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IALA WORKGROUP ON IMPROVEMENT OF RISK ASSESSMENT MODEL IWRAP

Results and advice to the Dutch Maritime Authority

Final Report

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CONTENTS

Page

1 INTRODUCTION ... 3
1.1 Project aim ... 3
1.2 Report aim ... 3

2 COMPARISONS BETWEEN IWRAP AND SAMSON ... 4
2.1 Comparison for real traffic situations ... 4
2.1.1 Case description ... 4
2.1.2 Results for ship-ship collisions ... 6
2.1.3 Results for ship-wind turbine collisions (allisions) ... 7
2.2 Comparisons for elementary traffic situations resulting in ship-ship collisions ... 8
2.2.1 Ship-ship collision modelling ... 8
2.2.2 Number of collisions for average traffic situation in area ... 8
2.2.3 Number of collisions for narrow traffic lane ... 12
2.2.4 Location of contributors to collisions ... 16
2.3 Influence of tails of lateral distribution on groundings/allisions ... 17
2.4 Conclusions from comparisons between IWRAP and SAMSON ... 19

3 REPLAYED COLLISIONS ... 22
3.1 Collisions between two sailing ships ... 22
3.1.1 Collision candidate or domain approach ... 23
3.1.2 Collision types ... 23
3.2 Allisions between sailing vessel and ship at anchor ... 24
3.3 Comparison between locations of real and calculated collisions ... 24

4 COMBINING IWRAP AND SAMSON ... 28
4.1 Provide guidance on the application and validity of the models ... 28
4.2 Provide possibilities to use modules of both models in combination ... 29
4.3 Changes implemented to IWRAP ... 30

5 CONCLUSIONS AND ADVICE FOR FUTURE WORK ... 31
5.1 Conclusions ... 31
5.1.1 Comparisons between IWRAP and SAMSON ... 31
5.1.2 Replayed collisions ... 32
5.1.3 Combining IWRAP and SAMSON ... 32
5.2 Advice for future work ... 32

APPENDICES ... 34

APPENDIX A TOWARDS AN IALA RISK MODEL

APPENDIX B COMPARISON OF PORT AND WATERWAY RISK ESTIMATION SOFTWARE PROGRAMS

APPENDIX C QUANTITATIVE RISK ASSESSMENT: COMPARISON IWRAP WITH SAMSON

APPENDIX D INVESTIGATION COLLISIONS FROM 2005-2013

APPENDIX E OIL OUTFLOW DISTRIBUTION

1 INTRODUCTION

1.1 Project aim

IALA has established a workgroup that aims to check whether the quantitative risk analysis tool IWRAP can be improved or extended with elements from other tools and SAMSON is the most important other tool. The final goal is to come to one harmonized, international way to calculate risks at sea. MARIN has been commissioned by Rijkswaterstaat to be part in this workgroup.

The ultimate goal of this project is described in APPENDIX A. The user of the IALA toolbox should get a clear recommendation which tool to use (and in what way) for a specific question. As the differences between both models can not easily be smoothed out, the merging of the models into one tool is not realistic and may not be desirable. Probably, at least for some time, both models will remain in use.

The work of this project group will follow two parallel tracks:

1. provide guidance on the application and validity of the models for evaluation of various types of risk sources;
2. provide possibilities to use modules of both models in combination.

In the end, there should be no discussion about the validity of the results, nor the possibility that one may select the module that provides the answer that he likes most.

1.2 Report aim

The aim of this report is to summarize the work that has been performed by the workgroup and to give advice on the integration of (parts of) SAMSON in the IALA risk management toolbox.

The workgroup started with a comparison between IWRAP and SAMSON. This work is described in Section 2. The next question was: “How do accidents happen in real situations and how can this best be modelled?”. Section 3 makes a start with answering this question by discussing a replay of AIS data of real collisions. Section 4 discusses the possibilities, issues and implementations already made of combining IWRAP and SAMSON. Finally, Section 5 describes the conclusions of the workgroup and gives advice for future work.

2 COMPARISONS BETWEEN IWRAP AND SAMSON

Several comparisons between IWRAP and SAMSON have been made. Before the start of the workgroup, the comparison in APPENDIX B was already available.

This Section describes the comparisons that have been performed and mentioned in the workgroup. First, Section 2.1 makes some comparisons for a real traffic situation. Next, Section 0 makes comparisons for some elementary traffic situations. Section 2.3 explains how the tails of lateral distributions influence the results of groundings/allisions. Finally, Section 2.4 summarizes the conclusions from the workgroup of the comparisons made.

2.1 Comparison for real traffic situations

This Section describes the comparisons made for real traffic situations. Section 2.1.1 describes the cases. Section 2.1.2 gives the results for ship-ship collisions and Section 2.1.3 gives the results for allisions (ship-wind turbine collisions).

2.1.1 Case description

Chapter 2 of APPENDIX C discusses the first comparisons done. A study area was defined and both SAMSON and IWRAP were used to create a traffic database and to calculate the collision frequencies between ships and between ships and wind turbines. The study area contains a northern and a southern part and calculations were done before (Figure 2-1) and after (Figure 2-2) the change in the traffic separation scheme.

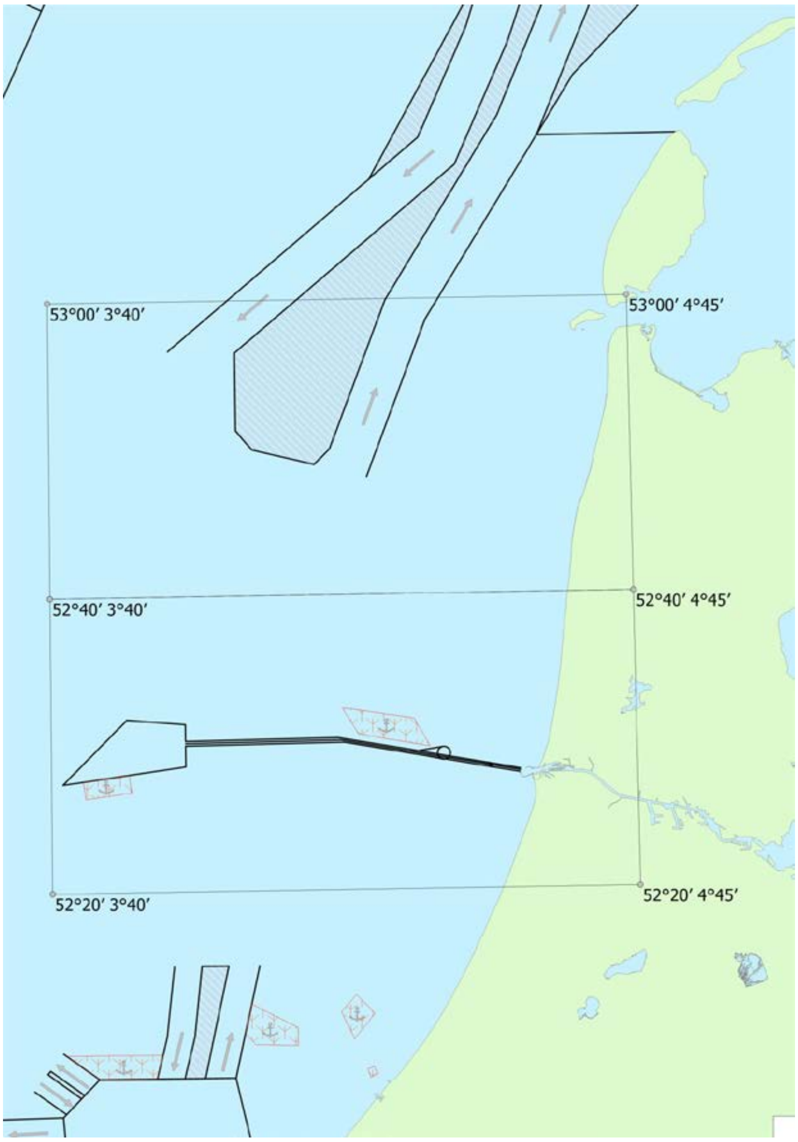

Figure 2-1 Study areas before change in traffic separation scheme

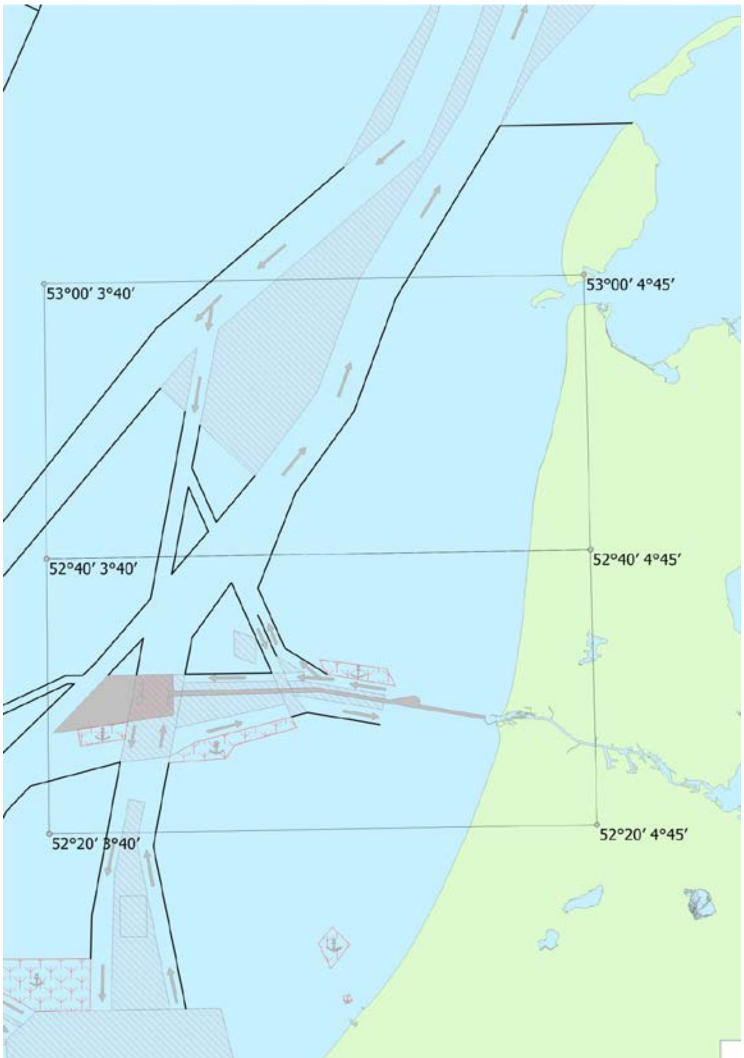

Figure 2-2 **Study areas after change in traffic separation schemes**

2.1.2 Results for ship-ship collisions

Table 2-1 shows that the resulting number of ship-ship collisions from SAMSON was higher than from IWRAP.

Table 2-1 **Expected <u>number of collisions</u> by SAMSON divided by that of IWRAP for both areas and before and after the route change**

Type of collision	SAMSON / IWRAP			
	Area North		Area South	
	before	after	before	After
head-on	0.15	1.39	2.61	0.36
overtaking	2.36	2.28	0.92	1.93
crossing	1.37	1.91	4.08	10.58
total	1.75	2.20	2.96	3.83

When looking into the reason of these differences, it was concluded that for the ship-ship collisions, the main source for the differences was the traffic modelling. Due to the 6 minute time step of the AIS data that was used by IWRAP, less ships were assigned to the traffic database. However, MARIN managed to assign approximately correct numbers to the traffic links by using another algorithm.

Table 2-3 shows that for approximately the same traffic database, the total expected number of ship-ship collisions calculated with SAMSON and IWRAP corresponds quite well, but the distribution over the different collision types (head-on, overtaking, crossing) is different. However, the definition of collision types in SAMSON and IWRAP is very different, see Table 2-2. Collisions indicated as crossings in IWRAP can be overtaking or head-on collisions in SAMSON depending on the crossing angle.

Table 2-2 Comparison of collision type definitions (head-on, crossing, overtaking)

Subject	IWRAP	SAMSON
Collision types	– crossing collisions are only calculated in waypoints of crossing legs – head-on and overtaking collisions calculated for traffic on the same leg	– interaction between the links – the collision type depends on the angle between the ships: - 0° to 30° is overtaking, - 150° to 180° is head-on, - angles in between are crossing.

Table 2-3 Expected <u>number of collisions</u> per year for the IWRAP database for the northern area before the route change

Type of collision	traffic database IWRAP before calculated with the models of SAMSON and IWRAP		
	IWRAP database with SAMSON	IWRAP	SAMSON / IWRAP
head-on	0.0015	0.0007	2.20
overtaking	0.0221	0.0121	1.82
crossing	0.0075	0.0172	0.44
total	0.0311	0.0299	1.04

The assignment method of AIS data to a route structure in IWRAP needs to be investigated, at least when using AIS data with a large (6 minutes) time step.
It is not clear whether such a change has been implemented in IWRAP.

DMA has told that based on this work, IWRAP has implemented the possibility of crossings that don't occur in waypoints. However, this change has not been reported in one of the lists of changes. It is also not clear whether this influences the number of collisions and the division over the collision types calculated by IWRAP.

2.1.3 Results for ship-wind turbine collisions (allisions)

The resulting number of ship-platform collisions (allisions) from SAMSON and IWRAP were very different because the models for this type of incident are completely different. In IWRAP, the wind park is modelled as an area, while in SAMSON each wind turbine is modelled separately. A drifting ship can strike more than one wind turbine.

Subject	IWRAP	SAMSON
Ship-object collision model	– Based on lateral distribution – Wind farm is modelled as an area (changed after this discussion, now it can be modelled as a structure and has its own causation factor)	– Probability of navigational error – Not sensitive to lateral distribution – Wind farm is modelled as individual wind turbines

2.2 Comparisons for elementary traffic situations resulting in ship-ship collisions

It is difficult to explain differences between calculation with SAMSON and IWRAP for real traffic situations. Therefore, comparisons were performed also with elementary traffic situations. Section 2.2.1 describes the parameters that influence a ship-ship collision model. Section 2.2.2 compares the calculated number of collisions for an average traffic situation. Section 2.2.3 compares the calculated number of collisions for a narrow traffic lane and 2.2.4 compares the location of the collisions.

2.2.1 Ship-ship collision modelling

Both models work with a traffic leg/link of a certain length and define the traffic on this link by:

- Number of ships per ship type and size;
- Speed per ship type and size;
- Mean offset of traffic flow from link center (in case of two directional traffic);
- Standard deviation.

2.2.2 Number of collisions for average traffic situation in area

For an average traffic situation of the real traffic as used in Section 2.1, both models are depicted in Figure 2-4.

The results for head-on, overtaking and crossing collisions are presented in Table 2-4, Table 2-5 and Table 2-6. The differences between SAMSON and IWRAP are of the same order of magnitude as for the real traffic situation in Table 2-1. The differences are due to the different choice in SAMSON’s casualty rate and in IWRAP’s causation factor. After this comparison, the SAMSON casualty rates have been updated based on the worldwide casualty database of the period 2003-2012.

The factor SAMSON/IWRAP for crossing collisions in Table 2-6 is not constant. One reason is that the number of ‘collision candidates’ in IWRAP is determined based on the projected dimensions of the ships (geometric width as shown in Figure 2-3) and thus is dependent on the angle between the tracks of the ships. In SAMSON, the ‘PRETS’ are determined with a circular domain with a constant diameter of 1 nautical mile. The dependency of the angle between the tracks in SAMSON is modelled by different casualty rates for overtaking, crossing and head-on encounters and the geometric width is modelled by a ship size dependent casualty rates that increase with the size (length, but not linear) of the ships.

