# Enclosure 2 to the NC PARS: Likelihood of Vessel Incident Comparison

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## Analysis Overview

This report shows calculated vessel incident frequencies for the NC PARS study area. This includes the North Carolina Wilmington East and West, and the South Carolina Grand Stand areas[1]. The vessel incident frequencies were calculated using the IALA Waterways Risk Assessment Program (IWRAP) software. Figure 1 shows the relevant areas.

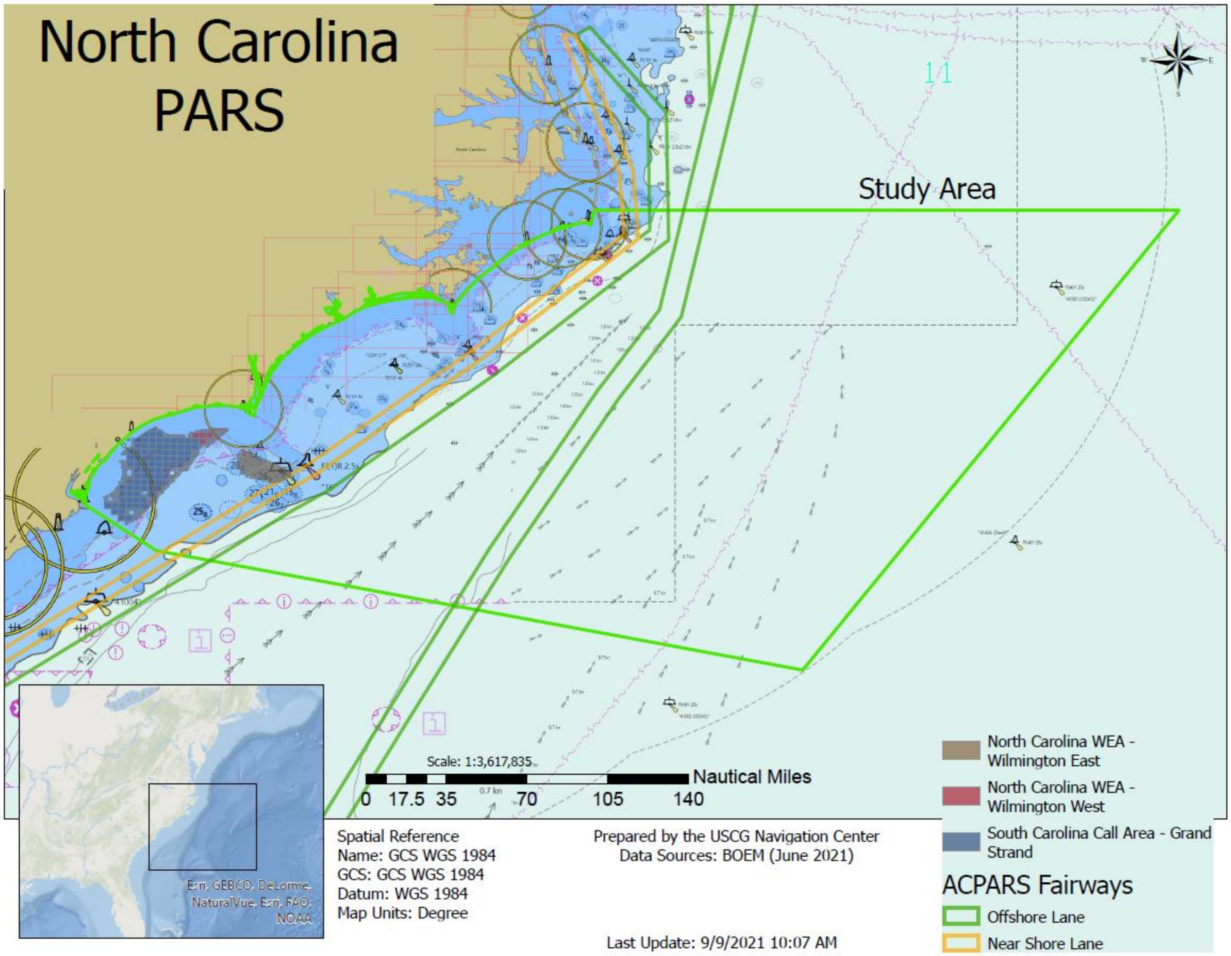


*Figure 1: Study Area Including Wind Areas*

## IWRAP Software and Model Overview

IWRAP is a tool that predicts the frequency of vessel collisions, allisions, and groundings (vessel incidents) in a specified geographic area. IWRAP evaluates and estimates the annual number of allisions, collisions, and groundings in a modeled area using Automatic Identification System (AIS)-derived vessel traffic data. The specific breakdown and definitions of types of incidents that IWRAP evaluates are detailed in Table 1.

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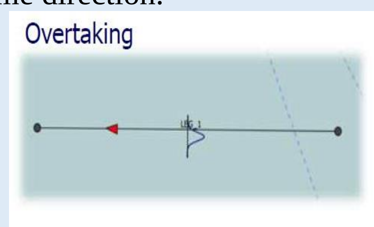
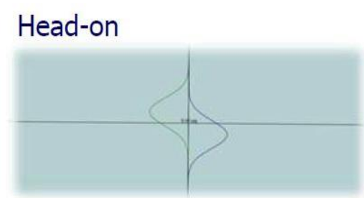
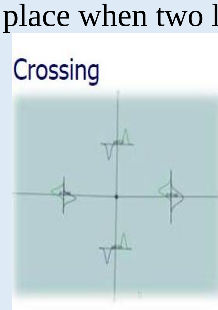
[1] Although these areas are not leased, they were evaluated in this report to capture the largest known area that may be leased in the future. The final areas are still under discussion by BOEM; the most up to date lease blocks are maintained by BOEM and can be viewed at: https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data.

