MONALISA 2.0 – Activity 4
Collision/conflict candidates and causation factors

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Executive Summary

IWRAP (IALA Waterway Risk Assessment Program) Mk2 is a statistical method that calculates ship-ship collision frequencies time independently. This means that you cannot study the effect of separating ships from each other in time, only in space. Therefore SSPA has, in the MonaLisa 2.0 project, developed a geometric method to classify close situations between vessels, mainly intended for use on routes in the planning stage of a voyage. Since IWRAP is recommended by IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities), it is interesting to relate the method developed by SSPA to IWRAP.

In the previous MonaLisa project it was concluded that there was a difference between the IWRAP calculation and the accident statistics. To find out a possible reason for the difference, it was suggested to study the influence of different causation factors on, among others, ship-ship collisions.

The scope of this study is:

• to compare two different ways of defining close situations between vessels: collision candidates according to IWRAP and conflict candidates according to SSPA’s developed method.
• to compare calculations of potential collisions performed with IWRAP and calculations of conflicts performed with SSPA’s developed method.
• to study the effect of using alternative causation factors for IWRAP calculations of ship-ship collision frequencies.

Two different Kattegat cases are investigated; Case I: “All commercial traffic” and Case II: “Commercial transit traffic”. This gives that in all, four calculations are made. The calculations are based on AIS data of the sea traffic during August 2014. Comparing the potential collisions and the conflicts case by case gives that there are about twice as much conflicts as there are potential collisions (2.0 for Case I and 1.8 for Case II). At a first glance this might seem as a large difference but when considering the context for this investigation it might not. The two methods are of different nature and close situations between vessels are defined in two principally different ways. Nevertheless, it is interesting to see if the number of conflicts is of the same order of magnitude as the potential collisions. And the answer is yes, which means that there are possibilities to adjust SSPA’s conflict candidate method towards IWRAP.

On the other hand, maybe that IWRAP should be adjusted towards SSPA’s conflict candidate method instead. Twice as much potential collisions would
make the calculated collision frequencies more similar to the accident statistics presented in the previous MonaLisa project. This would be a complement to using alternative causation factors for deviating collision frequencies. This is suggested for future studies.

In the present study, the effect of using alternative causation factors based on accident statistics showed expected results, i.e. the IWRAP calculation gave approximately the same total collision frequency as the accident statistics. However, the accident statistics are limited and to modify the five causation factors for collisions individually is not possible. To come to terms with this, a more detailed method based on Bayesian networks for estimating causation factors to be used in IWRAP is presented by Ravn (2012).

Returning to the comparison between the potential collisions and the conflicts, one can see that the most exposed route areas are pretty much the same for the calculations made with the two different methods.

Case I: “All commercial traffic” has a far more complex traffic situation than Case II: “Commercial transit traffic”. The number of potential collisions for Case I is about 5.5 times higher than for Case II. Corresponding figure for the number of conflicts is about 6.0. Accordingly, both methods show approximately the same increase, i.e. they behave similar when it comes to relative measurements. Relative difference between alternative scenarios are often studied in risk analysis.

The above gives a good basis for using SSPA’s conflict candidate method when constructing safer routes based on traffic coordination with separation both in time and space. For examples of such separations, see Holm (2015). However, some adjustments might be needed with respect to the absolute values.
1 Introduction

1.1 Background

IWRAP (IALA Waterway Risk Assessment Program) Mk2 is a statistical method that calculates ship-ship collision frequencies time independently. This means that you cannot study the effect of separating ships from each other in time, only in space. Since the route optimization software developed in the present MonaLisa 2.0 project includes traffic coordination with separation both in time and space in order to achieve green and safe routes, a risk assessment method that also copes with the time separation aspect is needed. Therefore SSPA has, in the MonaLisa 2.0 project, developed a geometric method to classify close situations between vessels, mainly intended for use on routes in the planning stage of a voyage. Since IWRAP is recommended by IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities), it is interesting to relate the method developed by SSPA to IWRAP.