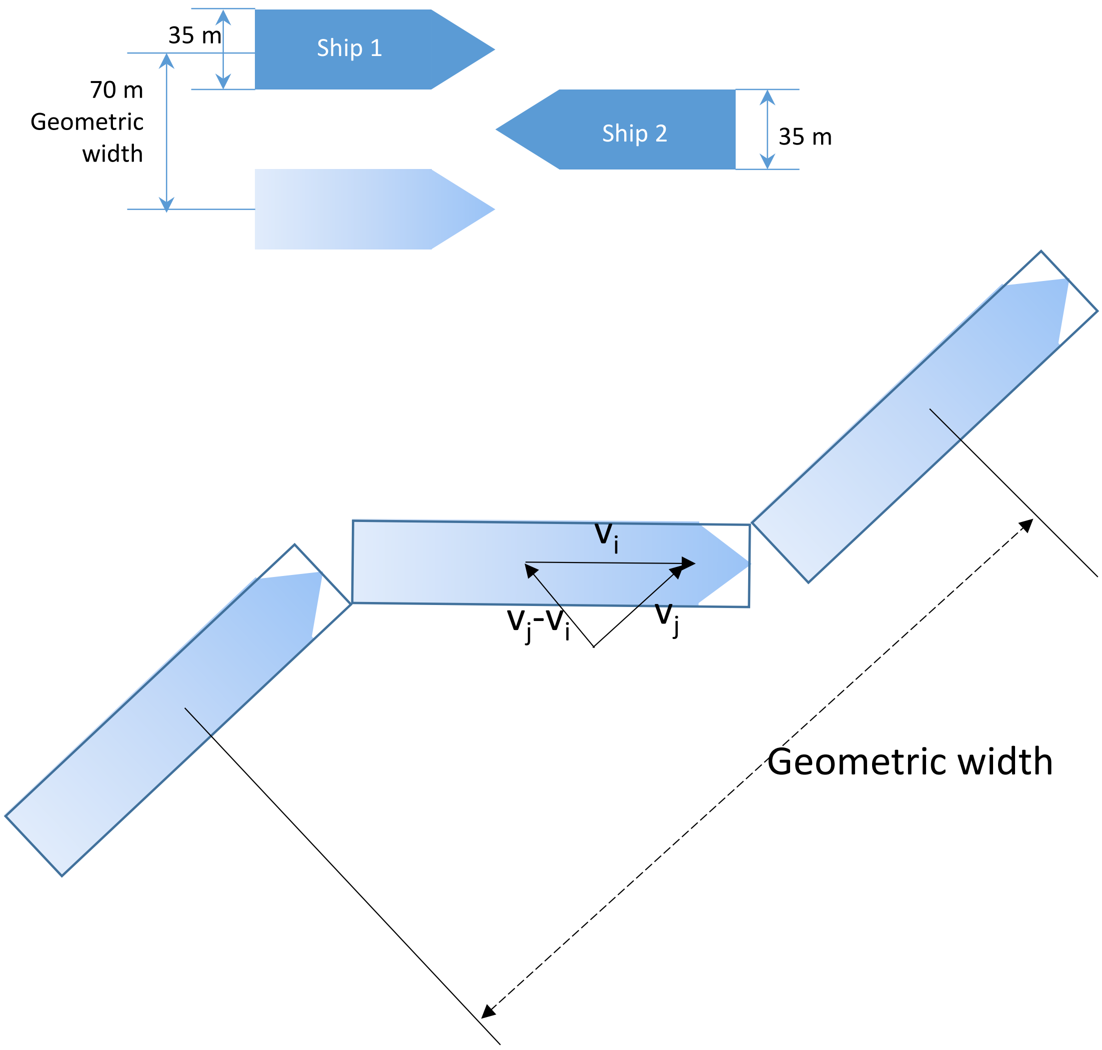

Figure 2-3 **Geometric width in IWRAP shown for head-on and for crossing. The geometric width depends on the ship size. For a head-on collision between two ships with a width of 35 m, the geometrical width is 70 m. This is the distance over which ship 1 can translate while still being on collision course with ship 2**

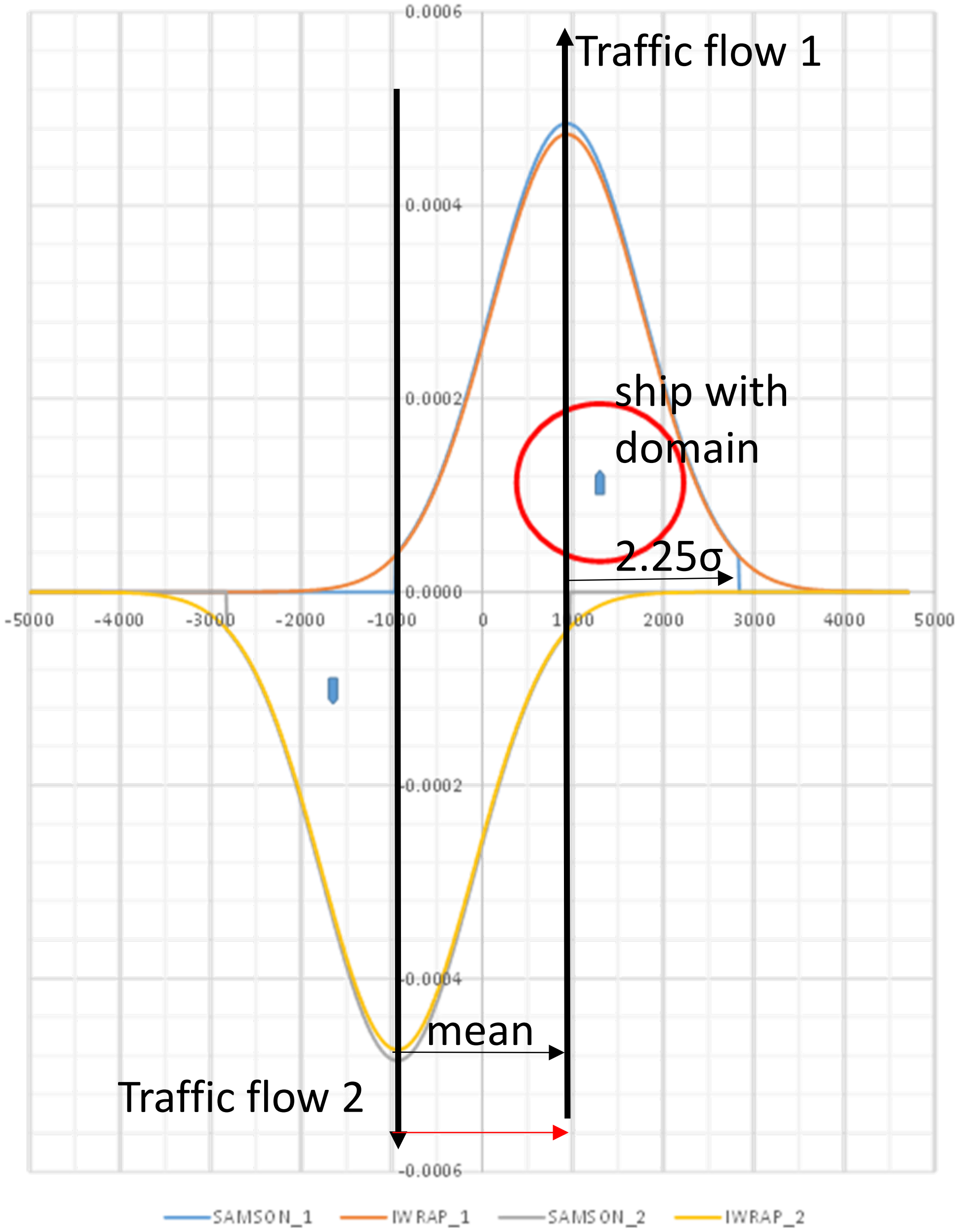

Figure 2-4 **Elementary traffic situation for two opposite traffic flows defined by a mean offset and a standard deviation of lateral positions. mean = ±935 m and σ = 842 m. 2.25σ is where the lateral distribution in SAMSON is cut off**

Head-on collisions
1000 tankers in each direction
Ship length=200m. Width=35m. Speed=15 knots

Table 2-4 Head-on collisions as the leg length changes

Leg length [m]	Normal distribution		IWRAP geometric width 70m			SAMSON domain diameter 1nm			SAMSON /IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
500	0	850	0.095	5.10E-05	4.87E-06	2.35	8.40E-06	1.97E-05	4.0
1000	0	850	0.191	5.10E-05	9.74E-06	4.69	8.40E-06	3.94E-05	4.0
5000	0	850	0.955	5.10E-05	4.87E-05	23.46	8.40E-06	1.97E-04	4.0
10000	0	850	1.909	5.10E-05	9.74E-05	46.93	8.40E-06	3.94E-04	4.0

Overtaking collisions
1000 tankers. Length=200 m. Width=35 m. Speed=15 knots
1000 container ships. Length=200 m. Width=30 m. Speed=21 knots

Table 2-5 Overtaking collisions as the leg length changes

Leg length [m]	Normal distribution		IWRAP geometric width 65m			SAMSON domain diameter 1nm			SAMSON /IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
500	0	850	0.013	1.2E-04	1.52E-06	0.34	2.6E-06	8.72E-07	0.6
1000	0	850	0.025	1.2E-04	3.04E-06	0.67	2.6E-06	1.74E-06	0.6
5000	0	850	0.127	1.2E-04	1.52E-05	3.35	2.6E-06	8.72E-06	0.6
10000	0	850	0.253	1.2E-04	3.04E-05	6.70	2.6E-06	1.74E-05	0.6

Crossing collisions at different angles
1000 tankers. Length=200 m. Width=35 m. Speed=15 knots
1000 tankers. Length=200 m. Width=35 m. Speed=15 knots

Table 2-6 Crossing collisions with fixed causation factor from wiki/IWRAP

Angle between legs [°]	**Normal distribution**		IWRAP geometric width depends on ship lengths, speeds and crossing angle			SAMSON domain diameter 1nm			SAMSON /IWRAP
	mean [m]	**σ [m]**	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT dependent on angle	collisions per year	
10			1.67	1.29E-04	2.15E-04	7.6	3.6E-06	2.74E-05	0.13
20			1.69	1.29E-04	2.19E-04	7.7	3.6E-06	2.77E-05	0.13
45			1.76	1.29E-04	2.27E-04	8.2	2.7E-05	2.26E-04	0.99
90			1.93	1.29E-04	2.49E-04	10.8	2.7E-05	2.95E-04	1.18
135			2.34	1.29E-04	3.02E-04	19.9	2.7E-05	5.45E-04	1.81
170			4.93	1.29E-04	6.36E-04	87.3	8.4E-06	7.33E-04	1.15

The main information of Table 4-4 and Table 4-5 of APPENDIX C can be summarized for head-on and overtaking calculations for average traffic situations in an area:

- For traffic links with a standard deviation greater than 300m and greater than the distance between the centre lines of the two links plus 200 metre
  - SAMSON/IWRAP is between 4.0 and 4.4 for head-on collisions
  - SAMSON/IWRAP is about 0.62 and 0.66 for overtaking collisions
- The factor 4.2 for head-on and 0.64 for overtaking is caused by the values of the causation factor and the casualty rate for tankers and container ships of 200 m and the difference between collision candidates and PRETS..

2.2.3 Number of collisions for narrow traffic lane

Calculations have also been performed for situations with a small standard deviation. For this situation there are three possibilities that observed in Table 4-4 and Table 4-5 of APPENDIX C:

1) When the average distance between the traffic flows (offset) is smaller than the standard deviation, the difference between IWRAP and SAMSON is equivalent to that for larger standard deviations.
2) When the lateral distribution is low compared to the mean offset, SAMSON calculates a relatively high number of potentially dangerous situations compared with IWRAP. This is due to the fact that the domain of 1 nautical mile in these situations is very large and a considerably number of ships are involved in a domain penetration, while IWRAP only calculates collisions in the tails of the distributions. This is visually shown in Figure 2-5 and further discussed in the remainder of this Section. In case the main value increases to a value such that 2 * 2.25 * the standard deviation + domain radius < 2 * mean, the situation described under next point has been reached.
3) Above a certain mean offset, SAMSON predicts zero collisions because of the cut off of the distribution, while IWRAP predicts still a very low number of collisions in the tails of the distributions.

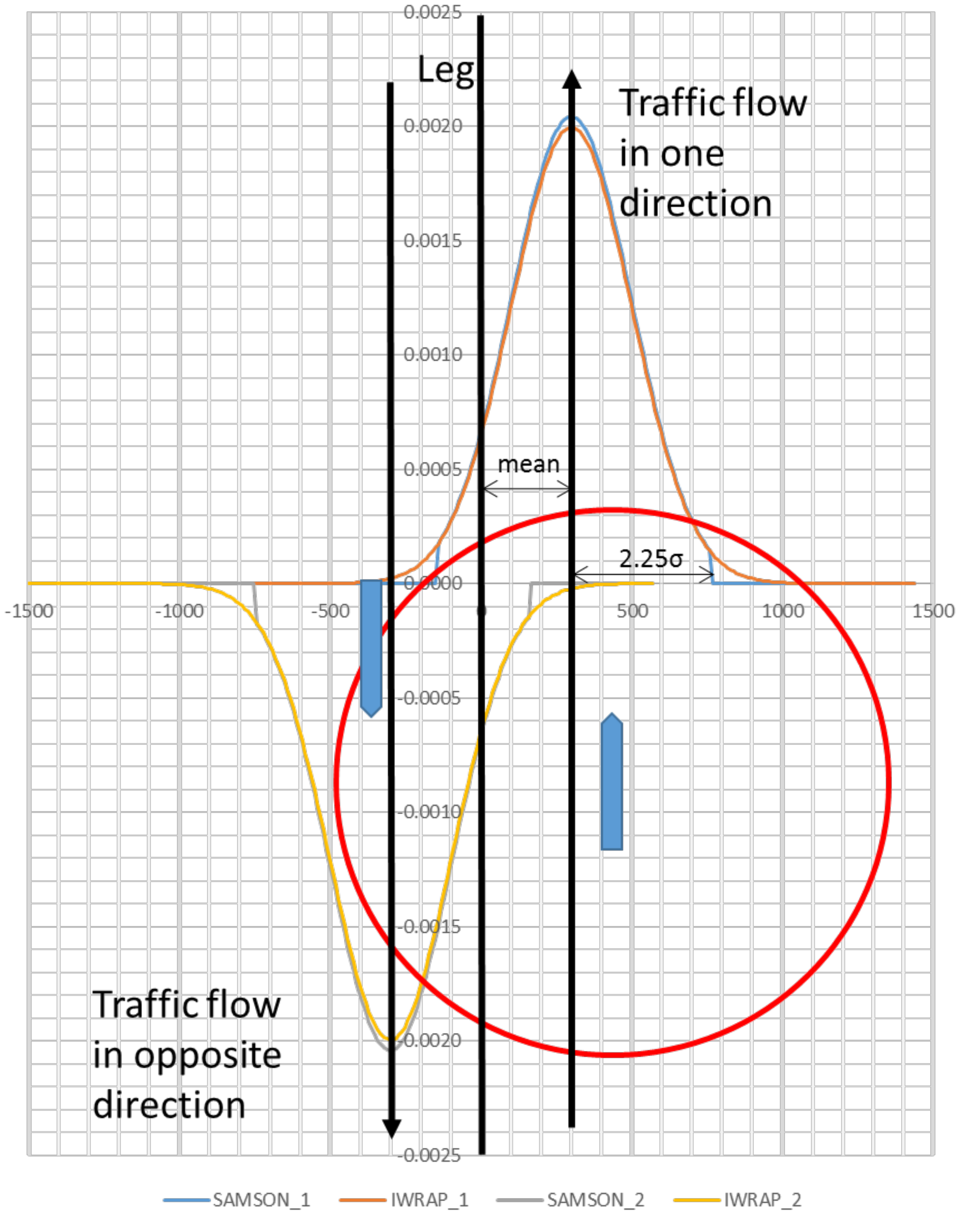

Figure 2-5 Elementary traffic situation with mean = ±300 m and σ = 200 m

The first rows in Table 2-7 and Table 2-8 contain very large differences between SAMSON and IWRAP which are caused by the narrow traffic lanes and the use of the domain of 1 nautical mile in SAMSON. These situations are not representative for traffic at sea, but more for example for the passage of a bridge. The question is how to correctly model collisions in narrow traffic lanes.

Table 2-7 Head-on collisions as the standard deviation changes

Leg length [m]	Normal distribution		IWRAP geometric width 70m			SAMSON domain diameter 1nm			SAMSON /IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
10000	±300	100	0.00	4.7E-05	1.00E-07	83.34	8.4E-06	7.00E-04	7000.7
10000	±300	200	0.86	5.1E-05	4.40E-05	74.18	8.4E-06	6.23E-04	14.2
10000	±300	500	2.26	5.1E-05	1.16E-04	56.40	8.4E-06	4.74E-04	4.1
10000	±300	1000	1.48	5.1E-05	7.60E-05	38.76	8.4E-06	3.26E-04	4.3

Table 2-8 Overtaking collisions as the standard deviation changes

Leg length [m]	Normal distribution		IWRAP geometric width 65m			SAMSON domain diameter 1nm			SAMSON /IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
10000	±300	100	0.00	1.5E-04	4.00E-08	11.91	2.6E-06	3.10E-05	773.9
10000	±300	200	0.11	1.2E-04	1.40E-05	10.60	2.6E-06	2.76E-05	2.0
10000	±300	500	0.30	1.2E-04	3.60E-05	8.06	2.6E-06	2.09E-05	0.6
10000	±300	1000	0.20	1.2E-04	2.40E-05	5.54	2.6E-06	1.44E-05	0.6
10000	±300	2000	0.11	1.2E-04	1.30E-05	3.10	2.6E-06	8.06E-06	0.6

When a lateral distribution with σ=100 m (the first row in the table) is combined with a small, but larger (than σ) mean offset from the centre of the link (300 m in this example), almost the total SAMSON traffic distribution (2.25*100 m + 300 m + 300 m+ 2.25*100 m = 1050 m) falls within the SAMSON radius of 0.5 nautical mile (1852/2 = 926 m) due the fact that the lateral distribution is cut off at 2.25σ. A very high number of potentially dangerous situations is calculated (see Figure 2-6).