| Incident Type | Definition |
|---|---|
| **Powered Grounding** | Powered groundings occur when a vessel fails to maneuver to avoid shallow water or shoals and strikes the ocean floor while under power. |
| **Drifting Grounding** | Drifting groundings occur when a vessel is no longer under the control of the mariner or has lost power and the vessel strikes the ocean floor. |
| **Powered Allision** | Powered allisions occur when a vessel fails to maneuver to avoid a structure or stationary object and strikes that object. Such objects include bridges or wind turbines. |
| **Drifting Allision** | Drifting allisions occur when a vessel is no longer under the control of the mariner or has lost power and strikes a structure or stationary object. Such objects include bridges or wind turbines. |
| **Overtaking Collision** | Overtaking collisions take place when two vessels are on the same leg moving the same direction.   |
| **Head-On Collision** | Head on collisions take place when two vessels are on the same leg moving in reciprocal directions.   |
| **Crossing Collision** | Crossing collisions take place when two legs cross at a waypoint.   |

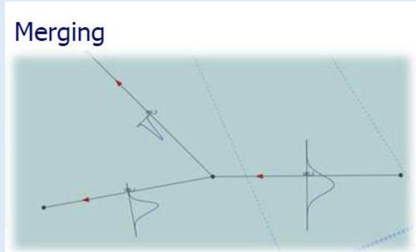
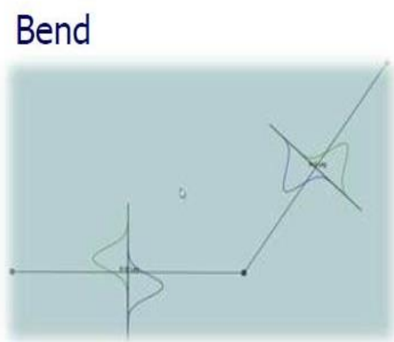
| Incident Type | Definition |
|---|---|
| **Merging Collision** | Merging collisions take place when several legs merge at a waypoint.   |
| **Bend Collision** | Bend collisions take place when ships on the same leg make a turn at a waypoint.   |

*Table 1: IWRAP Vessel Incident Types*

## Model Inputs

Model inputs include the data required by IWRAP in order to calculate probabilities of vessel incidents. The inputs include AIS data, bathymetry, and structures.

### *AIS Data*

For this analysis, the AIS data set is all AIS equipped vessel traffic in the study area in calendar year 2019. Figure 1 shows this area.

### *Bathymetry*

Bathymetry comes from ENC data (encdirect.noaa.gov) and is uploaded directly into IWRAP.

### *Model Structures*

Structures are modeled by creating a georeferenced representation of size and shape, and are uploaded directly to the software. The structures used in this analysis were created by NAVCEN in ArcGIS Pro, assuming fully developed wind areas, as monopile wind turbine generators with twelve-meter diameter bases. The turbines were spaced evenly in a one nautical mile grid pattern.

## Algorithm

Given the model inputs, the fundamental calculation used by IWRAP is:

$$\textit{Incident Frequency} = \textit{Geometric Frequency} \times \textit{Causation Factor}$$

*Geometric Frequency*

Geometric Frequency is the number of incident candidates that exist in an AIS data set. After an AIS data set is uploaded, a color-coded line density plot is used to visually identify the most frequented routes. A network is then developed by an analyst who assigns legs connected by waypoints to the highest density routes based on a visual evaluation. IWRAP then assigns statistical distributions of vessel traffic to legs and waypoints based on the AIS data. The distributions are used to determine the total number of opportunities for a collision to take place.

*Causation Factor*

The Causation Factor is a thinning probability applied to the geometric incident candidates. In other words, the causation factor allows IWRAP to determine how many of the candidates for collisions, allision, or grounding actually had an incident occur. The causation factor accounts for the tendency of vessels to avoid other vessels, structures, and grounding. A set of universally applicable causation factors, based on Bayesian statistics and rooted in studies of past incidents, was developed by International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) in cooperation with the academic community. These values are the default for the IWRAP incident frequency calculations and were not modified from the default for this report.

### Outputs

The resulting incident frequencies that are derived from the model are reported for each incident type described in Table 1 with the units years between incidents. These values represent the probabilities a certain type of incident will take place in any given year assuming the traffic makeup is similar to the sample year.

# NC PARS Model Development

In this analysis two models were considered, referred to as Alpha and Bravo.

## Alpha Model

The Alpha model is the baseline model in which no structures exist, and represents the probability that incidents will take place in the sample year. Since there are no structures in this model, allision frequencies do not exist.

## Bravo Model

The Bravo model assumes that traffic does not alter patterns and adds in the fully developed wind areas. Bravo is the most congested scenario; Bravo shows the maximum allision frequencies the projects may present.

## Alpha and Bravo Models' Leg Configuration

The network of legs for the model was developed in cooperation with CG District 5 Waterways based on the 2019 all vessels traffic density and includes 32 legs. The full model is shown in Figure 2 (additional larger scale screenshots are included in Appendix 1). Also in Figure 2, vessel traffic density for 2019 is represented on a yellow, orange, purple, and black scale. Yellow is the highest density areas and black the lowest density. The four colors represent quantiles with cutoffs at 99 (yellow), 95 (orange), 66 purple, and 0 (black) with a continuous gradient in between. The proposed ACPARS fairways as well as the wind areas are also shown in this figure, to provide context. The black lines represent the numbered legs connected by waypoints. Each leg has two distributions assigned, representing the two directions of travel on that leg, which were extracted from the AIS data. The legs used in this model are tabulated in Table 2.