In the previous MonaLisa project, a traffic and risk analysis was performed with IWRAP for passenger ships, cargo ships and tankers in the Kattegat (Johansson 2014). It was concluded that there was a difference between the IWRAP calculation and the accident statistics that should be investigated. To find out a possible reason for the difference, it was suggested to study the influence of different causation factors on, among others, ship-ship collisions. Causation factors specify the probability for the officer on watch to fail to react if the ship for example is on collision course towards another ship.

1.2 Scope and method

The scope of this study is:

• to compare two different ways of defining close situations between vessels: collision candidates according to IWRAP and conflict candidates according to SSPA’s developed method.

• to compare calculations of potential collisions performed with IWRAP and calculations of conflicts performed with SSPA’s developed method.

• to study the effect of using alternative causation factors for IWRAP calculations of ship-ship collision frequencies.
2 Theory of IWRAP

IWRAP (IALA Waterway Risk Assessment Program) Mk2 is a collision/grounding frequency calculation tool recommended by IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities). The module IWRAP Mk2 AIS Import supplied by GateHouse makes it possible to import ship data directly into IWRAP Mk2 and to extract and process the AIS data information.

IWRAP has its origin in the BaSSY toolbox developed within the BaSSY project which was a research project where SSPA Sweden was project coordinator. Technical University of Denmark together with GateHouse were the main developer of the toolbox. Today, the development of IWRAP is performed by IALA and GateHouse. SSPA has contributed to the development of IWRAP through tests and evaluations of the tool at early stages of the process and this work is still continued.

IWRAP calculates different types of grounding frequencies, ship-object collision (allision) frequencies, and ship-ship collision frequencies. Powered groundings\(^1\) can be the result of navigational or human errors, while the cause of drifting groundings\(^2\) is loss of propulsion. An allision is a collision between a moving vessel and a stationary object/structure. The ship-ship collision categories are chosen from the traffic situation the ships are in. These are collisions along the route such as head-on collisions of meeting ships or collisions in an overtaking situation; collisions due to crossing or merging routes, or collisions in connection to bends. Ship collisions with fishing ships or pleasure boats, i.e. with traffic that do not follow formal or informal routes, are also calculated by the tool (denoted area collisions).


Today most risk models for estimating the grounding or collision frequency are routed in the approach defined by Fujii et al (1974) and Macduff (1974). That is, the potential number of ship-ship collisions is first determined as if no aversive manoeuvres are made, i.e. the calculation is based on the assumption that the vessels are navigating blindly when operating at the considered waterway. The

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\(^1\) Powered grounding: a ship/boat with working engine is grounding due to e.g. navigational or human errors.

\(^2\) Drifting grounding: a ship/boat with a malfunctioning engine is drifting on ground.
thus obtained number of potential accident candidates (often called the \textit{geometric number of collision candidates}) is then multiplied by a specified \textit{causation probability} to find the actual number of accidents. The causation probability, which acts as a \textit{thinning probability} on the accident candidates, is estimated conditional on the defined blind navigation.

IWRAP calculates ship-ship collision frequencies according to the principles formulated by Fujii (1983). The procedure first involves the calculation of the geometric number of collision candidates ($N_G$)\(^3\) which subsequently is multiplied by the causation factor ($P_C$). Hence the frequency of collisions ($\lambda_{\text{Col}}$) becomes:

$$\lambda_{\text{Col}} = P_C \cdot N_G$$

Prerequisites for the analysis are that the ship traffic has been grouped into a number of different ship classes according to, vessel type, size, etc, and that the number of vessels per time unit has been registered for each waterway.

\textbf{2.1 Collision candidates}

Collisions may be divided into two types:

- collisions along the route segment, i.e. \textit{overtaking} or \textit{head-on} collisions, and
- collisions when two routes \textit{cross} each other, \textit{merge}, or intersect each other in a \textit{bend} of a waterway.

The procedure for calculation of the number of collision candidates, $N_G$, for the above mentioned two types are conceptually different. For the first type the geometric number of collision candidates becomes dependent on the lateral traffic distribution on the route whereas the second type is independent of the traffic distribution, see figure 1 and figure 2 below.

By inspecting figure 1 below, it can be seen that the probability of the path of two meeting ships overlapping, depends on the distribution of the lateral sailing position of the vessels. Also, the larger the $\mu$ –value, the smaller the probability of a collision becomes.