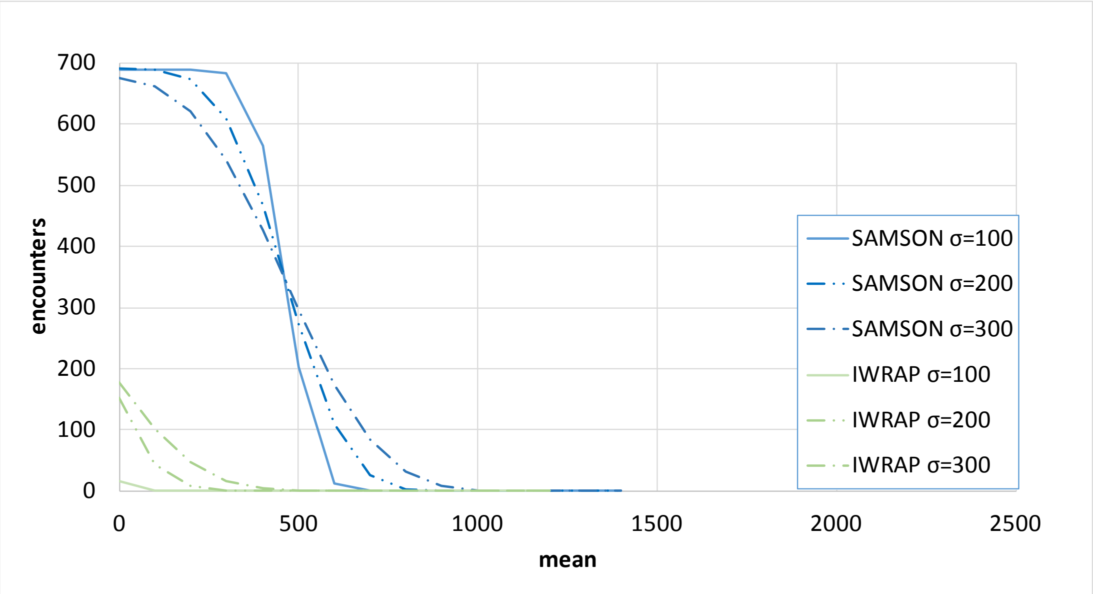

Figure 2-6 Calculated number of encounters with IWRAP and SAMSON for various combinations of mean and standard deviation

In this same example, due to the small standard deviation, combined with the larger mean offset, IWRAP calculates hardly any collision candidates. The only collisions that are calculated to occur, are due to the fact that the lateral distribution is not cut off. Although the tails of the distribution do not represent the traffic at these locations with sufficient accuracy, the calculated number of collisions is very low because of the low probabilities in the tails of the distributions. Therefore, this situation results in a factor between SAMSON and IWRAP that is extremely high.

More resulting encounter numbers for combinations of mean and standard deviation for IWRAP and SAMSON are visually depicted in Figure 2-7 and Figure 2-8.

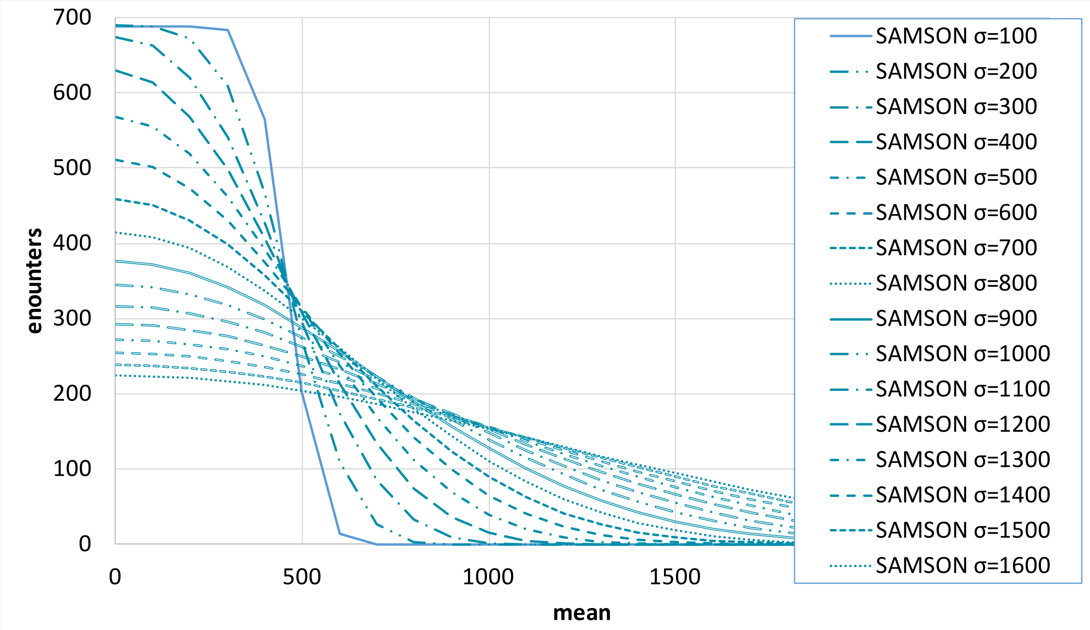

Figure 2-7 **Calculated number of encounters with SAMSON for various combinations of mean and standard deviation**

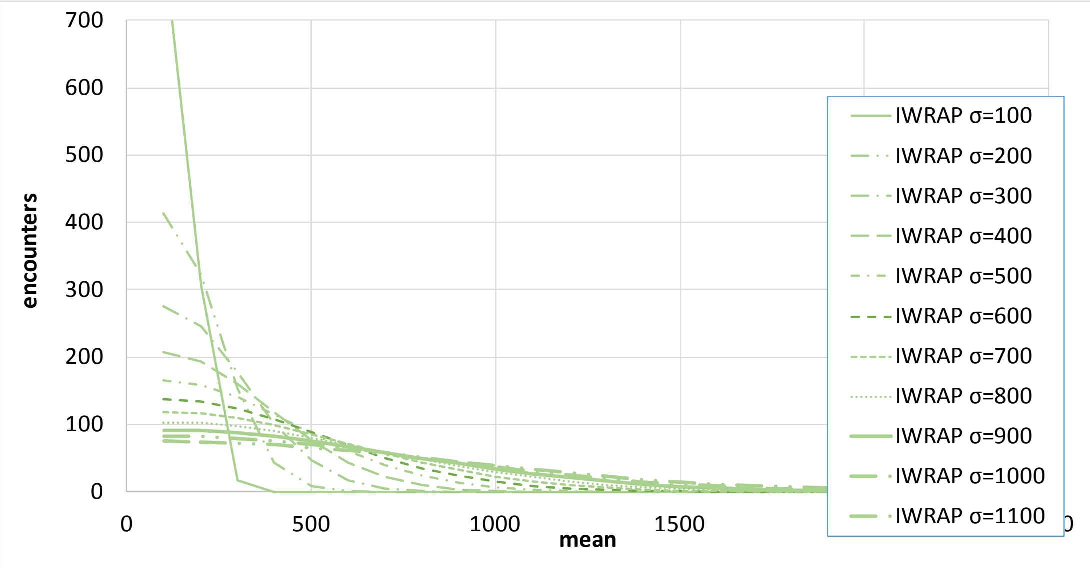

Figure 2-8 **Calculated number of encounters with IWRAP for various combinations of mean and standard deviation**

2.2.4 Location of contributors to collisions

Not only the number of collisions, but also the location of the potential contributors to collisions differs between SAMSON and IWRAP. This is illustrated by Figure 2-9 and Figure 2-10. For the average mean and standard deviation in the sea area of 2.1, the differences in the distribution are small, but for the situation with narrow traffic lanes on rivers or small sea straits, the differences are considerable.

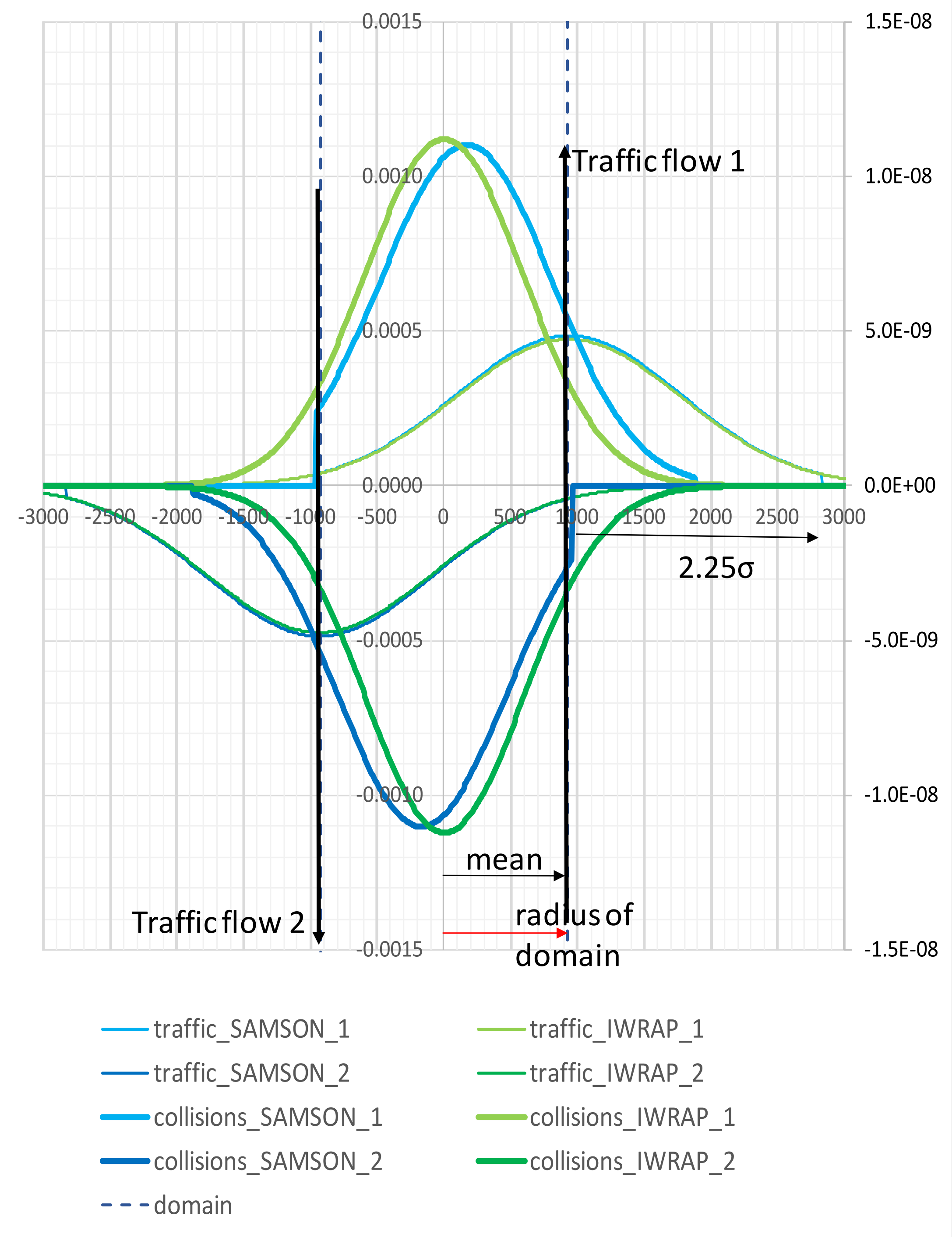

Figure 2-9 **Distribution of contributors to collisions for head-on with ±mean=935m and σ=842m**

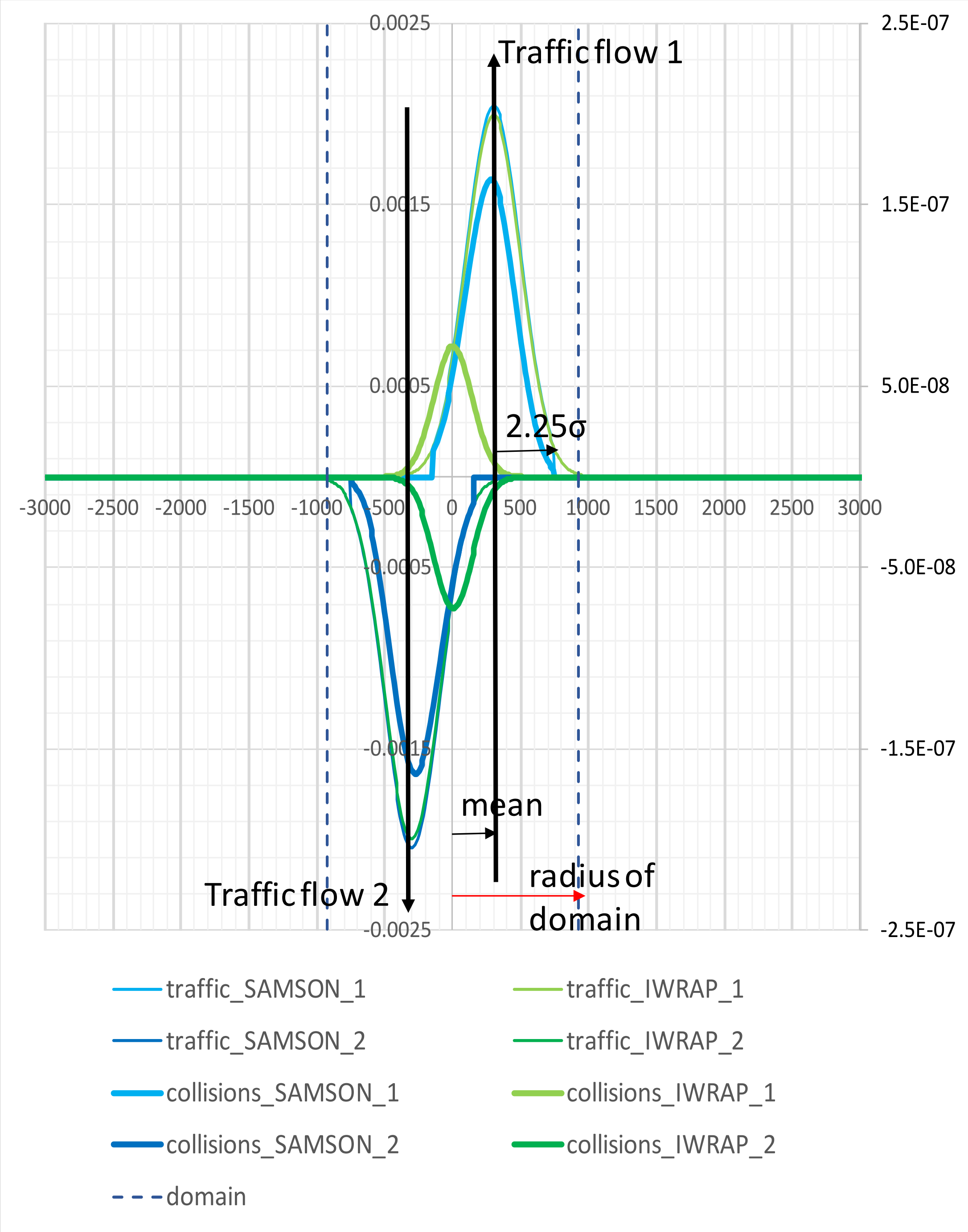

Figure 2-10 **Distribution of contributors to collisions for head-on with ±mean=300m and σ=200m**

2.3 Influence of tails of lateral distribution on groundings/allisions

In IWRAP, the lateral distribution is determined by assigning the AIS data to predetermined links. All ships within a predefined area around the predefined link with a course within an area around the course of the link are assigned to the link. The lateral distribution parameters mean and σ are determined from the positions of the assigned AIS data. These parameters are used for predicting the collision, grounding and contact risk.

In Figure 2-11 the situation is schematized for a leg from the IWRAP database. The AIS targets within a range of 5000m and a course difference of less than 15° are included in the assignment process. The black targets of Figure 2-11 are included and the red targets are ignored because they are located outside the range of 5000m or have a course difference > 15°. The mean and standard deviation for the leg are calculated from the targets included (black ones). This delivers a mean=974m and σ=978m. With these values, the lateral range limits are located on -3.55σ (portside) and 1.59σ (starboard). Thus, ships sailing in the tail on starboard side on a distance of more than 1.59σ are not included in the determination of the parameters of the lateral distribution. This makes clear that the tail of a lateral distribution is the most inaccurate part of the distribution. Therefore, the prediction of the grounding and contact risk cannot be determined accurately based on this tail. However, the grounding and contact risk in the IWRAP approach are only delivered by ships in those tails of the distribution.

Changing the shape of the lateral distribution from, for example, a normal distribution to the sum of a number of other distributions, can result in large changes in the tails of the distribution. This can also result in a change of an order of magnitude to the grounding or contact risk.

With the current grounding and allision model in IWRAP it is impossible to delete the tails of the distribution, because the number of collision candidates would reduce to zero.

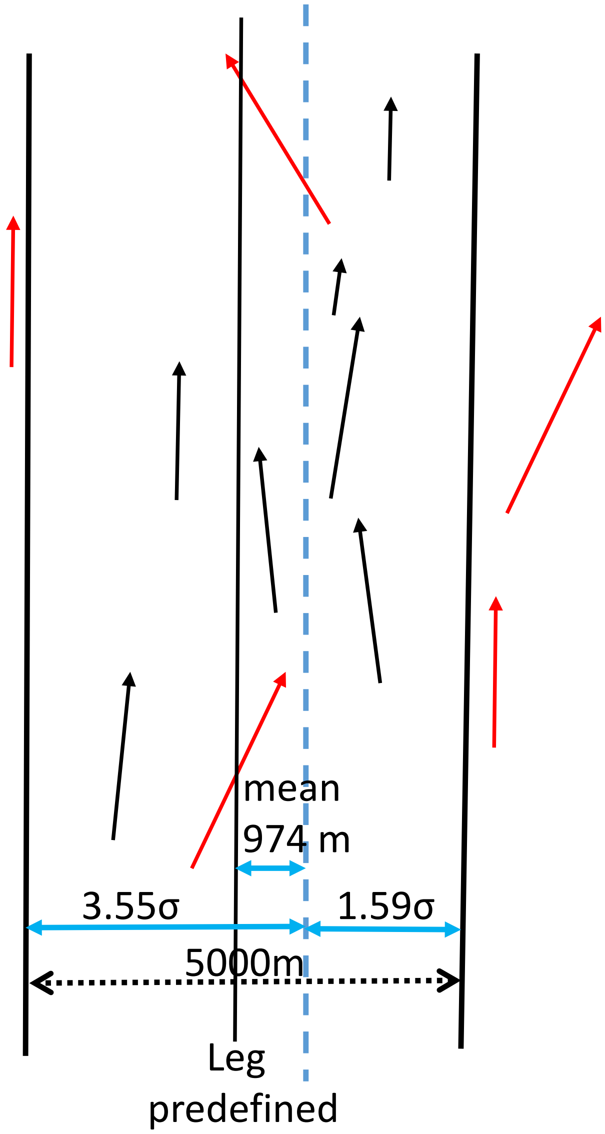

Figure 2-11 Leg with AIS targets

2.4 Conclusions from comparisons between IWRAP and SAMSON

The overviews made for the elementary traffic situations for ship-ship collisions help to obtain further insight in differences that occur due to the different models used in IWRAP and SAMSON.