| Leg | Description |
|---|---|
| **coastwise_1** | Legs for coastwise traffic. |
| **coastwise_2** | |
| **coastwise_3** | |
| **coastwise_4** | |
| **coastwise_5** | |
| **coastwise_6** | |
| **coastwise_7** | |
| **TSS_1** | Legs near or branching off the TSS approaching Cape Fear River. |
| **TSS_2** | |
| **TSS_split_1** | |
| **TSS_split_2** | |
| **TSS_split_3** | |
| **TSS_split_4** | |
| **TSS_split_5** | |
| **inlet_1** | Legs near inlets. Some of these legs cross through wind areas. |
| **inlet_2** | |
| **inlet_3** | |
| **inlet_4** | |
| **inlet_5** | |
| **inlet_6** | |
| **cross_1** | Legs that cross a wind area. |
| **cross_2** | |
| **cross_3** | |
| **cross_4** | |
| **cross_5** | |
| **cross_6** | |
| **shore_1** | Legs near the shore in the study area. |
| **shore_2** | |
| **shore_3** | |
| **shore_4** | |
| **exit_1** | Other legs. |
| **connection_1** | |

*Table 2: Alpha and Bravo Models' Legs*

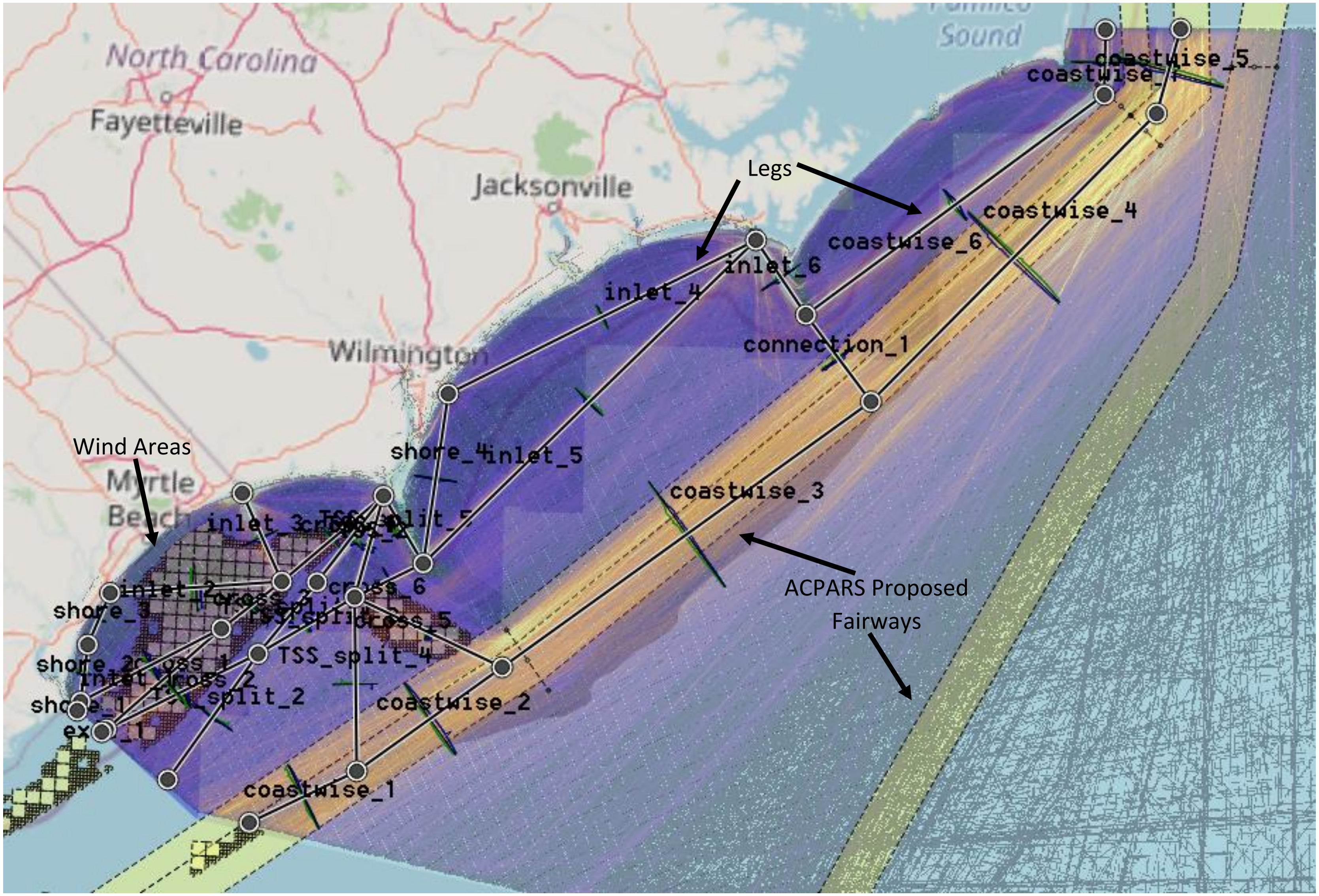



*Figure 2: NC PARS IWRAP Alpha and Bravo Leg Configuration*

## Results

Table 3 shows the results of the Alpha and Bravo models and the percentage change between results ( $\frac{New\ Model\ Value - Old\ Model\ Value}{Old\ Model\ Value} * 100$). The units are years between incidents. Appendix 2 contains a detailed presentation of these data by model and individual leg.

