opposite side of the Bornholmsgat. On both sides, there is enough of space and time for anchoring at more favourable water depth.

In case of unsuccessful anchoring, emergency towing capacity is available in the area by a dedicated Emergency Towing Vessel (ETV) stationed in Karlskrona about 60 nm away from the Bornholmsgat. The transit time for the ETV from Karlskrona to reach a drifting vessel in distress in the Bornholmsgat TSS, will be about 4 hours plus possible start-up time. This is somewhat more than the estimated average drifting time of a vessel without propulsion to reach the separation zone from a position in the centre of the traffic lane. The 4 hour transit time will, however, in normal weather conditions, be enough to reach a drifting vessel before it reaches areas outside the Bornholmsgat TSS where critical grounding or stranding risks may occur.

5 Conclusions and recommendations

5.1 Uncertainties and calculation accuracy

All risk analyses are associated with some uncertainties and in particular, if quantitative calculations are included, it is important to describe the sources and the magnitudes of the uncertainties. Uncertainties and inaccuracies origin from background statistics, prognosis data, assumptions, and mathematical modelling of probabilities. Risk analysis tools and models may generate quantitative results with many digits and seemingly high accuracy, but numerical risk and probability figures should be considered with care.

5.1.1 Quantitative event tree modelling

AIS-registrations
The presented AIS-registrations of vessel traffic in the Bornholmsgat are considered to be of high accuracy and show good agreement with other sources and official statistics. It represents the present traffic situation (registrations from 2017) and is not adjusted to reflect future predicted traffic during the operational life cycle of the NSP2.

Loss of propulsion
The blackout or drifting frequency derived from the AIS registrations in the area is found to agree reasonably well with empirical general blackout figures regularly applied in this type of risk assessments. The empirical figures are per se, based on obsolete data representing ships no longer in operation and not todays´ fleet and updated regulative safety schemes. Frequency figures on machinery failure and blackout, however, appear to be relatively constant despite introduction of new technologies and sophisticated maintenance and surveillance systems.

Wind statistics
The wind statistics used to identify the frequency of critical wind directions and speed are considered accurate and representative though it is not collected at the specific location of the Bornholmsgat TSS.

Drift speed
The estimation of drift speed for vessels without propulsion is based on simulations with two representative shiptypes, one tanker and one container vessels, and is considered to be accurate and represent the fleet of actual vessels in the area reasonably well.

Reluctance of anchoring in the separation zone
In the current situation without pipeline in the separation zone, it is assumed that no ship avoids emergency anchoring. Anchoring may, however, fail due to high drifting speed, too large depth, or failure of anchor winch, and lead to unwanted drifting into the opposite traffic lane. This is not considered in the

event tree model, and thus contributes to conservative calculations. The estimated fraction of vessels that do anchor in the separation despite the presence of the pipeline is a more uncertain assumption. It reflects the captains view of prioritization of the vessel safety prior to the pipeline safety as well as the possibility of safe anchoring in the separation zone without intrusion of the pipeline protection zone. The figure introduces a relatively high factor of uncertainty but the assumed figures are considered conservative.

Collision risk in the opposite traffic lane
The IWRAP tool, utilised for estimation of the probability of a drifting vessel being struck by a vessel heading in one of the one-directional traffic lanes, is associated with uncertainty, as this is not a standard method to simulate crossing traffic flows in IWRAP. The area is a TSS with high traffic density, generally calling for a high level of alertness among all vessels in the area, and it is considered likely that the drifting vessel will be detected and identified by passing ships.

5.1.2 Sensitivity analysis

Examples of comparative sensitivity of some event tree parameters are presented in Table 2 below with respect to their influence on estimated number of annual collisions with drifting vessels caused by delayed emergency anchoring.

Application of the model figures described in the report, referred as the base case in Table 2, indicates an expected collision frequency of $1{,}36 \times 10^{-6}$ which is equivalent to one collision in about 735 000 years. The tabulated four examples of paramtric variations (A,B, C, and D) introduce a wide range of factors adding additional conservative contribution to the calculations. The output collision frequencies differ from 2 to 5 times higher than the base case, but the results are still very small compared with the calculated current collision overtaking collision frequency in the TSS traffic lanes. The additional collision frequency caused by delayed emergency anchoring corresponds, in the base case to 0.6‰ and for iteration C and D, to 3‰ of the current collision frequency.