In figure 2 below, it can be seen that although the “risk area” is affected by the distribution of the traffic, the probability of the ships meeting each other is not.

\footnotesize{More correctly, it is pairs of collision candidates that are calculated since each collision contains two vessels.}
Figure 1. Head-on collision. Definition of $\mu$-ratio and traffic distribution. Source: Engberg (2010).

Figure 2. Crossing waterways with risk area of ship-ship collision. Source: Engberg (2010).
2.2 Causation factors

The default values that have been selected in IWRAP are presented in table 1 below. This value setting is mainly rooted in the observations by Fujii and Mizuki (1998).

Larsen (1993) performed a comprehensive study on defined causation probabilities in his study of ship collisions with bridges. The study also presented available causation probabilities for ship-ship collisions. Table 2 below represents an organized table of his review, which further has been extended (by Engberg (2010)) with some results not given by Larsen (1993). The full references to the authors in the table will not be given here.
Table 1. IWRAP default values of causation factors for ship-ship collisions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Causation factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-on collisions</td>
<td>$0.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Overtaking collisions</td>
<td>$1.1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Crossing collisions</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Collisions in bend</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Collisions in merging</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Table 2. Ship-ship collision causation factors from literature. Source: Engberg (2010).

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dover Strait</td>
<td>5.18</td>
<td>Head-on, no traffic separation</td>
<td>MacDuff [21]</td>
</tr>
<tr>
<td>Dover Strait</td>
<td>3.15</td>
<td>Head-on, with traffic separation</td>
<td>MacDuff [21]</td>
</tr>
<tr>
<td>Øresund, Denmark</td>
<td>0.27</td>
<td>Head on</td>
<td>Karlson et al. [19]</td>
</tr>
<tr>
<td>Japanese Straits</td>
<td>0.49</td>
<td>Head on</td>
<td>Fujii &amp; Mizuki [9]</td>
</tr>
<tr>
<td>Japanese Straits</td>
<td>1.23</td>
<td>Crossings</td>
<td>Fujii &amp; Mizuki [9]</td>
</tr>
<tr>
<td>Dover Strait</td>
<td>1.11</td>
<td>Crossings, no traffic separation</td>
<td>MacDuff [21]</td>
</tr>
<tr>
<td>Dover Strait</td>
<td>0.95</td>
<td>Crossings, with traffic separation</td>
<td>MacDuff [21]</td>
</tr>
<tr>
<td>Strait of Gibraltar</td>
<td>1.2</td>
<td></td>
<td>COWIconsult</td>
</tr>
<tr>
<td>Japanese Straits</td>
<td>1.10</td>
<td>Overtaking</td>
<td>Fujii &amp; Mizuki [9]</td>
</tr>
<tr>
<td>Great Belt, Denmark</td>
<td>1.30</td>
<td>At bends in lanes</td>
<td>Pedersen et al. [24]</td>
</tr>
<tr>
<td>Danish waters</td>
<td>3.0</td>
<td>Head-on and overtaking</td>
<td>COWIconsult Oil and Chemical Spills, 2007</td>
</tr>
</tbody>
</table>
3 Theory of SSPA’s conflict candidate method

IWRAP is a statistical method that calculates collision frequencies time independently. This means that you cannot study the effect of separating ships from each other in time, only in space. Since the route optimization software developed in the present MonaLisa 2.0 project includes traffic coordination with separation both in time and space in order to achieve green and safe routes, a risk assessment tool that also copes with the time separation aspect is needed. Causation factors are complicated to choose properly and their effect on the calculated result is significant (see also chapter 5). One way of dealing with this is to study the collision candidates instead. The hypothesis is that if the number of collision candidates decreases, also the collision frequency will do. A prerequisite for this is that the causation factors are assumed to be constant when the collision candidates vary.

IWRAP calculations of geometric collision candidates are based on the width of the vessels. For crossing, merging, and bend collisions also the length of the vessels is used. SSPA’s method of calculating collision candidates is mainly based on safety ellipses around the vessels. In order to make a distinction between IWRAP’s candidates based on the ships’ dimensions and SSPA’s mainly based on the ships’ safety ellipses, the candidates in SSPA’s method are denoted conflict candidates. Below a short description of SSPA’s conflict candidate method. More information on the method is to be found in the report *SSPA Route Optimizer and Conflict Solver* by Holm (2015).