| | Alpha | Bravo | |
|---|---|---|---|
| | Years Between Incidents | Percent Change (From Alpha) | Years Between Incidents |
| Powered Grounding | 5.02 | 0.040% | 5.022 |
| Drifting Grounding | 49.61 | 0.020% | 49.62 |
| **Total Groundings** | 4.559 | 0.044% | 4.561 |
| Powered Allision | --- | --- | 104.7 |
| Drifting Allision | --- | --- | 2,937 |
| **Total Allisions** | --- | --- | 101.1 |
| Overtaking | 3,596 | 0% | 3,596 |
| Head On | 1,892 | 0% | 1,892 |
| Crossing | 1.19E+05 | 0% | 1.19E+05 |
| Merging | 3.91E+05 | 0% | 3.91E+05 |
| Bend | 8,604 | 0% | 8,604 |
| **Total Collisions** | 1,071 | 0% | 1,071 |

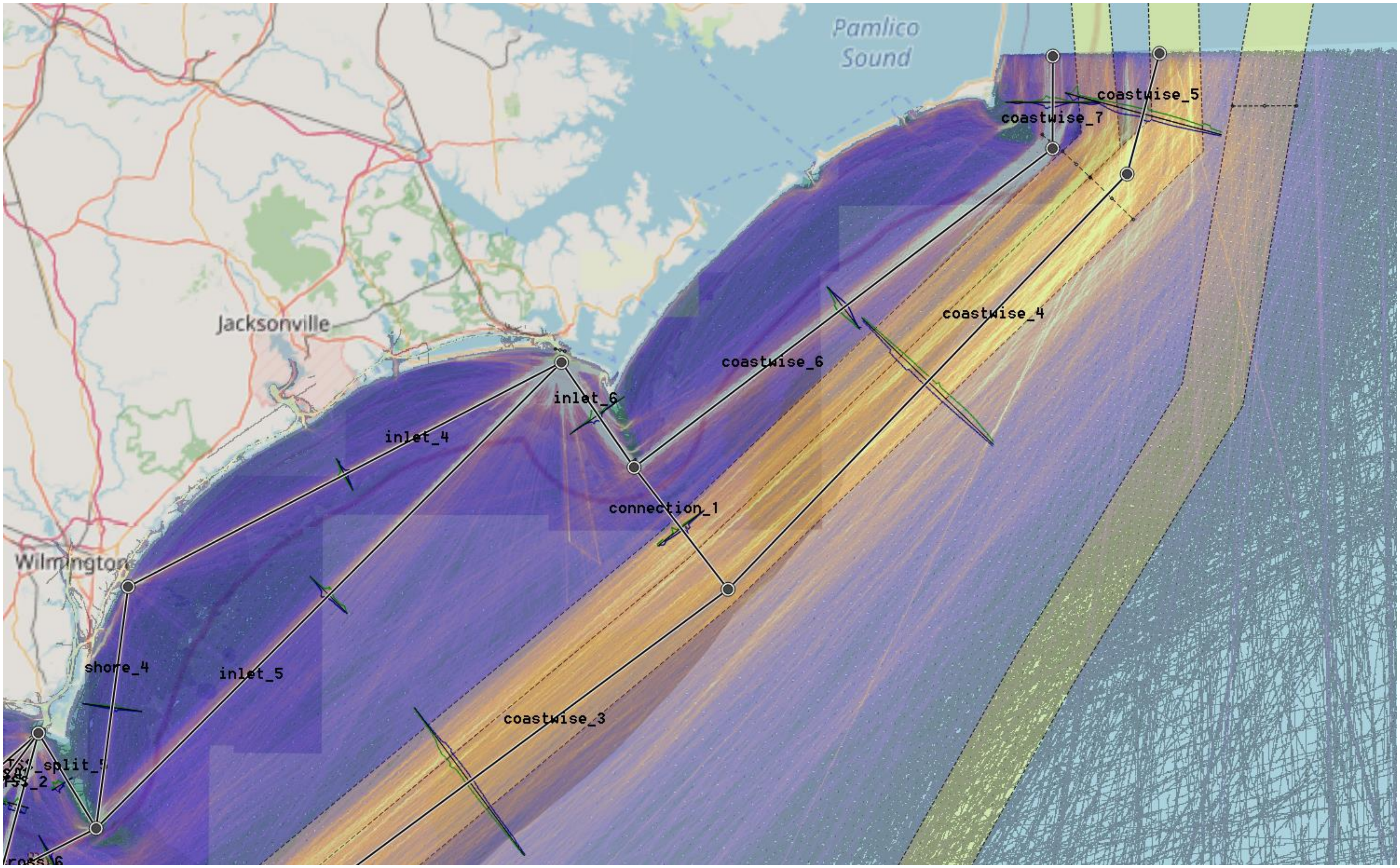
*Table 3: Alpha and Bravo Results*

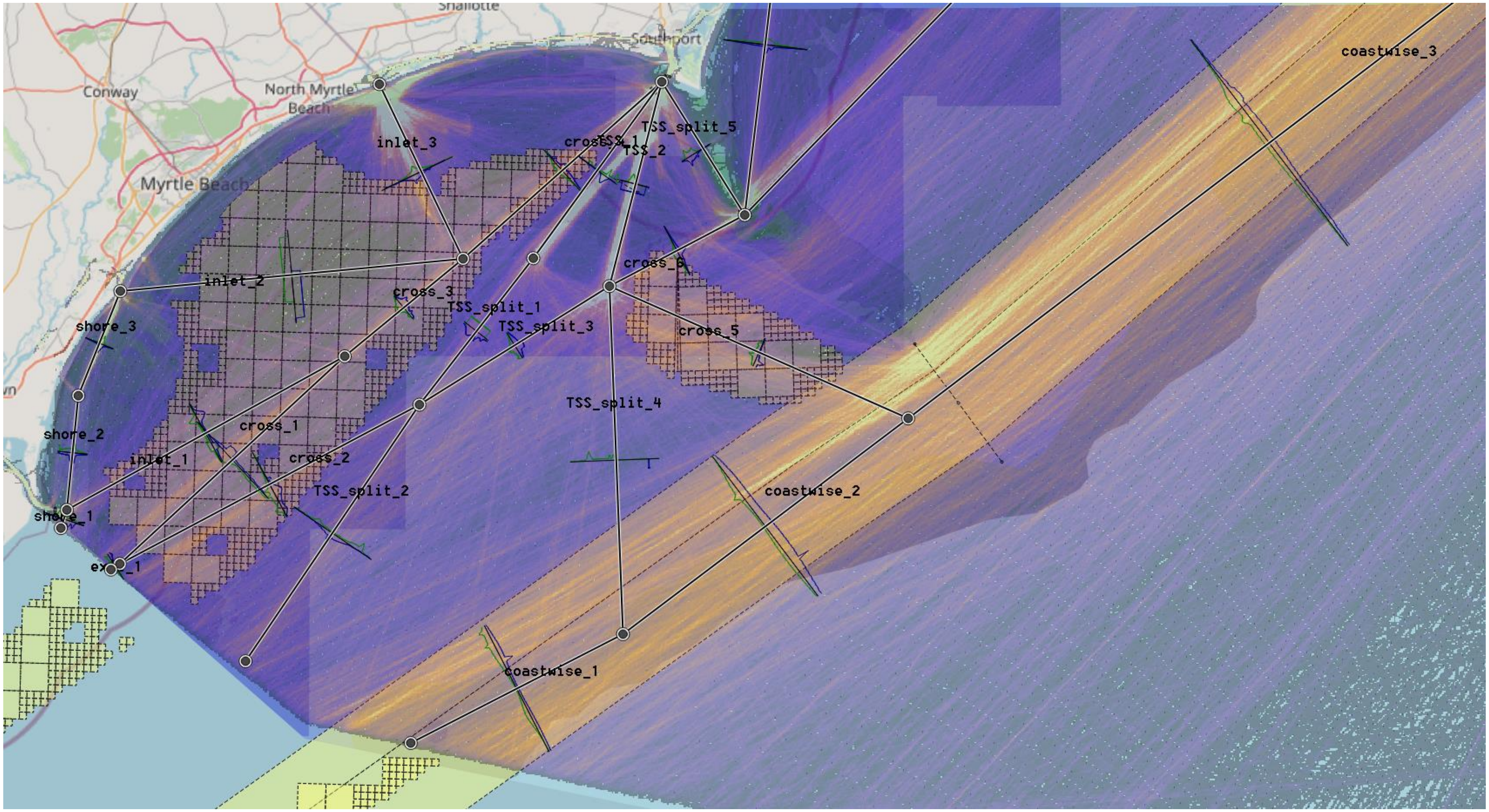
### Results Breakdown and Discussion

The probabilities from the models provide a basis to compare the relative likelihood of vessel incidents in the study area in the present configuration (Alpha) as well as in some projected future configuration (Bravo). While Alpha shows no allisions since there are no structures in the model, Bravo does show allisions due to the addition of the WTGs. However, some vessels would likely route around the WEAs depending on their size. In this model, it is anticipated that cargo and tank ships would re-route from cross_5 to another area. These vessel types make up 91% of the total traffic on cross_5. The other legs that cut through wind areas do not have any or have very little cargo and tank ship traffic, and smaller vessels are presumed to continue to route through the WEA.

Any vessels that re-route around the WEA will reduce the number of candidates for allision. However, when vessels re-route to other areas, they transit in already congested spaces. More vessels would then be present on certain legs in the model, increasing overtaking and head on collisions. Thus, it is anticipated that actual allisions would be less and actual collisions be greater in a real-world scenario than are represented in the Bravo case.

# Appendix 1: Additional Model Images




Southport
Conway
North Myrtle Beach
Myrtle Beach
coastwise_3
TSS_split_5
inlet_3
TSS_2
inlet_2
cross_6
cross_3
TSS_split_1
TSS_split_3
shore_3
cross_5
TSS_split_4
shore_2
cross_1
inlet_1
cross_2
TSS_split_2
coastwise_2
shore_1
coastwise_1