Although the models for IWRAP and SAMSON are quite different, the outcomes are not so different, due to the tuning of both models with either the causation factors or the casualty rates. The results from the models differ specifically for such situations where the lateral distribution and domain size are important (APPENDIX A).

The next question is: “How do accidents happen in real situations and how can this best be modelled?” The focus should not only be at ship-ship collisions, but also at ship-object allisions. This will not be easy to answer. A start is made in this project and reported in Section 3, but it is also a perfect subject for a large international research project.

Subject	IWRAP	SAMSON
Traffic modelling	– Intensity based on crossings in AIS – Various distributions possible, one of them is normal distribution including a tail	– Intensity based on port visits from Lloyd's List Intelligence – Normal distribution cut off at 2.25σ, compensated for by increasing other values.
Ship-ship collision model	– Number of collision candidates is based on the geometrical width of ships that are related to the ship size and on the lateral distribution: collision course – Collisions only occur where lateral distributions overlap – Multiplication of collision candidates with causation factors – Assumption: ships do perform deviating actions in case of collision course only (results in causation factor) – Collisions occur where ships meet each other	– Potentially dangerous situations or PRETS[1] (exposures/encounters) are based on penetration of a ship's domain by another ship. This is dependent on the lateral distribution as well. – Ship domain with diameter of 1 nautical mile – Collisions can occur when ships in the lateral distribution are 0.5 nautical miles apart – Less sensitive to lateral distribution – Multiplication of the encounters with casualty rates – Assumption: there is a relation between near misses and collisions (near misses are dependent on the ship domains). – Assumption: ships start to deviate from their straight course in case of a domain penetration – In case of parallel links, or for head-on collisions on one link, potential collisions are due to the ship domain also predicted in an area where ships do not meet each other but pass each on close distances

Subject	IWRAP	SAMSON
Grounding/stranding/allision model	– Similar to ship-object ramming model (also drift model?) – Tails of distribution are dominant factor – Wind farm modelled as sand bank/island)	– Ship-object ramming model with probability of navigational error used for powered grounding – Repair function based on actual drift time information used for drifted grounding – Wind farm modelled by individual wind turbines
Size classes	– Length classes	– Gross Tonnage classes
Type classes	– 14 ship types are included – Possible based on Lloyd's information	– SAMSON ship types – 36 for route committed – Based on Lloyd's information
Traffic modelling Small ships	– All ships with AIS that sail close to a link, are assigned to a link. Also platform and wind farm visiting. – Fishing ships and pleasure crafts as (one?) density (in total area?) – No density of platform visiting vessels close to the platform.	– Route committed ship types assigned to links. – Ship types with mission at sea as density per grid cell
Causation factor/casualty rate for ship-ship collisions	– Causation factor is similar for head-on and overtaking	

[1] "Potentially Risky Elementary Traffic Situation"

Subject	IWRAP	SAMSON
	– Causation factor is independent of ship size (difference due to difference in geometrical width) – Causation factor is independent of ship type – Causation factors for various locations are suggested – Causation factors are based on literature studies - Causation factor can be chosen by user	– Casualty rate increases with ship size representing the geometric factor – Casualty rate is different for different ship types – Casualty rate is not dependent on the sea area – The number of encounters from SAMSON for the North Sea is related to the number of collisions that occurred in the North Sea. The factors per ship type and size are correlated with the worldwide casualty data. – Casualty rate is updated after some years

3 REPLAYED COLLISIONS

APPENDIX D describes how AIS data has been traced back to study collisions that occurred in reality. The objectives of this part of the study were the following:

- Check the kind of collisions: do ships sail straight on and collide if they are on collision course (collision candidate model) or do ships interact if they get too close to each other and do they sometimes take erroneous actions (domain penetration model).
- Compare the fraction of overtaking, crossing and head-on collisions between actual collisions and SAMSON calculations.

Summarized over a large area and a long time period, it is possible to compare the model predictions (of SAMSON and IWRAP) with the reality. For the current investigation, the collisions from 2005 through 2013 in the Dutch Sector of the North Sea have been replayed.

However, not all collisions could be replayed, because:

- especially in the first years, the AIS coverage was not complete;
- sometimes AIS data was missing, just at the time of the collision;
- the number of fishing vessels that are obliged to have an AIS transponder on board has increased over the years.

The incident database contained 73 incidents in which more than one ship was involved. These incidents are classified as:

- 45 collisions between two sailing ships;
- 13 allisions in which a sailing ship hits a ship at anchor;
- 3 collisions (damages) during boarding of a pilot or crewmember;
- 12 incidents were not used by different reasons, (double records, waves, not located in the Dutch sector of the North Sea, collisions by two recreational vessels).

Real incidents were also plotted on a map with the results of SAMSON ship-ship collisions to check whether the incident locations are similar.

Section 3.1 describes the replay of collisions between two sailing ships. Section 3.2 describes the replay of allisions with ships at anchor. Section 3.3 compares the locations of real collisions with the results for a SAMSON calculation.

3.1 Collisions between two sailing ships

Tracing back the AIS data has been done with two objectives. Section 3.1.1 checks whether colliding ships were collision candidates following a collision course, or whether ships interacted with each other because of a domain penetration. Section 3.1.2 compares the fraction of real head-on, overtaking and crossing collisions with the fraction resulting from a SAMSON calculation.

3.1.1 Collision candidate or domain approach

Table 3-1 shows the conclusion from the replay of collisions between two sailing ships. Roughly 50% of the collisions for which AIS data was available occurred by collision candidates, thus following the IWRAP modelling. This 50% is also included in the SAMSON modelling, but SAMSON includes also the other 50%, which are ships penetrating the other ship's domain. Due to the causation factors and CASRAT's both models will predict the correct overall number of collisions.

Approximately 50% of the ships involved in the reported collisions are non-route committed.

Table 3-1 Classification of collisions

Collision type	AIS both ships available		No(t enough) AIS available	Total
	Action taken			
	No	Avoidance or wrong action		
Route committed – Route committed	7	8	2	17
Route committed – non-route committed	2	2	9	14
Non-route committed – non-route committed	1	1	12	14
Grand Total	10	11	23	45

3.1.2 Collision types

The 25 collisions between two sailing ships of which a collision type could be determined (not all of them having AIS) have been compared with the collision types calculated from SAMSON. As the numbers are very low, Table 3-2 only gives an indication of the differences between modelled and observed collision types. The differences in collision types between IWRAP and SAMSON in Section 2.1.2 and 2.2.2 were not very clear either.

Table 3-2 Expected number of SAMSON divided by the observed incident frequencies

collision type	Collisions per year: SAMSON/observed
Head-on	1.05
Overtaking	0.44
Crossing	1.34
All	1.10

3.2 Allisions between sailing vessel and ship at anchor

Allisions with ships at anchor occur quite regularly and can therefore not be neglected. All incidents with ships at anchor occurred by collision candidates.

Table 3-3 shows that the number of non-route committed ships involved and the number of allisions with ships in open sea cannot be neglected either.

Table 3-3 Allisions with ships at anchor in the Dutch sector of the North Sea

Allision type	In anchorage area	In open sea	Grand Total
R ship with R ship at anchor	4		4
R ship with N ship at anchor	1	2	3
N ship with R ship at anchor	3	1	4
N ship with N ship at anchor		2	2
Grand Total	8	5	13

SAMSON does not use the encounter model for allisions, such as ships at anchor, offshore platforms and wind turbines, but has developed a different model. A comparison between the observed and calculated allisions with ships at anchor has not been made in this project.

3.3 Comparison between locations of real and calculated collisions

The collisions from 2005 through 2012 in the Dutch Sector have been plotted together with the results of SAMSON ship-ship calculations.

Figure 3-1 shows the results for the collisions between two route committed ships. There is quite a good correspondence between the calculated and real collisions. The real collisions include data of 8 years. In this time frame, approximately 1 collision is expected in the red cells. Many collisions occurred on the border of the red and dark red cell in the approach of the Western Scheldt. Some of the collisions occurred in blue cells, but most occurred in darker coloured cells.

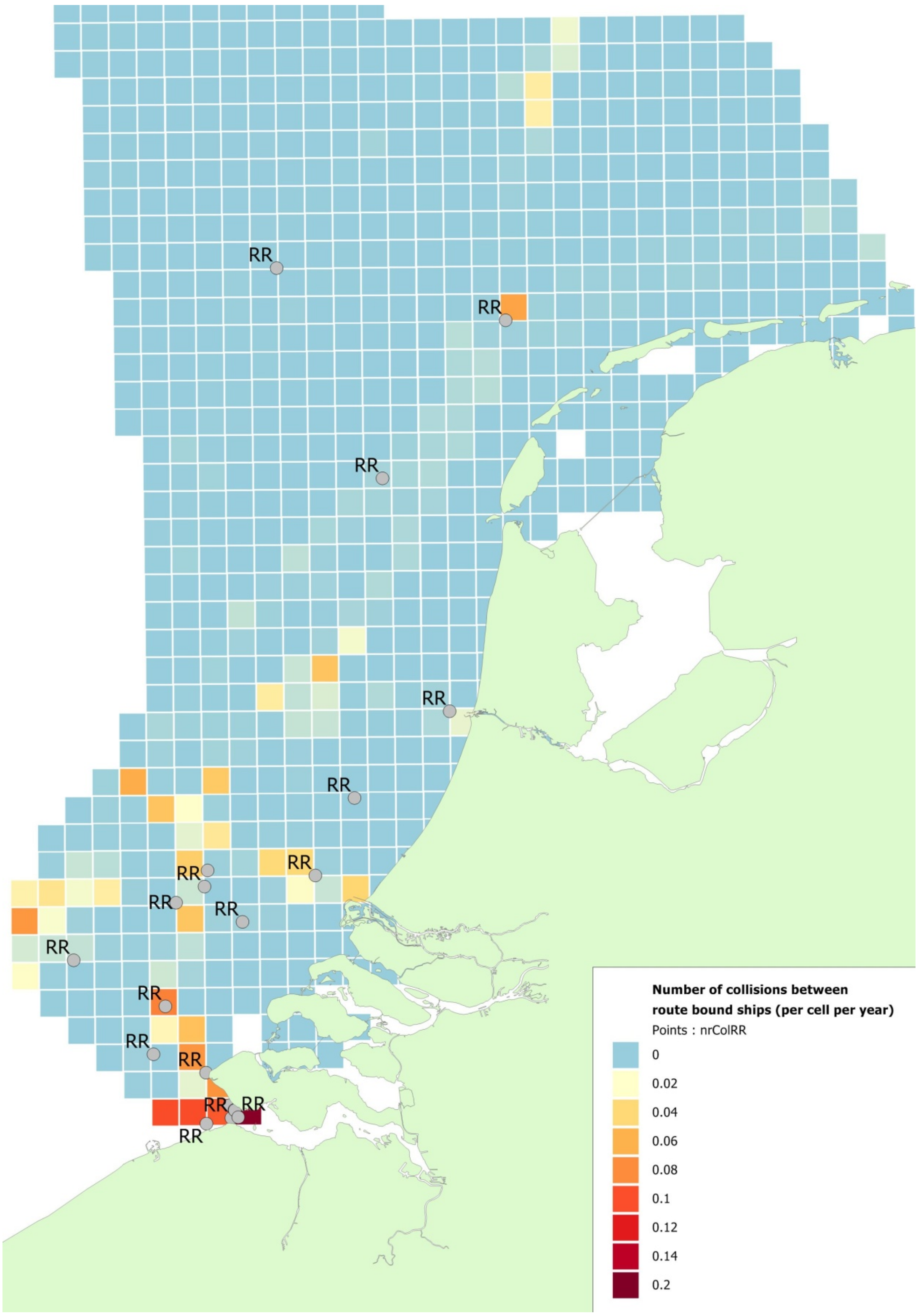

Figure 3-1 **Number of real and calculated collisions between route committed ships (RR is actual collisions between two route committed ships)**

Figure 3-2 shows the results for the collisions with at least one route committed ship included. The collisions between a route committed ship and a fishing vessel occur most of the time in blue cells. This means that it is difficult to predict the location of collisions with fishing vessels. Most of the collisions with work vessels occur in cells that at least have a yellow colour.

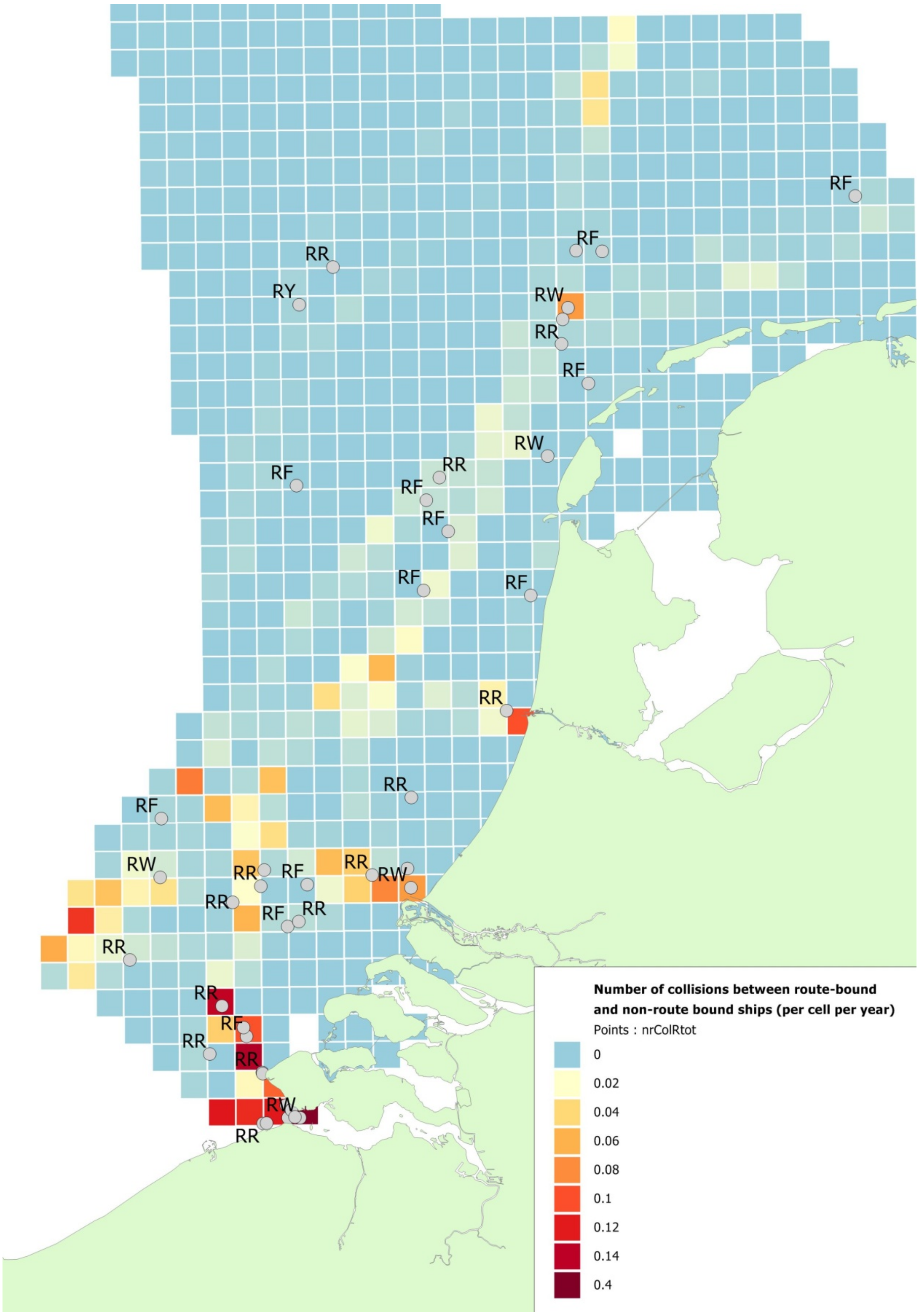

Figure 3-2 **Number of real and calculated collisions with at least one route committed ship involved (R = route committed ship), (W = work vessel, F = fishing vessel, Y = yacht)**

Figure 3-3 shows the results for the collisions between two non-route committed ships. These are modelled to occur really close to land, but do mainly occur slightly further at sea. Also for non-route committed ships, the approach to the Western Scheldt is the area where most real collisions occurred.