SSPA has, in the MonaLisa 2.0 project, developed a geometric method to classify close situations between vessels, mainly intended for use on routes in the planning stage of a voyage. Two vessels that fulfil the definition are called “conflict candidates”.

Conflict candidates are defined as two vessels where:

A. Their safety ellipses overlap, both spatially and in time, while each vessel travels on its route leg.

B. Their ellipses, constructed from the length and beam of each vessel, overlap, both spatially and in time, while each vessel travels on the prolonged part of its route leg.

Ship domains around the vessels have been used in marine traffic studies for a long time and the concept has undergone continuous development since the 1970’s, see e.g. Fujii and Tanaka (1971), Goodwin (1975), Coldwell (1983), Jingsong et al (1993), Pietrzykowski and Uriasz (2009), and Hansen et al (2013). Different shapes and sizes of ship domains are discussed based on ship
observations in the early days and AIS data nowadays. In this study we use a safety ellipse with the total size 4L in the longitudinal axis and 1.6L in the transverse axis, where L is the ship length according to AIS data. This is similar to the proposed size of the measured comfort zone made by Hansen et al (2013), although the length of each axis is divided by two since we measure ellipse-ellipse interaction whereas Hansen et al measured ellipse-ship interaction.

The prolonged part of the route leg is labelled FTA segment, an abbreviation of “Failure to Take Action”. The FTA segment adds room for error at each waypoint, i.e. the vessel might for any reason continue with the same speed and course on the FTA segment. The length of the FTA segment is set to 600 seconds (10 minutes), but not longer than the leg itself. On the FTA segment, an ellipse constructed from the length and beam of each vessel (approximately the vessel contours) are used.

Figure 3. From left to right, safety ellipse traveling on the route, ellipse constructed from the length and beam of each vessel (approximately the vessel contours) traveling on the FTA segment.
4 Conflicts and potential collisions in the Kattegat

This chapter shows calculations of potential collisions performed with IWRAP and calculations of conflicts performed with SSPA's developed method. In the present study, the term potential collisions will be used instead of collision candidates since the term candidate might bring the thoughts to a single vessel. This means that you get the number of collisions by multiplying the number of potential collisions with corresponding causation factor.

The number of potential collisions will be compared to the number of conflicts. Two different Kattegat cases are investigated; Case I: “All commercial traffic” and Case II: “Commercial transit traffic”. This gives that in all, four calculations are made. The calculations are based on AIS data of the sea traffic and the area chosen for the cases is limited by the coordinates in table 3. It is illustrated as a light blue area in figure 4.

Table 3. Coordinates for the studied area in the Kattegat cases.

<table>
<thead>
<tr>
<th>Longitude (deg)</th>
<th>Latitude (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.55037</td>
<td>58.02541</td>
</tr>
<tr>
<td>10.57234</td>
<td>57.66289</td>
</tr>
<tr>
<td>10.49338</td>
<td>55.51604</td>
</tr>
<tr>
<td>12.88840</td>
<td>56.10253</td>
</tr>
<tr>
<td>11.90375</td>
<td>57.43335</td>
</tr>
<tr>
<td>11.54601</td>
<td>57.70290</td>
</tr>
</tbody>
</table>
The cases are limited to the following:

- Based on AIS data provided by the Swedish Maritime Administration (SMA). The AIS data set used in this study does not contain all position messages sent by the ships since so much information is not needed for and will be heavy to handle with SSPA’s conflict candidate method. Only the important position messages, e.g. where the ships change course, have been kept.

- Only ship traffic during August\(^4\) 2014.

- Only ships of AIS type 60-89, i.e. passenger ships\(^5\), cargo ships and tankers.

- Case I: “All commercial traffic”: Only ships travelling within or passing or entering or leaving the area illustrated in figure 4 above.

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\(^4\) According to IWRAP, the data set used does not cover the whole of August. About two days are missing (30-31 of August).