# Appendix 2: Detailed Alpha and Bravo Case Results

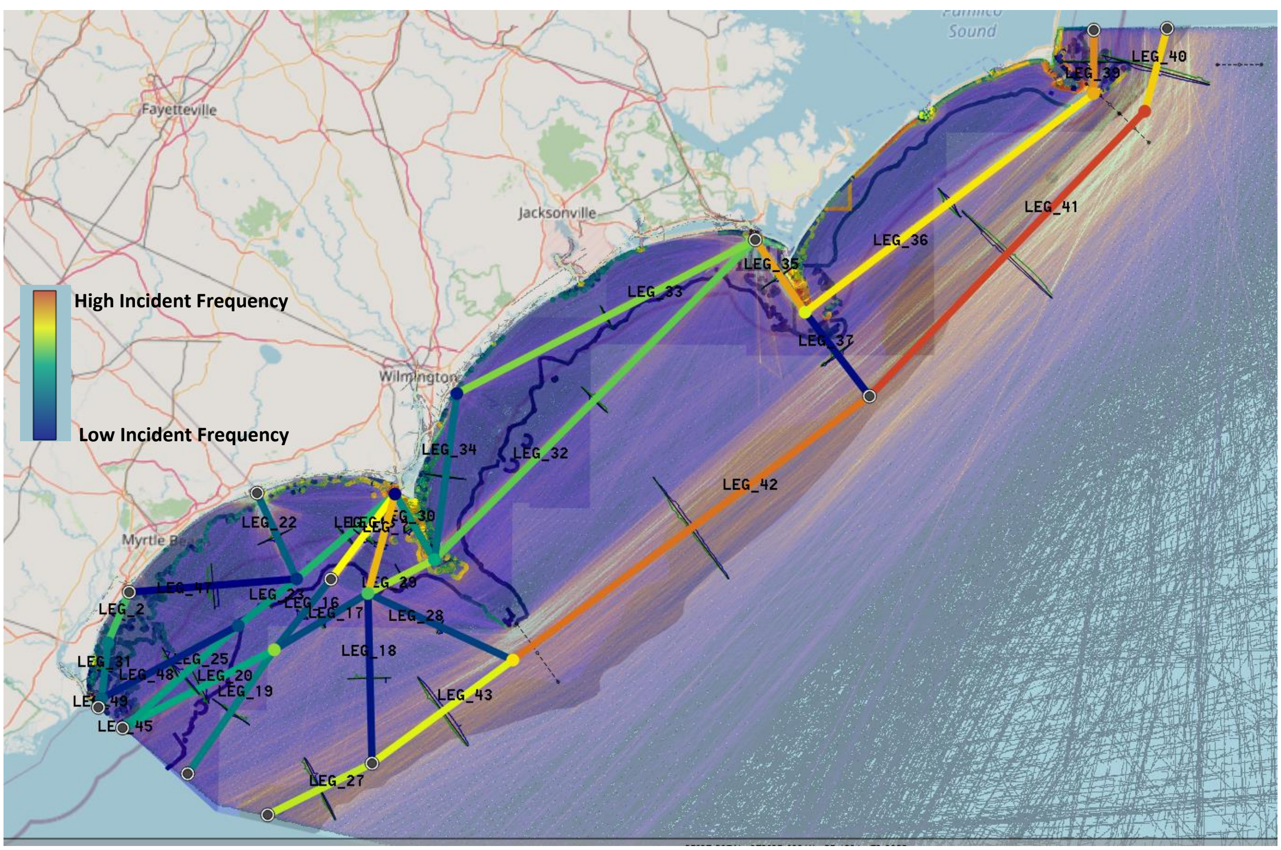
For models Alpha and Bravo, overall results are shown followed by tables containing groundings and collisions by leg. Alpha and Bravo collisions are shown only under Alpha since the collision results are the same in each case. Bravo also contains allision results. All units are years between incidents.

## Alpha

The Alpha Case is the base case with current traffic based on 2019 data and no developed wind areas. No allisions are contained in the base case as there are no structures in the model.

| Alpha Case – Overall Results (Years Between Incidents) | |
|---|---|
| Powered Grounding | 5.02 |
| Drifting Grounding | 49.61 |
| **Total Groundings** | 4.559 |
| Powered Allision | --- |
| Drifting Allision | --- |
| **Total Allisions** | --- |
| Overtaking | 3,596 |
| Head On | 1,892 |
| Crossing | 1.19E+05 |
| Merging | 3.91E+05 |
| Bend | 8,604 |
| Area | --- |
| **Total Collisions** | 1,071 |

*Table 4: Alpha Overall Results*



| Alpha Case – Groundings by Leg (Years Between Incidents) | | | |
|---|---|---|---|
| Leg | Powered | Drifting | Total |
| **coastwise_1** | --- | 1277589.1 | 1277589.1 |
| **coastwise_2** | 19449778.4 | 30470.4 | 30422.8 |
| **coastwise_3** | 8346.0 | 1638.7 | 1369.7 |
| **coastwise_4** | 50.6 | 193.8 | 40.1 |
| **coastwise_5** | 1055.7 | 6452.5 | 907.2 |
| **coastwise_6** | 297.8 | 1139.8 | 236.1 |
| **coastwise_7** | 1182.5 | 38393.6 | 1147.2 |
| **connection_1** | 139990.3 | 545795.6 | 111413.9 |
| **cross_1** | 1224523814189.5 | 70182.0 | 70182.0 |
| **cross_2** | --- | 87081.6 | 87081.6 |
| **cross_3** | --- | 7955819.7 | 7955819.7 |
| **cross_4** | 423.2 | 11353.0 | 408.0 |
| **cross_5** | --- | 20982.5 | 20982.5 |
| **cross_6** | 4367.3 | 38897.8 | 3926.4 |
| **exit_1** | --- | 26801195.3 | 26801195.3 |
| **inlet_1** | 5754.6 | 891122.5 | 5717.7 |
| **inlet_2** | --- | 2973906.1 | 2973906.1 |
| **inlet_3** | 1033.8 | 10500.1 | 941.1 |
| **inlet_4** | 3733.7 | 36185.9 | 3384.5 |
| **inlet_5** | 762.3 | 7008.0 | 687.5 |
| **inlet_6** | 160.7 | 901.3 | 136.4 |
| **shore_1** | 1248.7 | 80059.0 | 1229.5 |
| **shore_2** | 255.8 | 9621.5 | 249.2 |
| **shore_3** | 110436.6 | 2146373.3 | 105032.4 |
| **shore_4** | 316.3 | 3409.4 | 289.4 |
| **TSS_1** | 21.0 | 227.3 | 19.2 |
| **TSS_2** | 9.4 | 152.9 | 8.8 |
| **TSS_split_1** | --- | 65612.7 | 65612.7 |
| **TSS_split_2** | 32297878736.4 | 25316.7 | 25316.7 |
| **TSS_split_3** | --- | 2106130.9 | 2106130.9 |
| **TSS_split_4** | --- | 141958.5 | 141958.5 |
| **TSS_split_5** | 4825.3 | 3143.2 | 1903.4 |
| **Overall** | 5.0 | 49.6 | 4.6 |