The parameters related to the self-repair time and the the collision causation factors used for the IWRAP calculations are considered more uncertain than the others and indicate higher influence on the calculation output. However, the examples show that none of the parameters have a critical influence on the output and all results can stilll be considered insignificant compared with the current calcultated collision risks in the TSS lanes.

Table 2. Sensitivity analysis of four selected event tree parameters. Bold figures differ from the base case.

Parameters *Iteration*	*Blackout frequency per ship-hour*	*Critical wind speed for drifting*	*Self-repair percentage repaired before drifting into TSS*	*Probability of collision when drifting in TSS*	*Number of annual collisions in opposite TSS due to NSP2*
Base case ***Presented figures***	2×10^{-4}	5 m/s	90 %	North: $8,45 \times 10^{-6}$ South: $1,01 \times 10^{-5}$	$1,36 \times 10^{-6}$
A ***Increased blackout frequency***	$\mathbf{4.0 \times 10^{-4}}$	5 m/s	90 %	North: $8,45 \times 10^{-6}$ South: $1,01 \times 10^{-5}$	$2,73 \times 10^{-6}$
B **Reduced critical wind speed**	2×10^{-4}	**0 m/s**	90 %	North: $8,45 \times 10^{-6}$ South: $1,01 \times 10^{-5}$	$3,71 \times 10^{-6}$
C ***Reduced self-repair rate***	2×10^{-4}	5 m/s	**50 %**	North: $8,45 \times 10^{-6}$ South: $1,01 \times 10^{-5}$	$6,82 \times 10^{-6}$
D ***Increased probability of collision in opposite TSS***	2×10^{-4}	5 m/s	90 %	**North: $\mathbf{4,22 \times 10^{-5}}$** **South: $\mathbf{5,05 \times 10^{-5}}$**	$6,82 \times 10^{-6}$

5.2 Methodology

Documentation from the initial hazard identification workshop, together with the preparatory basic routeing studies and the present report, form the components of a Formal Safety Assessment FSA in applicable part. The direct maritime safety issues related to the construction and operational phases including collision with third-party vessels, have been addressed in dedicated risk assessment reports but a number of identified potential indirect risks are specifically addressed in this report. The applied event tree model provides a clear calculation scheme for quantification of the probabilities of collision accidents caused by potential delay of emergency anchoring due to the pipeline routeing in the separation zone. The estimated collision risk contribution caused by potential delay of emergency anchoring have been compared with calculated ship-ship collision frequency during the construction phase, and corresponding conclusions regarding assessment versus established acceptance criteria are made.

5.3 Indirect risk to the ship traffic and other maritime activities

5.3.1 Construction phase

Comparative assessment of various route alignment options show that collision risks between construction vessels and third-party vessels are minimised by routing options with a minimum of third-party traffic interaction in distance and timewise. The proposed NSP2 routeing in the separation zone is favourable from a collision point of view. The routeing across the precautionary area may generate somewhat more complex interaction with turning traffic and merging ship flows, but may also offer some more space for third-party vessels to pass aside the exclusion zone around the pipe-lay vessel. The size and shape of this exclusion zone is not yet finally decided, but may influence the magnitude of disturbance effects encountered by passing third-party vessels.

No specific indirect safety issues for third-party traffic during the construction phase were identified or subject for quantitative analysis.

5.3.2 Operational phase

The presented AIS analysis shows that successful anchoring in the separation zone is possible but it does not clearly confirm that the separation zone is considered particularly attractive for emergency anchoring of drifting vessels. The event tree model applied, shows that potential delay of emergency anchoring caused by the presence of pipelines in the separation zone, only generates a negligible contribution of indirect risk compared with other direct ship-ship collision risks. Regarding third-party risks to the public, the risk contribution potentially caused by delayed emergency anchoring is consequently also well below the established level of broadly acceptable risks. No complementary risk reduction measure specificcally addressing this issue is elaborated or proposed by the study.

5.4 Recommendations

The presented results of the study do not call for specific measures and no urgent recommendations specifically addressing the analysed indirect maritime risks have been identified. It is, however, shown that the shape and size of the exclusion zone encircling the pipe-lay vessel will influence the interaction effects with third-party vessels during the construction phase. It is therefore considered relevant to further examine and adjust the originally indicated zone of 1 nm radius, in cooperation with the Danish Maritime Authority, to find an optimum dimension with respect to safety for construction vessels as well as for passing third-party ships.

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