\(^5\) Not high speed craft (HSC).
Case II: “Commercial transit traffic”: Only ships passing the area illustrated in figure 4 above, through crossing two of the red lines.

4.1 IWRAP

4.1.1 Case I: "All commercial traffic"

Figure 5 below shows a density plot of “All commercial traffic” in the Kattegat. The density plot illustrates the traffic pattern where red lines indicate denser traffic than yellow, and yellow denser than white. Since the AIS data set used in this study does not contain all position messages sent by the ships (see above), IWRAP settings for importing AIS-data, for creating density plots, and for extracting ship traffic data have been adjusted to this fact.

Traffic routes (formal and informal) are identified from the density plot of “All commercial traffic” and are defined in IWRAP as paths (denoted legs) between waypoints. Each leg includes traffic in both directions. Figure 6 below shows the IWRAP model of the traffic routes for “All commercial traffic” including the leg width showing how much of the traffic that are covered. IWRAP extracts the ship traffic flows at each leg and recounts the information to one-year-data, i.e. August 2014 will represent the whole year 2014.
Figure 5. Density plot of Case I: “All commercial traffic” in the Kattegat. Performed by SSPA with IWRAP, based on AIS data from August 2014 provided by the Swedish Maritime Administration.
Figure 6. IWRAP model of the traffic routes for “All commercial traffic” including the leg width. Performed by SSPA with IWRAP, based on AIS data from August 2014 provided by the Swedish Maritime Administration.
The main input data required for the IWRAP calculations of the number of potential collisions are shown in the table below. The course deviation angle is set to 20 degrees. This means that the ship traffic that passes the passage line IWRAP uses with a maximum angle of ±20 degrees in relation to the leg direction is counted for\(^6\). Parallel legs interact with each other in IWRAP, i.e. head-on and overtaking collisions with ships belonging to different but parallel legs can take place. The parallel legs interaction angle is set to 20 degrees, which means that the maximum angle between two interacting legs is 20 degrees. Causation factors and causation reduction factors are set to 1 in order to get the potential collisions. Causation reduction factors are used in IWRAP for passenger ships and fast ferries since these two ship types are regarded to be navigated more safely, e.g. with two officers on watch.

Table 4. Main input data required for the IWRAP calculations of the number of potential collisions.

<table>
<thead>
<tr>
<th>Description</th>
<th>Input data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of navigational routes.</td>
<td>Identified on the density plot based on SMA’s AIS data for August 2014.</td>
</tr>
<tr>
<td>Ship traffic flow (recalculated to one year) on</td>
<td>SMA’s AIS data for August 2014. Course deviation angle: 20 degrees.</td>
</tr>
<tr>
<td>each leg, specified on ship type and length.</td>
<td></td>
</tr>
<tr>
<td>Lateral ship traffic distribution on each leg.</td>
<td>SMA’s AIS data for August 2014. Course deviation angle: 20 degrees.</td>
</tr>
<tr>
<td>Average ship speed on each leg, specified on</td>
<td>SMA’s AIS data for August 2014. Course deviation angle: 20 degrees.</td>
</tr>
<tr>
<td>ship type and length.</td>
<td></td>
</tr>
<tr>
<td>Average ship draught on each leg, specified on</td>
<td>SMA’s AIS data for August 2014. Course deviation angle: 20 degrees.</td>
</tr>
<tr>
<td>ship type and length.</td>
<td></td>
</tr>
<tr>
<td>Parallel legs interaction angle.</td>
<td>Set to 20 degrees.</td>
</tr>
<tr>
<td>Causation factors and causation reduction factors.</td>
<td>Set to 1 in order to get the potential collisions.</td>
</tr>
</tbody>
</table>

The figure below presents an illustration of the calculated potential collisions within legs and waypoints for Case I: “All commercial traffic”. It shows which

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\(^6\) IWRAP actually uses three parallel passage lines, all of them perpendicular to the leg direction. The main passage line is placed at the middle of the leg and the other two are placed at each side of the central. The two additional passage lines are placed on half the distance between the central one and the end waypoints. The ship traffic is counted for only if it passes the central passage line, fulfilling the requirements described, and at least one of the two additional passage lines.
legs/waypoints that are the most exposed ones. However, see first summary of facts below for information on how the illustrations should be interpreted.