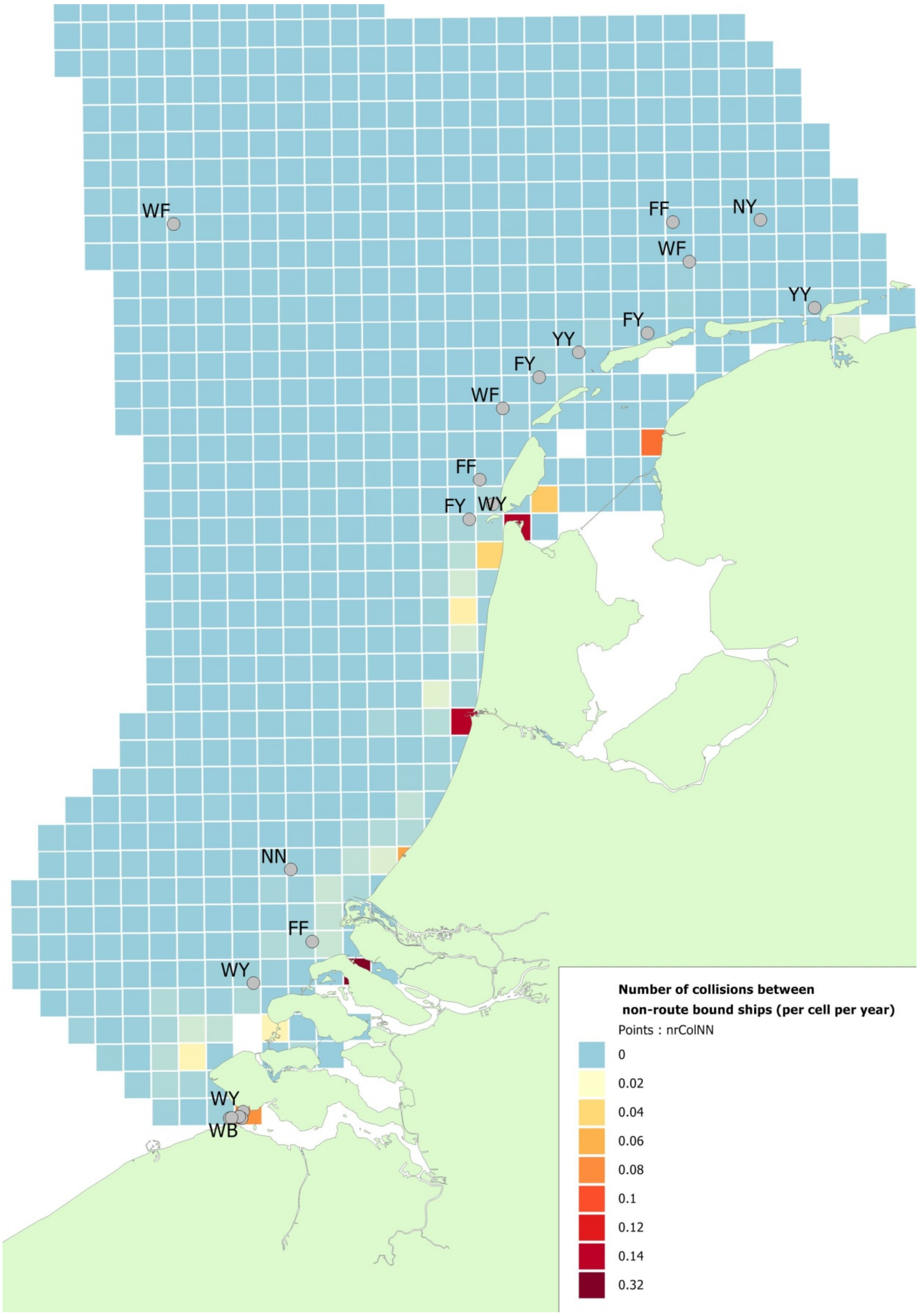

Figure 3-3 Number of real and calculated collisions between non-route committed ships (N = non-route committed vessel, W = work vessel, F = fishing vessel, Y = yacht, B = inland vessel)

4 COMBINING IWRAP AND SAMSON

The ultimate goal of this project is described in APPENDIX A. The user of the IALA toolbox should get a clear recommendation which tool to use (and in what way) for a specific question. As the differences between both models can not easily be smoothed out, the merging of the models into one tool is not realistic and may not be desirable. Probably, at least for some time, both models will remain in use. The work of this project group will follow two parallel tracks:

1. provide guidance on the application and validity of the models for evaluation of various types of risk sources (Section 4.1)
2. provide possibilities to use modules of both models in combination (Section 4.2)

Section 4.3 describes the changes that have already been made to IWRAP due to this project and other items that will be implemented.

4.1 Provide guidance on the application and validity of the models

A correct model should reflect relevant changes, for example in traffic organisation, in a plausible way, and not only reproduce the overall number of accidents in the actual situation.

It is interesting to see how the incident frequency changes with variation of input parameters, like lateral distributions, traffic link topology and route choice.

Even more relevant is the response to changes on a higher level: the modification of AtoN and TSSs, risk reducing measures like pilotage and VTS, traffic composition with respect to flag state, ETVs, etc. Those parameters may influence, in turn, the lateral distributions, route choices and causation factors or casualty rates. It is this response that indicates if a model is good to use for the evaluation of a change scenario.

It is essential to have evidence for the way the model should respond to a specific change; otherwise, the only way to decide is whether experts judge the behaviour as plausible. How to get this evidence? Because of the relatively low number of shipping accidents there will be no ‘proof’ of the resulting accident frequencies. For a number of aspects of the internals of the model, support may be found in traffic behaviour studies on basis of AIS, simulator studies, interviews, etc. Before choices can be made for one modelling or another, such materiel must be gathered or produced.

A large worldwide/European campaign is needed to bring together good quality incident reports and (non-down sampled) AIS data of the last period before the incident. Data analysis combined with simulator studies for single factors can produce the required information.

In the end, the tool will not only be used to evaluate changes relative to an existing situation, but also to rate the risks in a completely new scenario. In that case we expect an absolute rating, rather than a relative one. But when the effect of all parameters is represented correctly, every new scenario can be related to an existing one. By tuning the causation factor or casualty rate to the existing situation in a large area and over a number of years to get acceptable statistical reliability, this absolute level may be set.

In the end, there should be no discussion about the validity of the results, nor the possibility that one may select the module that provides the answer that he likes most. However, it may happen that in the end we are not able to tell, or do not agree on, which model is closest to reality in a specific situation.

4.2 Provide possibilities to use modules of both models in combination

Next to gaining insight in the differences between IWRAP and SAMSON and in gaining insight in real traffic and accident situations, options for combining IWRAP and SAMSON were investigated. Figure 4-1 shows several interfaces for data exchange that may be defined. The data import- and export facilities can then be added to both models.

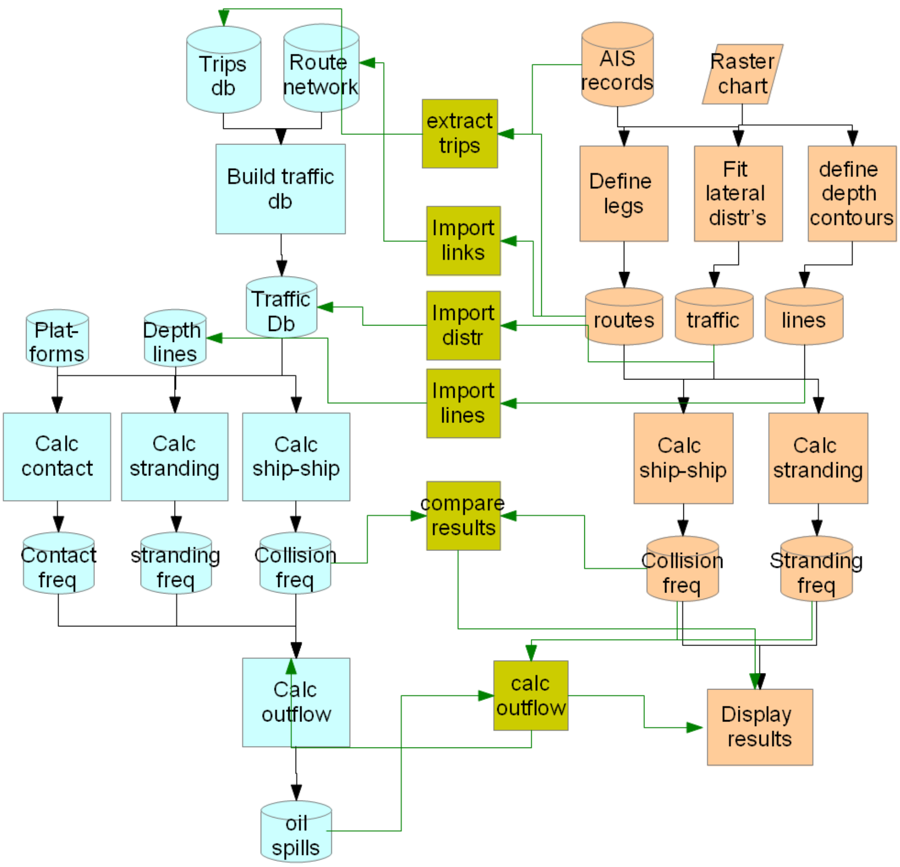

Figure 4-1 **SAMSON parts (left), IWRAP parts (right) and possible data interchange routes (one way shown)**

One interface that looked very promising from the beginning was to use the consequence model for oil outflow from SAMSON in IWRAP. The results can be shown in the IWRAP visualisation part again. On the other hand, Samson may benefit from the user friendly AIS import and analysis facility of IWRAP.

As a first step data interchange can be developed using intermediate files, leaving the SAMSON and IWRAP programs almost in their original state. This may evolve to a more integrated model suite in which the user may pick the most convenient module for each step in the process.

4.3 Changes implemented to IWRAP

APPENDIX E describes some tables, which belong to the SAMSON model, that describe the outflow of oil. These tables are made available to IALA for implementation in the free version of IWRAP.

Other items that have already been implemented in IWRAP due to this workgroup are:

- The repair time function for drifting ships
- The ship types can be customized by mapping Lloyd’s or AIS ship types to IWRAP ship types.
- AIS can be replayed and movies can be recorded.
- Wind farms can be modelled as structure instead of as an area
- Allisions are defined as separate category instead of as grounding, and this incident type obtained its own causation factor.

5 CONCLUSIONS AND ADVICE FOR FUTURE WORK

5.1 Conclusions

5.1.1 Comparisons between IWRAP and SAMSON

The comparisons between IWRAP and SAMSON have resulted in the following conclusions.

Although the models for IWRAP and SAMSON are quite different, the outcome for the expected number of ship-ship collisions for approximately the same traffic database corresponds quite well. This is due to the tuning of both models with either the causation factors or the casualty rates. The results from the models differ specifically for such situations where the lateral distribution and domain size are important.
The distribution over the different collision types (head-on, overtaking, crossing) is different.

The factor SAMSON/IWRAP for crossing collisions is not constant. One reason is that the geometric width of IWRAP, calculated from the dimensions of the ships decreases with collision angles while this collision diameter is constant (1 nautical mile) in SAMSON. The dependency of the collision angle in SAMSON is modelled by different casualty rates for overtaking, crossing and head-on encounters and the geometric width is modelled by a ship size dependent casualty rates

The assignment method of AIS data to a route structure in IWRAP needs to be investigated, at least when using AIS data with a large (6 minutes) time step.

The resulting number of ship-wind turbine collisions from SAMSON was higher than from IWRAP. The reason is that the models for this type of incident are completely different.

For situations with narrow traffic lanes, SAMSON calculates a high number of potentially dangerous situations compared with IWRAP. This is due to the fact that the domain of 1 nautical mile in these situations is very large and almost all ships are involved in a domain penetration, while this is not the case with IWRAP. These situations are not representative for traffic at sea, but more for example for the passage of a bridge. The question is how to correctly model collisions in narrow traffic lanes.

Not only the number of collisions, but also the location of the potential contributors to collisions differs between SAMSON and IWRAP. For an average traffic situation at sea, the differences in the distribution are small, but for the situation with narrow traffic lanes, the differences are considerable.

The tail of a lateral distribution is the most inaccurate part of the distribution. Therefore, the prediction of the grounding and contact risk cannot be determined accurately based on this tail. However, the grounding and contact risk in the IWRAP approach are only delivered by ships in those tails of the distribution. With the current grounding and allision model in IWRAP it is impossible to delete the tails of the distribution, because the number of collision candidates would reduce to zero.

5.1.2 Replayed collisions

Approximately 50% of the collisions occurred by collision candidates, thus following the IWRAP modelling. This 50% is also included in the SAMSON modelling, but SAMSON includes also the other 50%, which are ships penetrating the other ship's domain. Due to the causation factors and CASRAT's both models will predict the correct overall number of collisions.

Approximately 50% of the ships involved in the reported collisions are non-route committed.

Allisions with ships at anchor occur quite regularly and can therefore not be neglected. All incidents with ships at anchor occurred by collision candidates.

5.1.3 Combining IWRAP and SAMSON

DMA has told that based on this work, IWRAP has implemented the possibility of crossings that don't occur in waypoints. It is not clear whether this influences the number of collisions and the division over the collision types calculated by IWRAP.

Tables containing the probability of oil outflow are made available to IALA for implementation in the free version of IWRAP.

Also the repair time function for drifting ships has been implemented in IWRAP based on SAMSON documentation.

5.2 Advice for future work

As the differences between both models can not easily be smoothed out, the merging of the models into one tool is not realistic and may not be desirable. Probably, at least for some time, both models will remain in use.

To be able to provide guidance on the application and validity of the models for the evaluation of various types of risk sources more work has to be done. This Section gives advice on the next steps to take.

For traffic situations with small lateral distributions combined with a small, but larger (than the standard deviation) mean offset from the centre of the leg, large differences were found between IWRAP and SAMSON. The advice is to start future work on these situations. These traffic situations occur for narrow traffic lanes, for example on rivers and at sea when traffic lanes are forced together by the introduction of wind farms. One of the questions to be answered is: how do ships interact and how shall this be modelled?

The SAMSON CASRAT's are updated regularly, while the IWRAP causation factors are based on relatively old literature studies. The question is raised how the causation factors in IWRAP can be improved.

MARIN has a risk index available. This would also be of interest to IALA. Further cooperation could also be aimed in that direction.

Some more specific questions that have been raised in the workgroup are:

- Do ships only collide when the lateral distributions overlap (as in IWRAP), or also when they are sailing further from each other (maximum 0.5 nautical mile like in SAMSON): first study shows 50% each.
- Does the number of overtaking collisions increase when the traffic is forced together by for example the introduction of a wind farm?
- Is the ratio between calculated head-on overtaking and crossing collisions in accordance with real collision data?

It is important to gain better understanding of real ship behaviour to find out how these situations should be best described. It is essential to have evidence for the way the model should respond to specific situations, or to a specific change; otherwise, the only way to decide is whether experts judge the behaviour as plausible. A Horizon 2020 project would be an opportunity to bring together good quality incident reports and (non-down sampled) AIS data of the last period before the incidents. Data analysis combined with simulator studies for single factors can probably produce the required information. Such a project could start in 2017. 2016 can be used to develop the scope of work and to work out a good approach.

Other aspects that are advised to look into at a later stage are allisions, including those with ships at anchor.

Meanwhile, the mapping of strong and weak points of both models should be continued.

APPENDICES

APPENDIX A TOWARDS AN IALA RISK MODEL

Towards an IALA risk model

Considerations for the IALA project on harmonisation of risk modelling.
Ernst Bolt, June 2014

The ultimate goal of this project should be that a user of the IALA toolbox gets a clear recommendation which tool to use (and in what way) for a specific question. It may be possible to merge Samson and Iwrap into a single tool, but it may also prove necessary to provide a choice of different methods depending on the situation. In the end, there should be no discussion about the validity of the results, nor the possibility that one may select the module that provides the answer that he likes most.

It has already been noted that there are at some points slightly different approaches to the risk calculation. Most important is perhaps the following:

> The 'potentially dangerous situation' or PRETS[1] (exposure) as used by Samson differs from the 'number of collision candidates' used in IWRAP. This is not only a matter of definition but also a different way of modelling.
>
> The modelling behind IWRAP is that, if all ships would ignore other traffic and follow the tracks with the prescribed lateral distribution, this would mathematically result in a number of hits. Because there is intelligence on the bridge this number is reduced by the causation factor to get the expected number of collisions.
> In Samson it is rather the other way around. Although mariners will try to pass each other at a safe distance, it might happen that they fail to take the appropriate actions (due to lack of attention, human error, mechanical failure or whatever). The probability that such an error occurs and is not discovered in time to save the situation is represented by the casualty rate. For a number of course deviations the probability that such an error would occur is combined with the time available for corrective action, before the other vessel (or obstacle or coastline) is hit.

Discussion

> *[Knud]*
> *I would not stress so much the "potential intelligence and intensions of the mariners" behind the models - The fact is:*
>
> 1. *In IWRAP there is no ship domain – it is zero and therefore all probability of an accident is only in the causation factor.*
>   *[Ernst] There is also a probability in the lateral distribution of traffic. For example, if you would cut off the tails of this distribution, some collisions simply cannot occur.*
> 2. *In SAMSON there is a certain ship domain and therefore the probability has two elements:*
>   - *part 1 in the domain (because the ships must not collide) and*
>   *[Ernst] This is not really different from Iwrap. The difference is that for Samson ships that enter each other's domain contribute to the collision*

---

[1] "Potentially Risky Elementary Traffic Situation"

probability, whereas in Iwrap only ships that (statistically) enter each other's hull contour do.

- *part 2 in the casualty rate.*

Because both models are referenced to the same type of data (the real accidents were the ships really hit each other) the results are mostly the same and differ specifically for such situations only where the lateral distribution and domain size is important.
Summing up my opinion to make the application of the models more consistent:

- *The SAMSON domain model would more precisely and perfectly describe the incidents because it is more for violating a ships domain – in this case the casrate should be related to the number of incidents.*
- *The IWRAP ship shape model is more suitable for accidents where the ship really hit each other – the causation factor is related to the real accidents.*

[Ernst] I think this can be either way. Iwrap would be better to describe the 'near misses' that are the result of a late avoidance manoeuvre, and Samson better to describe collisions that result from miscommunication and incorrect manoeuvring. A potential problem for the Iwrap approach is that by choosing a too narrow lateral distribution the number of collision candidates would get too small for a statistical analysis.