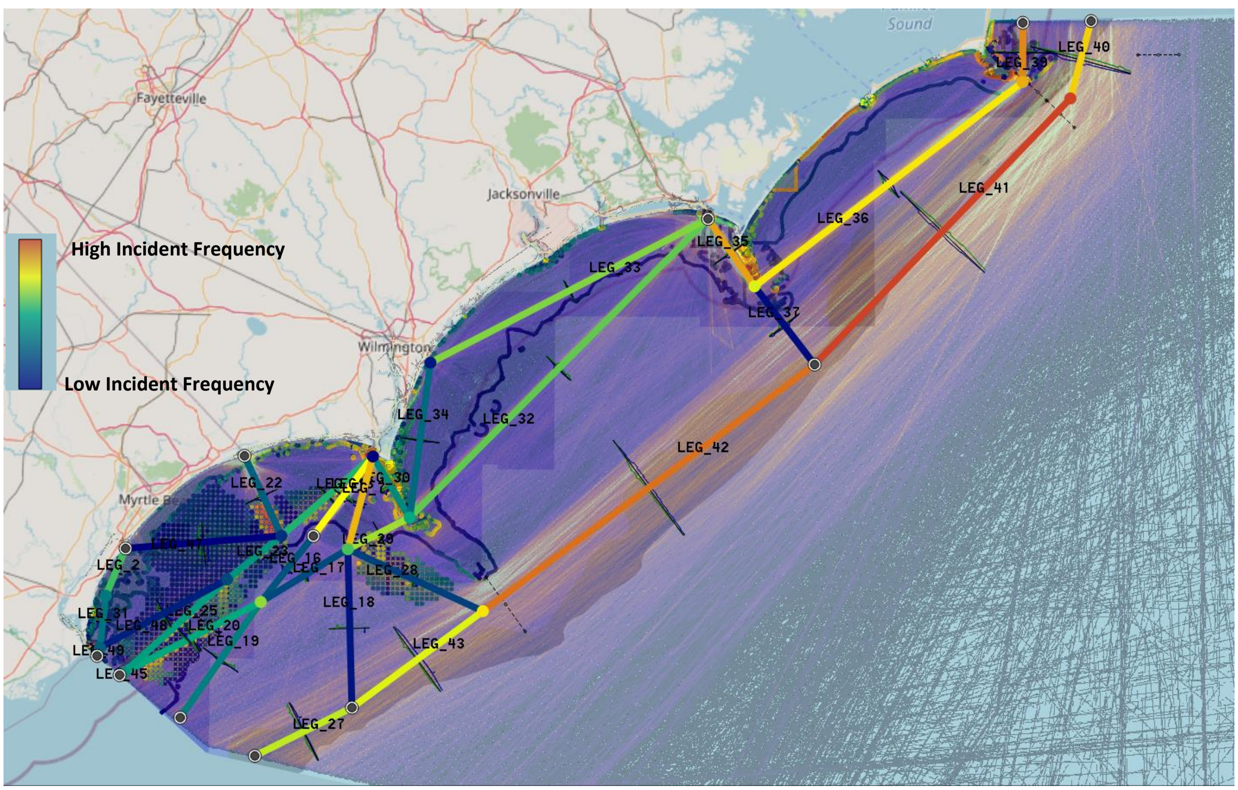
| Alpha and Bravo Cases – Collisions by Leg (Years Between Incidents) | | |
|---|---|---|
| Leg | Head On | Overtaking |
| **coastwise_1** | 87527.2 | 482723.8 |
| **coastwise_2** | 55840.8 | 227632.3 |
| **coastwise_3** | 6743.7 | 28510.9 |
| **coastwise_4** | 5018.2 | 6069.4 |
| **coastwise_5** | 75118.3 | 282806.1 |
| **coastwise_6** | 17183.8 | 92416.8 |
| **coastwise_7** | 52606.1 | 217271.5 |
| **connection_1** | 45448006.7 | 153746483.1 |
| **cross_1** | 650861.4 | 2379371.2 |
| **cross_2** | 561210.3 | 2190186.4 |
| **cross_3** | 1511264.2 | 5798121.4 |
| **cross_4** | 431161.3 | 2205434.4 |
| **cross_5** | 2165910.7 | 4690012.5 |
| **cross_6** | 553058.5 | 1682771.6 |
| **exit_1** | 100348786.8 | 277390906.1 |
| **inlet_1** | 5318024.9 | 33002607.1 |
| **inlet_2** | 414948050.4 | 561962622.5 |
| **inlet_3** | 2193414.8 | 3128068.6 |
| **inlet_4** | 116857.2 | 753813.0 |
| **inlet_5** | 100958.3 | 345872.1 |
| **inlet_6** | 38547.8 | 174872.7 |
| **shore_1** | 67820977.0 | 122140969.8 |
| **shore_2** | 2732888.2 | 5987298.7 |
| **shore_3** | 1346093.2 | 2232914.4 |
| **shore_4** | 848575.9 | 2493469.9 |
| **TSS_1** | 644115.1 | 71842.1 |
| **TSS_2** | 470177.5 | 43087.6 |
| **TSS_split_1** | 6212914.7 | 1717660.9 |
| **TSS_split_2** | 2561992.1 | 900791.7 |
| **TSS_split_3** | 2086319.7 | 7135776.0 |
| **TSS_split_4** | 756072450703.1 | 20057330.8 |
| **TSS_split_5** | 1705359.5 | 4701581.4 |
| **Overall** | 1891.6 | 3595.7 |

## Bravo

The Bravo Case represents the fully developed scenario with no re-routing of vessel traffic around the wind farms. Allisions are expected to increase from zero. Collisions are expected to remain the same as the Alpha Case.

| Bravo Case – Overall Results (Years Between Incidents) | |
|---|---|
| Powered Grounding | 5.022 |
| Drifting Grounding | 49.62 |
| **Total Groundings** | 4.561 |
| Powered Allision | 104.7 |
| Drifting Allision | 2,937 |
| **Total Allisions** | 101.1 |
| Overtaking | 3,596 |
| Head On | 1,892 |
| Crossing | 1.19E+05 |
| Merging | 3.91E+05 |
| Bend | 8,604 |
| Area | --- |
| **Total Collisions** | 1,071 |