**Summary of facts**

The information in this summary of facts has been provided by Engberg (2014).

The IWRAP illustrations of collisions show which legs/waypoints that are the most exposed ones. As the bar below shows, blue represents the most exposed and yellow the least. There are also cases where the legs/waypoints are uncoloured. This means that no frequency value has been calculated. For example, no calculations are made for the end-waypoints in the outer boundary of the model (the original black waypoints of the model will be visible).

Note that the range of colours is relative within each IWRAP calculation job, i.e. a certain colour could represent different absolute values of frequencies in different jobs. Besides, within each job there are two separate ranges used: one for ship-ship collisions within legs (Overtaking and Head-on), and one for ship-ship collisions within waypoints (Crossing, Merging, and Bend). This means that the illustrations cannot be used as comparison between these two frequency groups. They can neither be used as comparison between different IWRAP calculation jobs.

In the illustrations, the frequencies are standardized by length (however, not in the waypoints).
Figure 7. Illustration of potential collisions within legs and waypoints for Case I: “All commercial traffic”. Calculated with IWRAP.
The table below shows the number of potential collisions for Case I: “All commercial traffic”, calculated with IWRAP.

**Table 5. Number of potential collisions for Case I: “All commercial traffic”.

**Frequency (potential collisions/year)**

- Overtaking 827.152
- HeadOn 336.831
- Crossing 373.126
- Merging 208.6
- Bend 396.154

**Total 2141.86**

Since the ship traffic flows has been recounted to one-year-data, the total number of potential collisions during August 2014 can be calculated by dividing the calculated frequency with the same factor, in this case 12.6213. This gives about 170 potential collisions during August 2014.

4.1.2 Case II: “Commercial transit traffic”

The procedure for calculating the potential collisions for Case II: “Commercial transit traffic” is the same as for Case I: “All commercial traffic”. Figure 8 below shows a density plot of “Commercial transit traffic” in the Kattegat.
Figure 8. Density plot of Case II: “Commercial transit traffic” in the Kattegat. Performed by SSPA with IWRAP, based on AIS data from August 2014 provided by the Swedish Maritime Administration.

Figure 9 below shows the IWRAP model of the traffic routes for “Commercial transit traffic” including the leg width showing how much of the traffic that are covered.
Figure 9. IWRAP model of the traffic routes for “Commercial transit traffic” including the leg width. Performed by SSPA with IWRAP, based on AIS data from August 2014 provided by the Swedish Maritime Administration.

The figure below presents an illustration of the calculated potential collisions within legs and waypoints for Case II: “Commercial transit traffic”. It show which legs/waypoints that are the most exposed ones.
Figure 10. Illustration of potential collisions within legs and waypoints for Case II: “Commercial transit traffic”. Calculated with IWRAP.

The table below shows the number of potential collisions for Case II: “Commercial transit traffic”.

Table 6. Number of potential collisions for Case II: “Commercial transit traffic”.

<table>
<thead>
<tr>
<th>Frequency (potential collisions/year)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking</td>
<td>162.59</td>
</tr>
<tr>
<td>HeadOn</td>
<td>52.2101</td>
</tr>
<tr>
<td>Crossing</td>
<td>23.2281</td>
</tr>
<tr>
<td>Merging</td>
<td>29.509</td>
</tr>
<tr>
<td>Bend</td>
<td>129.781</td>
</tr>
</tbody>
</table>
Total 397.318

Since the ship traffic flows has been recounted to one-year-data, the total number of potential collisions during August 2014 can be calculated by dividing the calculated frequency with the same factor, in this case 12.6328. This gives about 31 potential collisions during August 2014.

4.2 SSPA's conflict candidate method

The calculations in this section are performed by Holm (2015) and a more detailed description is to be found in the report *SSPA Route Optimizer and Conflict Solver*.
4.2.1 Case I: “All commercial traffic”

The figure below presents an illustration of the identified conflicts (dots) on top of deduced voyage plans from AIS data for Case I: “All commercial traffic”. It shows which route areas that are the most exposed ones.