This difference has consequences for the use of the tool. Samson is less sensitive to changes in the lateral distribution of ship traffic on a specific traffic link. This may be an advantage in case this distribution is unknown, but it may as well be a disadvantage if the effect of (a change which would cause) a different distribution is investigated. Then again, the effect shown by the model may be different from the real world effect. The lateral distribution in Iwrap is averaged over time, whereas the distribution during an overtaking or meeting will probably be very different.

Another difference is that Samson uses casualty rates that are derived for the North Sea on basis of accident records, and Iwrap suggests a standard causation factor based on world literature. Although the difference is not fundamental – an Iwrap user may specify his own causation rate[2] – a practical problem is that historical traffic data for all traffic links, including the lateral distributions is needed to derive the causation factor. In this sense it is connected to the difference described above.

The casualty rate or the causation factor may be adjusted to reproduce the present yearly number of accidents in the area under study, although this must be done on a highly aggregate level to have some statistical reliability. This means that the computed frequency of an existing situation is close to the recorded frequency, regardless of the detailed modelling inside – simply because the results are calibrated to be close.

Discussion

[Knud] I do not really understand this phrase: in case we want to get the casrats or causation factors we only need measurements of encounters from AIS and relate this to the real accidents numbers – Or do we first need a traffic model to calculate the encounters?

---

[2] On what basis is not clear – there is probably no' jurisdiction' available. Changing the causation rate is risky and may open the possibility to manipulate the results. But it is the only method for the time being to address changes in measures increasing safety like vts piloting,…

[Ernst] The phrase does not refer to the determination of casrats or causation factor as such, but tries to point out that almost regardless of the parameter you choose (number of encounters, number of collision candidates or, say, number of ships per square mile) – if you determine the ratio of the number of accidents to this parameter and apply this ratio to a similar area the answer will never be far off. My point was that you'd want a model to reflect relevant changes in traffic organisation etc. in a plausible way, and not only to reproduce the overall number of accidents in the actual situation.

Interesting however, is how the frequency changes with variation of input parameters, like lateral distributions, traffic link topology and route choice.

Even more relevant is the response to changes on a higher level: the modification of AtoN and TSSs, risk reducing measures like pilotage and VTS, traffic composition with respect to flag state, ETVs, etc. Those parameters may influence, in turn, the lateral distributions, route choices and causation factors or casualty rates. It is this response that indicates if a model is good to use for the evaluation of a change scenario.

It is essential to have evidence for the way the model should response to a specific change; otherwise, the only way to decide is whether experts judge the behaviour as plausible. How to get this evidence? Because of the relatively low number of shipping accidents there will be no 'proof' of the resulting accident frequencies. For a number of aspects of the internals of the model, support may be found in traffic behaviour studies on basis of AIS, simulator studies, interviews, etc. Before choices can be made for one modelling or another, such materiel must be gathered or produced.

Discussion

[Knud]The problem is to find these "factors" which are related to probability (this means a large number of cases) from studies where you are mostly limited (e.g. in the number of simulations and variations of the conditions) because of budget reasons. The only way is to record precisely the details AND the results of real changes in the world traffic… What we need is:

1. *a campaign to record and analyse traffic and accidents around the globe to get these data and factors. IALA could be the institution to bring partners together for such a big global project.*

   [Ernst] Yes – the more data the better; but it will not be easy to get consistent, reliable data with the desired level of detail. Especially because we are interested in details of the (15-30) minutes before the accidents. So you would need data on the level of the national MAIBs I suppose. And then find a way to extract the parameter values from the textual report.

2. *[Knud] A specific research project in a region (e.g. EUROPE) would be a good start to lay down a foundation how this should be done – HORIZON 2020? E.g. Big data analysis relevance, and specific simulation studies for single factors*

In the end, the tool will not only be used to evaluate changes relative to an existing situation, but also to rate the risks in a completely new scenario. In that case we expect an absolute rating, rather than a relative one. But when the effect of all parameters is represented correctly, every new scenario can be related to an existing one. By tuning the causation factor or casualty rate to the existing situation in a large area and over a number of years to get acceptable statistical reliability, this absolute level may be set.

Way forward

The differences between both models can not easily be smoothed out. Consequently, the merging of the models into one tool is not a realistic route and may not be desirable. Probably, at least for some time, both models will remain in use. The work of this project group will follow two parallel tracks:

1. provide possibilities to use modules of both models in combination
2. provide guidance on the application and validity of the models for evaluation of various types of risk sources.

Ad 1.

Recalling the diagram drawn up at the first work group meeting, there are several interfaces for data exchange that may be defined. The data import- and export facilities can then be added to both models.

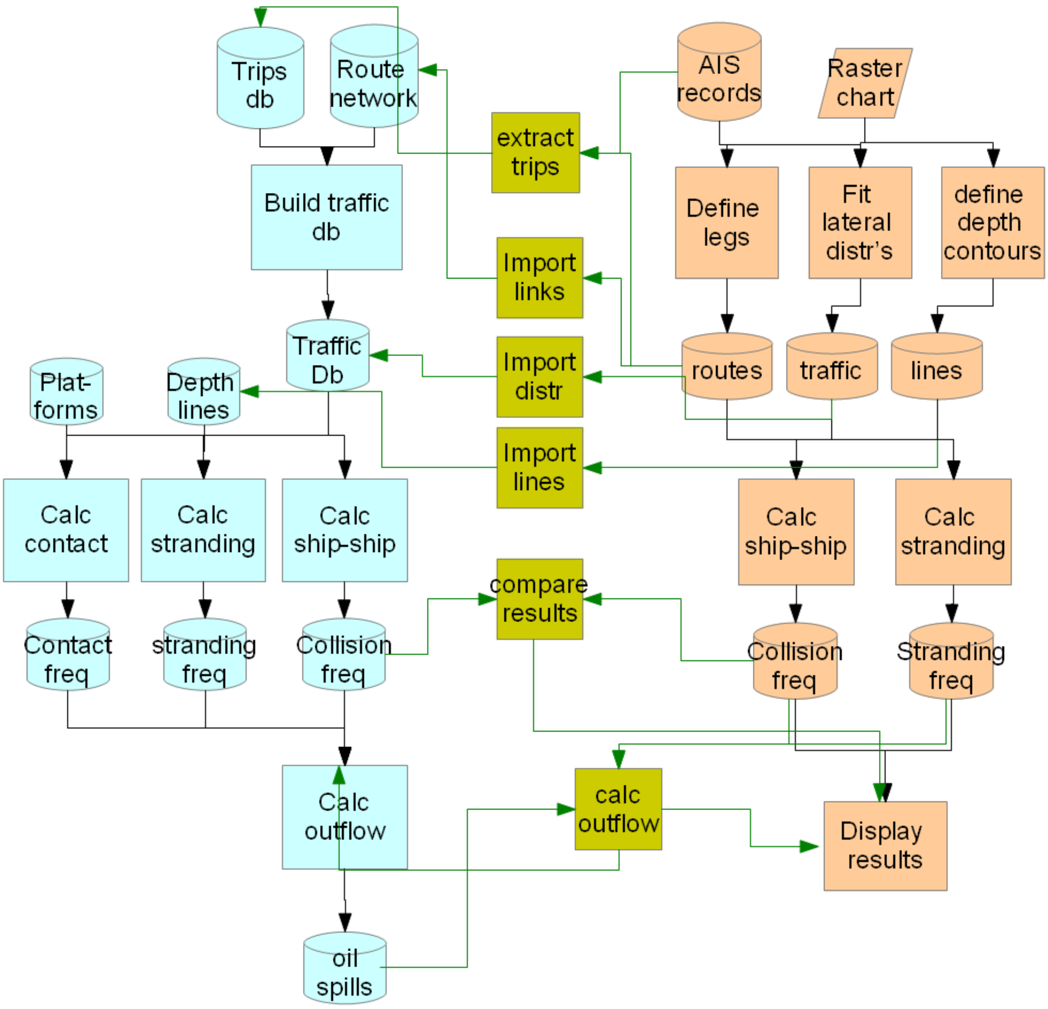

Figure 1 – Samson parts (left), Iwrap parts (right) and possible data interchange routes (one way shown)

As an example, the calculation of consequences of an accident, from Samson, can be added to the Iwrap work flow. The results can be shown in the Iwrap visualisation part again. On the other hand, Samson may benefit from the user friendly AIS import and analysis facility of Iwrap.

As a first step data interchange can be developed using intermediate files, leaving the Samson and Iwrap programs almost in their original state. This may evolve to a more integrated model suite in which the user may pick the most convenient module for each step in the process.

Discussion

[Knud]Could there be a sort of business model for that approach, e.g. another module in the professional IWRAP where MARIN and Gatehouse team up to make a consequences module?

[Ernst] I doubt whether the revenues will justify the trouble. There could be other motives though, like stressing that this module is only meant for use by professionals, or keeping track of all users of the module.

Ad 2.

Irrespective of progress under 1., at some point a user has to decide which model to use for the actual risk calculation. The investigation of the conditions and actions immediately before an accident as going on now may provide some foundation for such a decision. It may also happen that in the end we are not able to tell, or do not agree on, which model is closest to reality in a specific situation.

APPENDIX B COMPARISON OF PORT AND WATERWAY RISK ESTIMATION SOFTWARE PROGRAMS

Comparison of Port and Waterway Risk Estimation Software Programs

Modules to describe / represent	**Name: IWRAP Mk II Source: IALA / Gate House (DK)**	**Name: SAMSON Source: MARIN (NL)**
Traffic data flow model structure	– Routes represented by Leg structure for straight segments, Bends, Junctions – Specification of the legs of the route; – Specification of the traffic distribution across leg for each leg in each direction; – Specification of the number of ships for each leg in each direction; – Specification of the causation factors for each leg in each direction; – For junction waypoints (i.e. waypoints to which more than two legs are adjacent) specify the proportion of ships sailing from one leg to the other; – Specification of depth curves and grounds.	– Routes represented by Leg structure for straight segments, Bends, Junctions – Specification of the legs of the route; – Specification of the traffic distribution across leg for each leg in each direction; – Specification of the number of ships for each leg in each direction; – It is really impossible to determine causation factors for each leg, because for most legs no data is available. The probabilities of accidents have to be predicted by the model based on model parameters, layout and environmental conditions. The model and parameters of SAMSON are the result of thoroughly analysis of casualty databases and related traffic. – Specification of depth curves and grounds. – The none-route-bound traffic (fishing, dredging, suppliers, service ships) are given by means of area densities on a grid –
Traffic data flow input	– Manual user input and extensive editing functions – Access to all data – Automatic input from AIS recordings (commercial part) for identifying legs and distributions	– In most applications the traffic database is generated from voyage data, containing number of ships per type and size class per year from port A to B. A route generator is developed to determine the shortest route along the legs taken into account the rules of the road (as TSS, ITS) and water depth. – Nowadays AIS data is a good source

Modules to describe / represent	Name: IWRAP Mk II Source: IALA / Gate House (DK)	Name: SAMSON Source: MARIN (NL)
		–
Geographic reference tools	– IWRAP Standard maps with Depth curves and grounds – Creating depth curves using Google Earth – Scanned paper charts – Raster scan charts – ECDIS /ENC	– charts of Chartworld – The ECDIS kernel of SevenCs is used to display results and getting geographical data
Modelling Probability of casualties	– Probability calculation of geometric casualties /events – Causation factors to address Human impact to avoid casualties, assigned ▪ globally to all ships and legs, ▪ individually to legs, ship types, extras e.g. …	– Models are used to predict the probability of casualties. The powered contact model is different. The causation factor is replaced by a more robust model that predicts ramming (= powered) contacts. The model includes the possibility to anchor given the environmental conditions, repairing function, drift velocity models (depending on ship type, size and environmental conditions) and current are incorporated in the drifting models. – All models work with ship type and ship size classes.
Sources for Risk Modelling parameters (e.g. Causation factors)	– Basic data from research based on accident data (Fuji and others) to be used as standard values in the program – Development of new and specific parameters in IALA Working group using Bayesian networks and future cases of traffic analysis by IALA members uploaded to IALA server	– See above, there is no general valid causation factor that can be applied in all circumstances. It depends too much on the local traffic and layout. Therefore factors of old papers cannot be applied elsewhere. SAMSON contains an adapted model. – Bayesian networks are not used..
Type of Casualties addressed	– Collisions (crossings, head-on & overtaking) – Groundings – Drifting and Grounding frequency (depending on black out frequencies and repair times & dominant drift direction) – collision with Area traffic –	– Collisions (crossings, head-on & overtaking) – Groundings – Contacts with offshore objects (platforms and wind farms) – Fire explosions – Foundering – Loss of life – Damages of pipelines and cables on or in the seabed

Modules to describe / represent	Name: IWRAP Mk II Source: IALA / Gate House (DK)	Name: SAMSON Source: MARIN (NL)
		–
Analysis & Presentation of results	– Tables of risk figures per probability type for entire area – Coloured legs representing relative risk figures – User defined diagrams / Graphs for risk per ship type and encounter (ship-ship collisions for striking ships and struck ships) – Summary reports – results are stored as csv-files –	– The basic result are tables with probability type and size for a given area for each incident – During the years presentations were tailor made for studies, thus many formats of results, spreadsheets, pictures, databases exist.
Risk Modelling	– Not addressed, only probability results	– Risk modelled by costs for loss of lives, oil spill and structural damage (containing economical consequences by delay, assistance, salvage, delay, loss of income)
Risk Control options	– Indirectly addressed: 1. Probability of casualties can be investigated by changing the routes legs and distribution of traffic according to guesses for the potential changes in that traffic parameters 2. Causation factors could be adjusted for considering role of VTS and other options – to e investigated further…	– Indirectly addressed 1. Probability of casualties can be investigated by changing the routes legs and distribution of traffic according to guesses for the potential changes in that traffic parameters 2. Measures could be defined for a user defined area. For example the effect of VTS or pilots. 3. The risk reducing effect of an ETV (Emergency Towing Vessel) could be determined by defining the position and the capabilities of ETVs
Operational Risk Estimation	– Not addressed, only annual rate or other time periods for calculating probability of casualties	– On-line calculation of current risk level for given sea areas and traffic composition / distribution – Allocation of risk values (Dynamic Risk Index) to individual ships in the area – Simulation of effect of risk control options as prediction

Modules to describe / represent	Name: IWRAP Mk II Source: IALA / Gate House (DK)	Name: SAMSON Source: MARIN (NL)
		–
Purchase details	– Basic version for manual data input is free for IALA members – Commercial version available for automatic data import from AIS and other features	– Open for discussion with MARIN and the Dutch maritime authority, owner of the model.
???	–	–
	–	–

APPENDIX C QUANTITATIVE RISK ASSESSMENT: COMPARISON IWRAP WITH SAMSON

MARIN

QUANTITATIVE RISK ASSESSMENT: COMPARISON IWRAP WITH SAMSON

Final Report

Report No. : 27656-1-MSCN-rev.2
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QUANTITATIVE RISK ASSESSMENT: COMPARISON IWRAP WITH SAMSON

Ordered by

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0	Draft	May 11, 2014	C. van der Tak, MSc	
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CONTENTS

Page

1 INTRODUCTION 4

2 THE MEETING OF APRIL 11TH, 2014 AT SCHIPHOL 5
2.1 Results of the calculations that have been discussed at the meeting 5
2.2 Comparison of the results for the two areas 7
2.2.1 Results of the calculations with SAMSON 7
2.2.2 Results of the calculations with IWRAP 11
2.2.3 Comparison of the results for the northern and southern area before and after the change 12
2.3 Calculation with approximately the same database, the IWRAP database for the northern area before the route change 13
2.4 Notes of the meeting 17

3 COMPARISON OF ELEMENTARY TRAFFIC SITUATIONS 19

4 IMPACT OF THE MEAN AND STANDARD DEVATION 25
4.1 Average mean and standard deviation 25
4.2 Varying domain sizes 27
4.3 Ratio between the SAMSON and IWRAP predictions 29
4.4 Location of the collisions 32

5 CAUSATION FACTOR VERSUS CASUALTY RATE 35

6 IMPACT OF THE TAILS OF THE LATERAL DISTRIBUTION 36

7 WHY A DOMAIN DIAMETER OF ONE NAUTICAL MILE 38

8 CONCLUSIONS 43

REFERENCES 44

1 INTRODUCTION

The results of the Quantitative Risk Assessment (QRA) models IWRAP and SAMSON have been compared for a sea area NNW of IJmuiden. The results have been presented and discussed in a meeting on April 11th, 2014. The discussions have resulted in a wish for additional investigation of the differences between the models.

This document tries to summarize and explain the differences between IWRAP and SAMSON. The results discussed in the meeting and the notes of the meeting of April 11th prepared by Roger Barker and Ernst Bolt are given in Chapter 2.

It was decided that Erik Sonne Ravn would propose a number of elementary traffic situations for which the encounters and collisions would be determined. The results by IWRAP and SAMSON for these situations are presented in Chapter 3.
In Chapter 4 the observed parameters for the mean and σ are determined for the sea area NNW of IJmuiden, in order to compare these results with those of the artificial legs in Chapter 4.
Chapter 5 describes the difference between the causation factor and the casualty rate.
Chapter 6 deals the role of the tails of the lateral distribution.
Chapter 7 contains the background of the use of a circular domain with a radius of 0.5 nm.
Finally, the conclusions are presented in chapter 8.

2 THE MEETING OF APRIL 11TH, 2014 AT SCHIPHOL

2.1 Results of the calculations that have been discussed at the meeting

Two adjacent sea areas of the Netherlands were chosen for the comparison between IWRAP and SAMSON. Calculations have been made for both areas before and after the change in the route structure, which took place at August 1st, 2013. The areas are depicted in Figure 2-1 and Figure 2-2.