*Table 5: Bravo Overall Results*



| Bravo Case – Groundings by Leg (Years Between Incidents) | | | |
|---|---|---|---|
| Leg | Powered | Drifting | Total |
| **coastwise_1** | --- | 1619446.453 | 1619446.453 |
| **coastwise_2** | 19811304.8 | 31466.4 | 31416.5 |
| **coastwise_3** | 8346.0 | 1642.3 | 1372.3 |
| **coastwise_4** | 50.6 | 193.8 | 40.1 |
| **coastwise_5** | 1055.7 | 6452.5 | 907.2 |
| **coastwise_6** | 297.8 | 1139.8 | 236.1 |
| **coastwise_7** | 1182.5 | 38393.6 | 1147.2 |
| **connection_1** | 139990.3 | 545795.6 | 111413.9 |
| **cross_1** | 1293254338168.3 | 70709.5 | 70709.5 |
| **cross_2** | --- | 88478.2 | 88478.2 |
| **cross_3** | --- | 8220996.2 | 8220996.2 |
| **cross_4** | 433.1 | 11358.7 | 417.2 |
| **cross_5** | --- | 21179.7 | 21179.7 |
| **cross_6** | 4376.6 | 38904.9 | 3934.0 |
| **exit_1** | --- | 27034759.1 | 27034759.1 |
| **inlet_1** | 6042.2 | 891375.5 | 6001.6 |
| **inlet_2** | --- | 3000955.0 | 3000955.0 |
| **inlet_3** | 1037.8 | 10506.7 | 944.5 |
| **inlet_4** | 3733.7 | 36185.9 | 3384.5 |
| **inlet_5** | 762.3 | 7008.0 | 687.5 |
| **inlet_6** | 160.7 | 901.3 | 136.4 |
| **shore_1** | 1248.7 | 80059.0 | 1229.5 |
| **shore_2** | 255.8 | 9621.5 | 249.2 |
| **shore_3** | 110436.6 | 2147334.9 | 105034.7 |
| **shore_4** | 316.3 | 3409.4 | 289.4 |
| **TSS_1** | 21.0 | 227.4 | 19.2 |
| **TSS_2** | 9.4 | 152.9 | 8.8 |
| **TSS_split_1** | --- | 67369.5 | 67369.5 |
| **TSS_split_2** | 32297878736.4 | 25935.0 | 25935.0 |
| **TSS_split_3** | --- | 2153759.5 | 2153759.5 |
| **TSS_split_4** | --- | 144144.9 | 144144.9 |
| **TSS_split_5** | 4825.3 | 3143.2 | 1903.4 |
| **Overall** | 5.0 | 49.6 | 4.6 |

| Bravo Case – Allisions by Leg (Years Between Incidents) | | | |
|---|---|---|---|
| Leg | Powered | Drifting | Total |
| **coastwise_1** | --- | 3.5E+09 | 3.5E+09 |
| **coastwise_2** | 16979.8 | 1.1E+05 | 1.5E+04 |
| **coastwise_3** | --- | 4.7E+04 | 4.7E+04 |
| **coastwise_4** | --- | 6.6E+12 | 6.6E+12 |
| **coastwise_5** | --- | 4.5E+13 | 4.5E+13 |
| **coastwise_6** | --- | 3.6E+13 | 3.6E+13 |
| **coastwise_7** | --- | 2.9E+13 | 2.9E+13 |
| **connection_1** | --- | --- | --- |
| **cross_1** | 405.8 | 1.5E+04 | 3.9E+02 |
| **cross_2** | 519.5 | 1.6E+04 | 5.0E+02 |
| **cross_3** | 910.9 | 5.1E+04 | 9.0E+02 |
| **cross_4** | 568.4 | 3.0E+04 | 5.6E+02 |
| **cross_5** | 2066.7 | 4.9E+04 | 2.0E+03 |
| **cross_6** | 2773.5 | 8.9E+04 | 2.7E+03 |
| **exit_1** | --- | 4.5E+09 | 4.5E+09 |
| **inlet_1** | 1073.0 | 7.4E+04 | 1.1E+03 |
| **inlet_2** | 9372.9 | 2.1E+05 | 9.0E+03 |
| **inlet_3** | 2945.3 | 1.2E+05 | 2.9E+03 |
| **inlet_4** | --- | 1.3E+06 | 1.3E+06 |
| **inlet_5** | --- | 3.8E+05 | 3.8E+05 |
| **inlet_6** | --- | 5.9E+06 | 5.9E+06 |
| **shore_1** | 1.3E+12 | 6.9E+09 | 6.9E+09 |
| **shore_2** | 1.4E+10 | 3.7E+05 | 3.7E+05 |
| **shore_3** | --- | 3.2E+05 | 3.2E+05 |
| **shore_4** | 5.6E+12 | 7.3E+05 | 7.3E+05 |
| **TSS_1** | 1.1E+05 | 6.3E+04 | 4.0E+04 |
| **TSS_2** | --- | 7.2E+04 | 7.2E+04 |
| **TSS_split_1** | 3623552.2 | 1.6E+05 | 1.5E+05 |
| **TSS_split_2** | 66987.0 | 9.7E+04 | 4.0E+04 |
| **TSS_split_3** | 187689484.3 | 1.3E+05 | 1.3E+05 |
| **TSS_split_4** | 27358711.7 | 8.8E+05 | 8.5E+05 |
| **TSS_split_5** | --- | 8.2E+05 | 8.2E+05 |
| **Overall** | 104.7 | 2.9E+03 | 1.0E+02 |