Figure 11. Identified conflicts (dots) on top of deduced voyage plans from AIS data for Case I: “All commercial traffic”. Performed with SSPA’s conflict candidate method, based on AIS data from August 2014 provided by the Swedish Maritime Administration.

The total number of conflicts is calculated to be 337 during August 2014.
4.2.2 Case II: “Commercial transit traffic”

The figure below presents an illustration of the identified conflicts (dots) on top of deduced voyage plans from AIS data for Case II: “Commercial transit traffic”. It shows which route areas that are the most exposed ones.

Figure 12. Identified conflicts (dots) on top of deduced voyage plans from AIS data for Case II: “Commercial transit traffic”. Performed with SSPA’s conflict candidate method, based on AIS data from August 2014 provided by the Swedish Maritime Administration.
The total number of conflicts is calculated to be 56 during August 2014.

5 Causation factors for the Kattegat

In the previous MonaLisa project, a traffic and risk analysis was performed with IWRAP for the present main traffic (passenger ships, cargo ships and tankers) in the Kattegat (Johansson 2014). It was concluded that there was a difference between the IWRAP calculation and the accident statistics that should be investigated. To find out a possible reason for the difference, it was suggested to study the influence of different causation factors on powered groundings and collisions or the influence of different blackout frequencies on drifting groundings. First a short recapitulation of some of the results from the risk analysis performed in the previous study.

The table below shows the grounding and collision frequencies for the present situation, calculated with IWRAP in the previous MonaLisa project.

<table>
<thead>
<tr>
<th>Frequency (incidents/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powered Grounding: 0.75</td>
</tr>
<tr>
<td>Drifting Grounding: 0.24</td>
</tr>
<tr>
<td><strong>Total Groundings: 0.99</strong></td>
</tr>
<tr>
<td>Overtaking: 0.055</td>
</tr>
<tr>
<td>HeadOn: 0.021</td>
</tr>
<tr>
<td>Crossing: 0.032</td>
</tr>
<tr>
<td>Merging: 0.023</td>
</tr>
<tr>
<td>Bend: 0.10</td>
</tr>
<tr>
<td><strong>Total Collisions: 0.23</strong></td>
</tr>
</tbody>
</table>

Swedish and Danish accident statistics in the Kattegat were analysed in the previous MonaLisa project. Below, the statistics for the Kattegat are presented as comparison to the calculated grounding and collision frequencies. The time period for the accident statistics is 1993-2009, i.e. 17 years. The possibility of increased safety at sea during this time period has not been taken into account. Possible changes of the traffic flows during the period has not been studied either.
Groundings (including Contact damage): 41
This gives 41/17 accidents/year = 2.4 accidents/year

Collisions: 11
This gives 11/17 accidents/year = 0.65 accidents/year

Comparing with the IWRAP calculations one can see that the statistics gives about 2.4 times higher figures for total groundings and about 2.8 times higher figures for total collisions.

The present study is focused on ship-ship collisions why IWRAP calculations in order to further investigate corresponding causation factors will be performed. The IWRAP model constructed for Case I: “All commercial traffic” in chapter 4 is similar to the one used in the previous MonaLisa project and are assumed to be suitable for these further investigations.

In order to verify this, the ship traffic flow at the legs at the Skaw are summed up and compared with similar flows presented by Johansson (2014). The comparison shows a reasonable amount of ship passages. That is also the case with the passages to/from Gothenburg, and the passages east of the island of Anholt.

The suitability of the model is also verified below, where the calculated collisions are presented and illustrated for Case I: “All commercial traffic”. The IWRAP calculation is performed as in chapter 4 but the causation factors and causation reduction factors are set to the IWRAP default values instead of 1. Comparing the collision frequencies calculated in the previous and present MonaLisa project give similar results (0.23 versus 0.18).

Table 8. Collision frequencies for Case I: “All commercial traffic”. Causation factors and causation reduction factors according to IWRAP’s default values.