The northern area is much simpler than the southern one, because the latter contains the new traffic separation scheme for the approach to Amsterdam.

The objective of the calculations with both programs was to describe the collision and grounding risk and the risk of contact with offshore installations in the area.

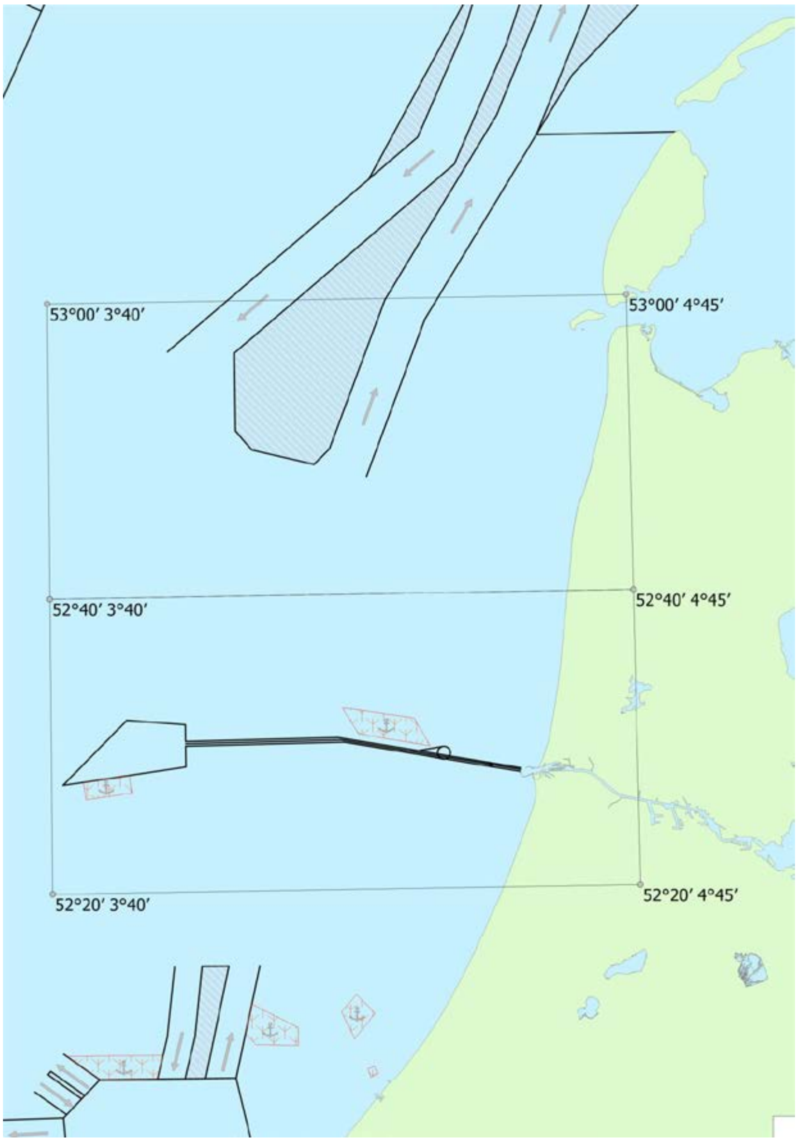

Figure 2-1 **Study areas before change in traffic separation scheme**

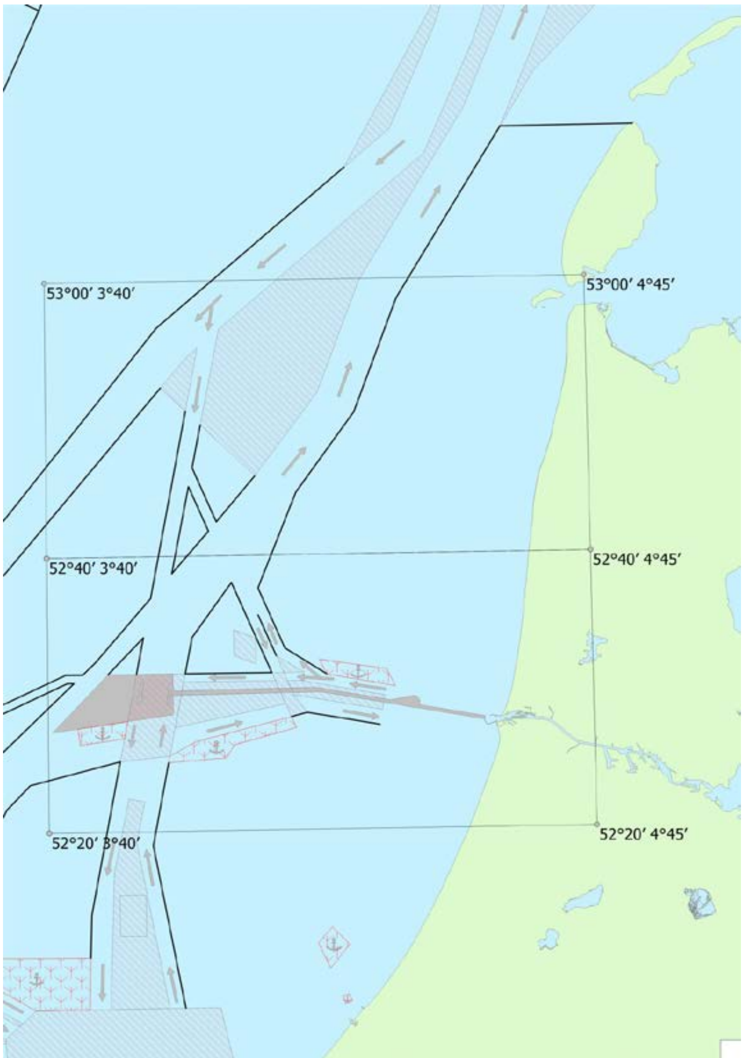

Figure 2-2 **Study areas after change in traffic separation schemes**

IWRAP has used AIS of 15-7-2012 to 15-7-2013 for the situation before August 1, 2013 and of 15-8-2013 to 15-3-2014 for the situation after. For the latter period the numbers have been multiplied with 1.75 to obtain a full year. SAMSON has used the traffic databases that are available already. They are based on the port visits in 2008 obtained from Lloyd's List Intelligence.

The objective was to calculate the number of incidents with both models and to compare them with each other. This is described in chapter 2.2. The disadvantage of such an approach is that the differences in summarized results cannot be explained. That was indeed the result of this approach, summarized in chapter 2.2.3.

Therefore, it was decided to filter out the differences by the modelling of the traffic by using the same traffic database within the calculations. The traffic database of IWRAP before August 2013 was used for this purpose in the SAMSON model. The IWRAP traffic xml-file has been delivered to MARIN. The xml-file contains the traffic and the parameters for the lateral distribution assuming a normal distribution. MARIN has converted this xml-file in a traffic database for use in the SAMSON environment. This made it possible to execute additional calculations with IWRAP and SAMSON using the same traffic database. The results are described in chapter 2.3.

2.2 Comparison of the results for the two areas

2.2.1 Results of the calculations with SAMSON

The traffic database of SAMSON used for the calculations before the change on August 1st, 2013 is presented in Figure 2-3 and for the period thereafter in Figure 2-4. The figures show that the traffic after the change in route structure is more concentrated in one-way traffic lanes.

Figure 2-3 Traffic of 2008 on route structure before August 2013

Figure 2-4 Traffic of 2008 on route structure after August 2013

Table 4-1 contains the main results of the calculations with SAMSON for both databases in both areas.

Table 2-1 Results of the calculations with SAMSON

	Unit	before North	after North	before South	after South
Average number of ships in the area					
OBO's	Ships	0.010	0.010	0.028	0.026
Chemical tankers	Ships	0.701	0.700	1.320	1.349
Oil tankers	ships	0.158	0.155	0.377	0.376
Gas tankers	ships	0.219	0.249	0.263	0.212
Bulkers	ships	0.854	0.847	0.842	0.814
Unitised	ships	2.523	2.633	2.431	2.022
General Dry Cargo	ships	5.066	5.193	4.909	4.652
Passengers + conv, ferries	ships	0.103	0.163	0.193	0.160
High Speed Ferries	ships	0.000	0.000	0.000	0.000
Other	ships	0.398	0.347	0.605	0.657
Total Route-bound	ships	10.032	10.297	10.968	10.268
Total Non-route-bound	ships	5.463	5.463	14.406	14.406
Safety					
Ships involved in collisions		0.373	0.347	0.839	0.862
Stranding after navigat, failure	ships/year	0.000	0.000	0.024	0.008
Stranding after technical failure	ships/year	0.000	0.000	0.000	0.000
Ramming against platform	ships/year	0.040	0.042	0.032	0.026
Drifting against platform	ships/year	0.005	0.005	0.002	0.002
Ramming against ship at anchor	ships/year	0.000	0.000	0.162	0.086
Drifting against ship at anchor	ships/year	0.000	0.000	0.002	0.001
Foundering	ships/year	0.065	0.065	0.094	0.093
Hull Failure	ships/year	0.062	0.063	0.087	0.085
Fire/ Explosion	ships/year	0.127	0.129	0.176	0.169
Total	ships/year	0.672	0.652	1.418	1.331
Economy					
Shipping costs, fixed + fuel	M€ / year	81	85	90	81
Ship miles	Mnm/year	1.138	1.173	1.231	1.134
Emissions					
KW used	GWh	572	590	588	522
CO2	kton / year	282	290	291	258
CO	kton / year	1.091	1.119	1.119	0.994
SO2	kton / year	2.890	2.965	2.971	2.632
NOx	kton / year	7.347	7.520	7.504	6.652
Oil					
Shipping accidents	probability/yr	0.3857	0.3683	0.7073	0.7200
Chem+olie tankers in accidents	probability/yr	0.0447	0.0374	0.1597	0.1704
Oil tanker in accidents	probability/yr	0.0091	0.0069	0.0407	0.0405
Oil spills	probability/yr	0.0014	0.0011	0.0064	0.0066
Oil spill more than 10000 m3	probability/yr	0.0000	0.0000	0.0008	0.0008
Oil spill more than 30000 m3	probability/yr	0.0000	0.0000	0.0003	0.0003
Oil spill more than 100000 m3	probability/yr	0.0000	0.0000	0.0001	0.0000
Oil spilt	m3 / year	3.264	1.772	41.906	35.747
Chemical spills after collision					
Very Large Ecological Risk	probability/yr	0.0002	0.0001	0.0007	0.0005
Large Ecological Risk	probability/yr	0.0000	0.0000	0.0001	0.0001
Medium Ecological Risk	probability/yr	0.0001	0.0001	0.0004	0.0005
Low Ecological Risk	probability/yr	0.0003	0.0002	0.0008	0.0007
Negligible Ecological Risk	probability/yr	0.0004	0.0004	0.0015	0.0020
Costs collisions and foundering					
Repairing	M€ /year	0.017	0.013	0.063	0.067
Salavage	M€ /year	0.009	0.007	0.031	0.033
Cleaning and environment,costs	M€ /year	0.015	0.006	0.170	0.131
Costs of delay	M€ /year	0.006	0.006	0.013	0.016
Loss of income	M€ /year	0.029	0.026	0.083	0.093
Willingness to pay for deaths	M€ /year	0.084	0.119	0.198	0.177
Ship+cargo when sinking	M€ /year	0.527	0.538	0.534	0.502
Total	M€ /year	0.686	0.714	1.093	1.019

The overall impact of the change in the route structure is presented in Table 2-2. The number of overtaking collision has increased because the traffic is more concentrated in a smaller number of routes. The number of head-on collisions in the southern area has decreased by the new traffic separation scheme in the approach to IJmuiden/Amsterdam. The number of crossings has increased in the southern area because ships have to follow the new TSS which delivers extra crossing encounters when entering or leaving the TSS. In total, there is a slight increase in the number of calculated collisions by the change in route structure. However, the change in route structure was initiated to make room for future wind farms, not to decrease the number of collisions.

Table 2-2 Expected number of ships involved in collisions by SAMSON for the two areas before and after the change of the route structure

Type of collision	Area North			Area South			Total area change in %
	before	after	change in %	before	after	change in %	
head-on	0.0002	0.0006	161.3%	0.0808	0.0152	-81.2%	-80.6%
overtaking	0.0571	0.0715	25.1%	0.0196	0.0451	129.7%	51.8%
crossing	0.0471	0.0149	-68.3%	0.2023	0.2964	46.5%	24.8%
total	0.1044	0.0869	-16.8%	0.3027	0.3566	17.8%	9.0%

Figure 2-5 shows the two wind farms in the southern area for which the probability of collision with a wind turbine has been calculated with the SAMSON model. The probabilities before the route change are given in Table 2-3 and after the route change in Table 2-4. Table 2-5 shows the changes in percentages. The probability of hitting by a non-route-bound (fishing, supply, work and recreation vessels) is not changed because the sailing behaviour of these ships is not affected by the route change.

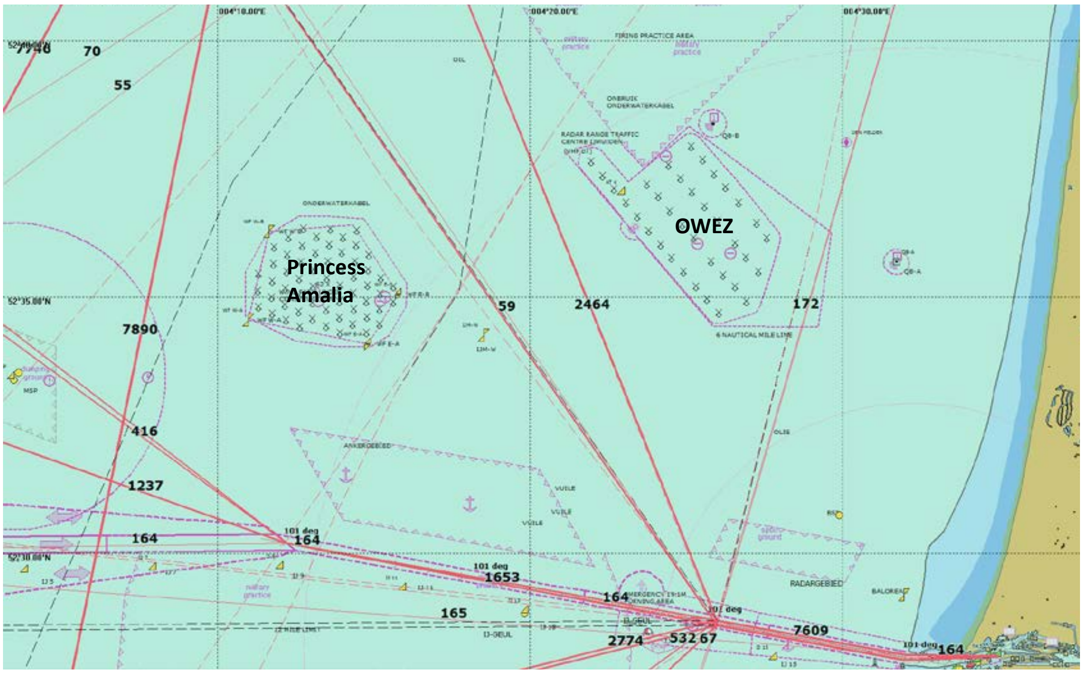

Figure 2-5 Wind farms OWEZ and Princess Amalia with traffic database before

Table 2-3 Expected number of ships hitting the wind turbines of the two wind farms by SAMSON before the change of the route structure

Wind farm	Number of wind turbines	Probability per year				
		Ramming		drifting		Total
		R-ships	N-ships	R-ships	N-ships	
OWEZ	36	0.0019	0.0060	0.0085	0.0039	0.0203
Princess Amalia	60	0.0048	0.0108	0.0224	0.0044	0.0425
Grand Total	96	0.0067	0.0169	0.0309	0.0083	0.0627
Is once in .. years		150	59	32	120	16

Table 2-4 Expected number of ships hitting the wind turbines of the two wind farms by SAMSON after the change of the route structure

Wind farm	Number of wind turbines	Probability per year				
		ramming		drifting		Total
		R-ships	N-ships	R-ships	N-ships	
OWEZ	36	0.0000	0.0060	0.0066	0.0039	0.0165
Princess Amalia	60	0.0007	0.0108	0.0191	0.0044	0.0351
Grand Total	96	0.0007	0.0169	0.0257	0.0083	0.0516
Is once in .. years		1455	59	39	120	19

Table 2-5 Change in number of ships hitting in the wind turbines of the two wind farms calculated with SAMSON by the change of the route structure,

Wind farm	Number of wind turbines	Probability per year				
		ramming		drifting		Total
		R-ships	N-ships	R-ships	N-ships	
OWEZ	36	-98.9%	0.0%	-22.6%	0.0%	-18.5%
Princess Amalia	60	-86.1%	0.0%	-14.5%	0.0%	-17.4%
Grand Total	96	-89.7%	0.0%	-16.7%	0.0%	-17.7%

Table 2-6 Expected number <u>R-ships</u> hitting in the wind turbines of the two wind farms by SAMSON after the change of the route structure

Southern area	Number of wind turbines	Probability per year for R-ships		
		before	after	change in %
Powered	96	0.0067	0.0066	-90%
Drift	96	0.0309	0.0191	-17%
Total	96	0.0376	0.0257	-30%

2.2.2 Results of the calculations with IWRAP

The results for the collision probabilities of IWRAP are summarized in Table 2-7 and Table 2-8.