<table>
<thead>
<tr>
<th>Frequency (incidents/year)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtaking</td>
<td>0.0692308</td>
</tr>
<tr>
<td>HeadOn</td>
<td>0.0126584</td>
</tr>
<tr>
<td>Crossing</td>
<td>0.0323768</td>
</tr>
<tr>
<td>Merging</td>
<td>0.0231943</td>
</tr>
<tr>
<td>Bend</td>
<td>0.0460379</td>
</tr>
<tr>
<td><strong>Total Collisions</strong></td>
<td><strong>0.183498</strong></td>
</tr>
</tbody>
</table>
Figure 13. Illustration of collisions within legs and waypoints for Case I: “All commercial traffic”. Causation factors and causation reduction factors according to IWRAP’s default values.

Comparing this IWRAP calculation with the accident statistics, one can see that the statistics gives about 3.6 times higher figures for total collisions. The effect of using alternative causation factors are therefore tested with a correction factor of 3.6 for all collision causation factors. The calculated result is presented and illustrated below.
Table 9. Collision frequencies for Case I: “All commercial traffic”. Causation factors 3.6 times IWRAP’s default values and causation reduction factors according to IWRAP’s default values.

**Frequency (incidents/year)**
- Overtaking 0.249231
- HeadOn 0.0455701
- Crossing 0.115304
- Merging 0.0834996
- Bend 0.165736

**Total Collisions 0.659341**
Figure 14. Illustration of collisions within legs and waypoints for Case I: “All commercial traffic”. Causation factors 3.6 times IWRAP’s default values and causation reduction factors according to IWRAP’s default values.

6 Conclusions and discussion

The table below shows, for the two studied cases during August 2014, the calculated number of potential collisions according to IWRAP’s collision candidate method and the identified number of conflicts according to SSPA’s conflict candidate method.

<table>
<thead>
<tr>
<th></th>
<th>Potential collisions, IWRAP</th>
<th>Conflicts, SSPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case I: “All commercial traffic”</td>
<td>170</td>
<td>337</td>
</tr>
<tr>
<td>Case II: “Commercial transit traffic”</td>
<td>31</td>
<td>56</td>
</tr>
</tbody>
</table>

Comparing the potential collisions and the conflicts case by case gives that there are about twice as much conflicts as there are potential collisions (2.0 for Case I and 1.8 for Case II). At a first glance this might seem as a large difference but when considering the context for this investigation it might not. The two methods are of different nature and close situations between vessels are defined in two principally different ways. Nevertheless, it is interesting to see if the number of conflicts is of the same order of magnitude as the potential collisions. And the answer is yes, which means that there are possibilities to adjust SSPA’s conflict candidate method towards IWRAP.

On the other hand, maybe that IWRAP should be adjusted towards SSPA’s conflict candidate method instead. Twice as much potential collisions would make the calculated collision frequencies more similar to the accident statistics presented in the previous MonaLisa project. This would be a complement to using alternative causation factors for deviating collision frequencies. This is suggested for future studies.

In the present study, the effect of using alternative causation factors based on accident statistics showed expected results, i.e. the IWRAP calculation gave
approximately the same total collision frequency as the accident statistics. However, the accident statistics are limited and to modify the five causation factors for collisions individually is not possible. To come to terms with this, a more detailed method based on Bayesian networks for estimating causation factors to be used in IWRAP is presented by Ravn (2012).

Returning to the comparison between the potential collisions and the conflicts, one can see that the most exposed route areas are pretty much the same for the calculations made with the two different methods. This is clear when comparing figure 7 and 10 with figure 11 and 12, respectively.

Case I: “All commercial traffic” has a far more complex traffic situation than Case II: “Commercial transit traffic”. The number of potential collisions for Case I is about 5.5 times higher than for Case II. Corresponding figure for the number of conflicts is about 6.0. The increase is illustrated in the figure below. Accordingly, both methods show approximately the same increase, i.e. they behave similar when it comes to relative measurements. Relative difference between alternative scenarios are often studied in risk analysis.

The above gives a good basis for using SSPA’s conflict candidate method when constructing safer routes based on traffic coordination with separation both in time and space. For examples of such separations, see Holm (2015). However, some adjustments might be needed with respect to the absolute values.

![Figure 15. Number of potential collisions calculated with IWRAP and number of conflicts identified with SSPA’s conflict candidate method. Both for the two studied cases during August 2014.](image-url)
7 References


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