Table 2-7 Expected <u>number of collisions</u> by IWRAP for the two areas before and after the change of the route structure

Type of collision	Area North			Area South			Total area change in %
	before	After	change in %	before	after	change in %	
head-on	0.0007	0.0002	-70%	0.0155	0.0209	35%	30%
overtaking	0.0121	0.0157	30%	0.0107	0.0117	9%	20%
crossing	0.0172	0.0039	-77%	0.0248	0.0140	-44%	-57%
total	0.0299	0.0198	-34%	0.0511	0.0466	-9%	-18%

The collision risk for the two wind farms is given in Table 2-8.

Table 2-8 Expected number ships hitting in the wind turbines of the two wind farms by IWRAP after the change of the route structure

Southern area	Number of wind turbines	Probability per year for R-ships		
		before	after	change in %
Powered	96	0.0001	0.0006	336%
Drift	96	0.0006	0.0013	125%
Total	96	0.0007	0.0018	165%

2.2.3 Comparison of the results for the northern and southern area before and after the change

When comparing the calculated results of IWRAP and SAMSON one has to keep in mind that in SAMSON always the number of ships involved in a collision is used, while in IWRAP the number of collision is used. Because in nearly all cases two ships are involved in a collision the “ships involved in a collision” of SAMSON has to be divided by 2 to get the number of collisions.
In Table 2-9 the expected collisions by SAMSON are divided by those of IWRAP.

Table 2-9 Expected number of collisions by SAMSON divided by that of IWRAP for both areas and before and after the route change

Type of collision	SAMSON (= Table 2-2/2) / IWRAP(= Table 2-7)			
	Area North		Area South	
	before	after	before	After
head-on	0.15	1.39	2.61	0.36
overtaking	2.36	2.28	0.92	1.93
crossing	1.37	1.91	4.08	10.58
total	1.75	2.20	2.96	3.83

In fact the number of collisions cannot be compared for each collision type as is done in Table 2-9 because in IWRAP overtaking collisions are only counted between ships sailing in the same direction on the same leg and head-on collisions are only counted for ships sailing in the opposite direction on the same leg, while in SAMSON an absolute course difference of 60° is used for overtaking collisions and 150° to 180° for head-on collisions. These collisions can also be calculated between different legs.

The collisions with the wind farms are divided on each other in Table 2-10.

Table 2-10 Expected number R-ships hitting in the wind turbines by SAMSON divided by that of IWRAP before and after the route change

Southern area	Number of wind turbines	SAMSON (= Table 2-6) / IWRAP(= Table 2-8)	
		before	after
Powered	96	67	1
Drift	96	52	20
Total	96	54	15

At this moment the large difference in probability of colliding a wind turbine of a wind farm is not analyzed in depth. The reason is that the models of IWRAP and SAMSON for this type of incident are completely different. An extensive comparison is necessary in a later stage.

The difference in the number of collisions between ships is mainly caused by differences in:

- Model for describing the traffic within the area;
- The models for the prediction of the number of collisions based on the traffic modelled;
- The difference in the use of the causation factor versus the casualty rate.

These aspects are further investigated. In order to exclude the difference by traffic modelling as much as possible, the comparison is redone for the IWRAP traffic database for the northern area before the route change that is converted to a SAMSON traffic database. The results are described in chapter 2.3.

2.3 Calculation with approximately the same database, the IWRAP database for the northern area before the route change

The traffic database for the northern area before the route change is presented in Figure 2-6. Figure 2-7 shows the traffic database composed from the xml-file that describes the traffic movements for this case in IWRAP. The same traffic links (legs in IWRAP) have been used. Each ship movement on a leg in IWRAP given by a ship type and a range in length is put in a SAMSON ship type and size class. The mean and standard deviation based on a normal distribution on each leg of IWRAP is used in SAMSON. By following this approach, the IWRAP database that is imported in SAMSON fits quite well with the original IWRAP traffic database. However, a comparison between Figure 2-6 (SAMSON) and Figure 2-7 (for use in SAMSON but generated by IWRAP) shows considerable differences in the number of movements per year. The SAMSON database of Figure 2-6 has much more traffic through the Texel TSS than IWRAP. Further, the number of movements in the most northern part of the north going lane is with 13777 much lower than the total of 20100 (=18859+1241) of the preceding legs. The differences with the SAMSON database are large.

The large difference is investigated by determining the number of movements through different areas from AIS data. The IWRAP database in this area is based on the AIS position data each 6 minutes stored on the North Sea server. MARIN doesn't have this data, but receives all AIS data sent by the ships in this area from the Netherlands Coastguard. The number of movements are indicated with the blue lines and numbers in Figure 2-7. It shows that 22669 ships follow the north going traffic lane of the Texel-TSS, thus much more than the 13777 in the most northern leg and much a little more than the 20100 for the southern part in the lane.

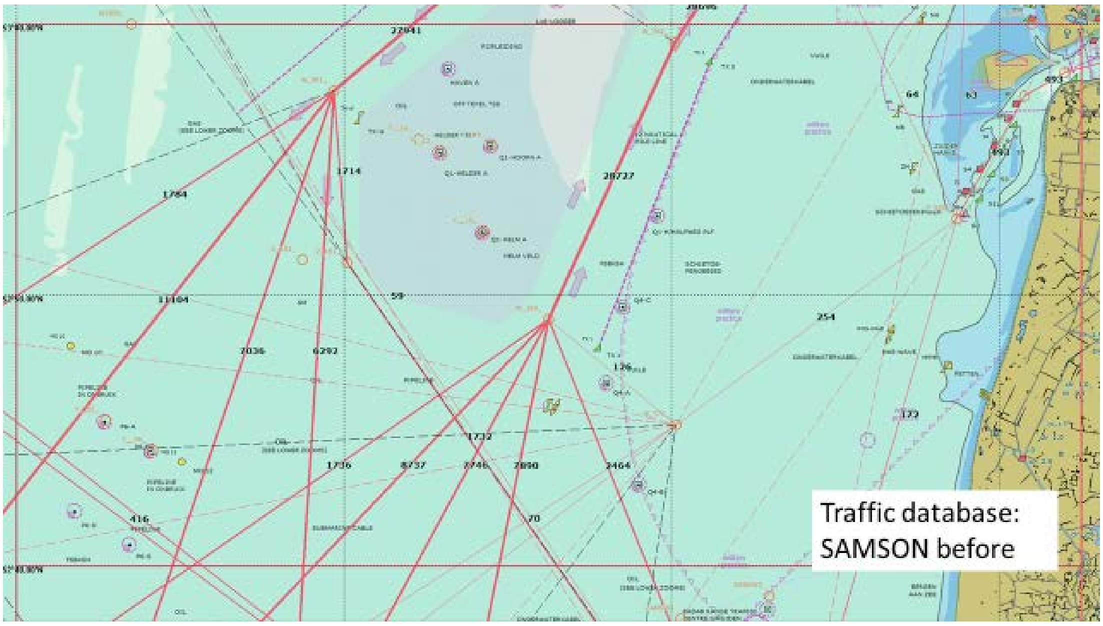

Figure 2-6 Traffic database of 2008 of SAMSON

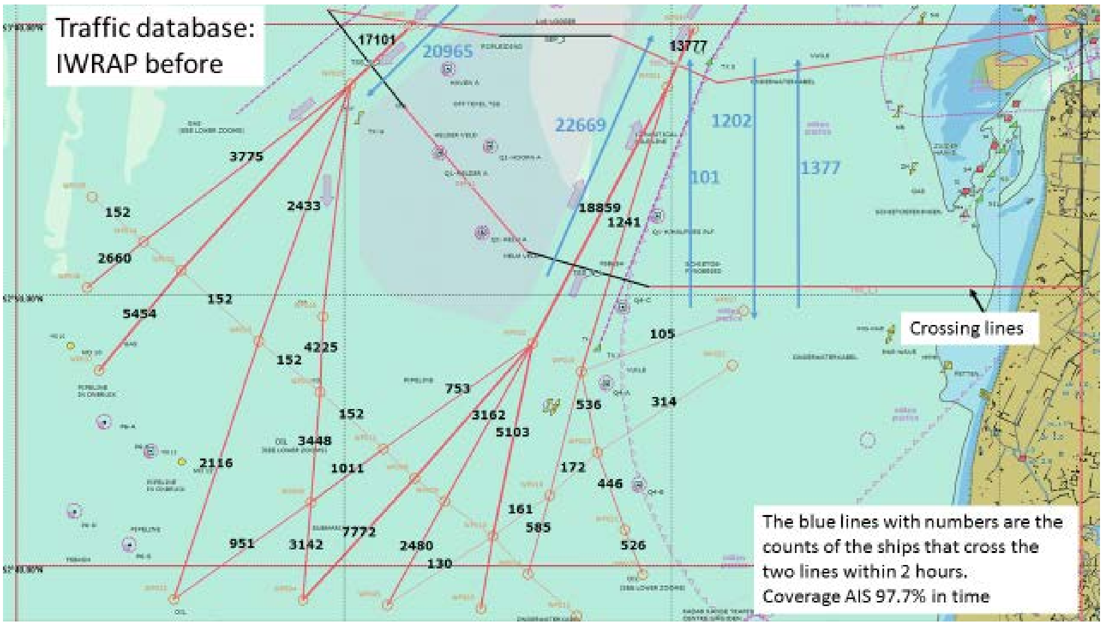

Figure 2-7 Traffic database of IWRAP with in blue movements counted from AIS data

Figure 2-8 shows the result when the AIS data available at MARIN is assigned to the legs of the IWRAP database. Within this assignment the same limits for the deviation of the leg centerline and the deviation in course have been used as defined in the xml-file of IWRAP. This assignment results in the database presented in Figure 2-8. Comparing Figure 2-8 with Figure 2-7 shows that by the assignment procedure of MARIN, more traffic has been assigned to the route.

Further, the number of vessels in the opposite direction is much lower by using the MARIN procedure. Because the number of collisions is roughly the square of the number of movements, the collision prediction by IWRAP will be lower than by SAMSON (with the SAMSON database). Further, the number of ship movements against the main direction is counted in IWRAP, while in SAMSON an ideal route structure is assumed without rogues in the TSS lanes. In reality, there are some rogues during short time but with a frequency much lower than counted by IWRAP. This will deliver too much head-on collisions in IWRAP.

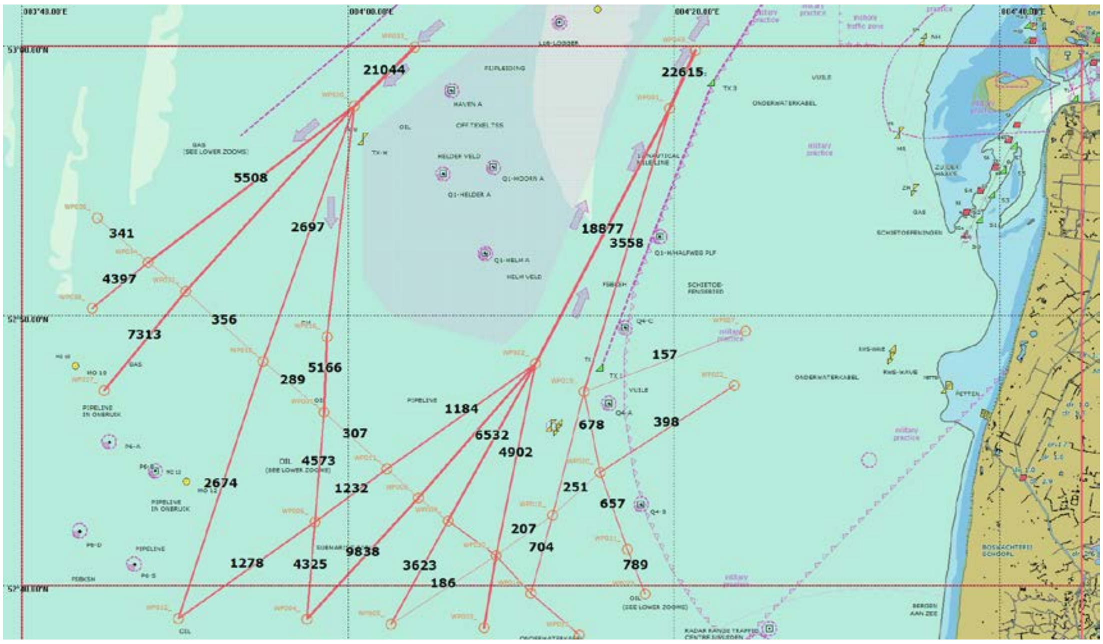

Figure 2-8 AIS data assigned to the route structure of IWRAP

Table 2-11 contains the expected collisions for approximately the same database, calculated with respectively the SAMSON and IWRAP models. These values are much smaller than the expected collisions for north before the route change based on the SAMSON database in Table 2-2. The reason is that the SAMSON traffic database has more movements over the links. The average number of ships in the area based on the SAMSON model is 10.0 while this is 6.85 based on the IWRAP database. Because the number of collisions has a quadratic relationship with the number of ships, this means that the collision level with the SAMSON database (Table 2-2) is about 2.1 times higher than with the IWRAP database in Table 2-11. Further, the SAMSON database (Figure 2-6) contains more crossing links than the IWRAP database (Figure 2-7), which gives in relatively more crossing collisions.

Table 2-11 Expected number of collisions per year for the IWRAP database for the northern area before the route change

Type of collision	traffic database IWRAP before calculated with the models of SAMSON and IWRAP		
	IWRAP database with SAMSON	IWRAP	SAMSON / IWRAP
head-on	0.0015	0.0007	2.20
overtaking	0.0221	0.0121	1.82
crossing	0.0075	0.0172	0.44
total	0.0311	0.0299	1.04

The factor SAMSON divided by IWRAP for head on and overtaking (see Table 2-11) are now much closer to 1.0 than in Table 2-9 for the Northern area before the route change. The factors for head-on and overtaking are larger than 1.0 and for crossing smaller than 1.0. This was expected because collisions that are classified as crossings in IWRAP are classified as head-on or overtaking collisions in SAMSON.

The conclusion is:

- The modelling of the traffic is the main source for the differences in the expected number of collisions.
- For approximately the same database, the total expected number of collisions calculated with SAMSON and IWRAP corresponds quit well, but the distribution over the different type of collisions is different;
- The assignment method of AIS data to a route structure needs to be investigated;

The difference in the collision models is further analyzed and discussed in next meetings.

2.4 Notes of the meeting

The meeting of April 11th, 2014 was held at Schiphol

Attendees: Knud Benedict
Roger Barker
Trond Langemeyr
Erik Sonne Ravn
Ernst Bolt
Jos van Doorn
Anke Cotteleer
Kees van der Tak
Absent: Omar Frits Eriksson

The notes of the meeting prepared by Roger Barker and Ernst Bolt are:

Marin

- Explanation of vessel traffic figures from 2008
- Then comparison with IWRAP data,
- Results from Samson
- Differences in the traffic database explored
  - Traffic numbers – AIS or voyage data
    Different ways to use AIS records: assign to leg when (one or more?) crossing lines are intersected vs mapping every AIS record to a small portion of a leg
- Encounters
  - For comparison domain assessment needs to be the same
- Probability of accident – casualty rate or causation factor
- Discussion about the difference in assessment of the angle of interaction of traffic on a leg, between Samson and IWRAP
  - Encounter between routes handled by Samson
  - Overtaking and crossing assessment use different angles
    As in SAMSON the interaction is not bound to legs or nodes, vessels on different legs may either be classified as crossing or overtaking. [Note: if IWRAP is adapted to 'unbound interaction' a similar way to distinguish overtaking and crossing encounters may be needed.]
- Actual wind farm incidents compared

IWRAP

- Assignment of the legs can make significant difference to the results
  - Erik will ask Per to make the calculation of encounters independent of the legs.
- Distribution curves and different types discussed comparison. IWRAP using both normal and complicated curves to fit density function on AIS data
  - Samson uses normal distribution which is adjusted to maintain desired distance to wind farms. The calculation of encounters is however less sensitive to this distribution due to the underlying model to evaluate the *exposure*..

<u>Simple Sample</u>

- 1000 tankers both directions
- 1000 tankers + 1000 container ships both directions
    - Significant difference in the results
- Sensitivity to lateral distribution is apparent. An ‘encounter’ for SAMSON is that two ships are within .5nm from each other (and thus would have an opportunity to hit each other when something goes wrong), whereas for IWRAP it is the case that two ships would collide if they didn’t start an collision avoidance manoeuvre.

<u>comparison</u>

- Size of Domain / definition of Encounter
- Cr or Cf that is use of causation factor by IWRAP or Casualty rate by Samson
- Traffic data

Conclusion on collision and grounding risk

- Try to identify where the differences in results arise
- Use simple legs again with:
    - Crossing
    - Overtaking
    - Change standard deviation
    - Address the domain issue

What is our goal?

- That both models produce the same risk for the same situation (or that the difference is explainable)
- That both models indicate the same change in risk as a result of changes in the situation
- It is desirable to have a tool that is not very sensitive to input parameters with a very uncertain value. On the other hand it should respond in a plausible (expert opinion? AIS data analysis? Near-miss reports?) manner to changes in those parameters.
- If there are large differences it might be impossible to decide which result is closest to reality.

Consequence module?

- First see that Samson consequence part can be separated, then specify its input requirements
- Technical possibilities for output from IWRAP (more data may need to be stored)
- Modular approach may be preferred.

Erik has recorded items to take forward to Per at Gatehouse on IWRAP considerations

3 COMPARISON OF ELEMENTARY TRAFFIC SITUATIONS

The elementary traffic situations for comparison have been proposed by Erik Sonne Ravn. Figure 3-1 shows the layout for the leg with mean = ±300m and σ = 200 m.

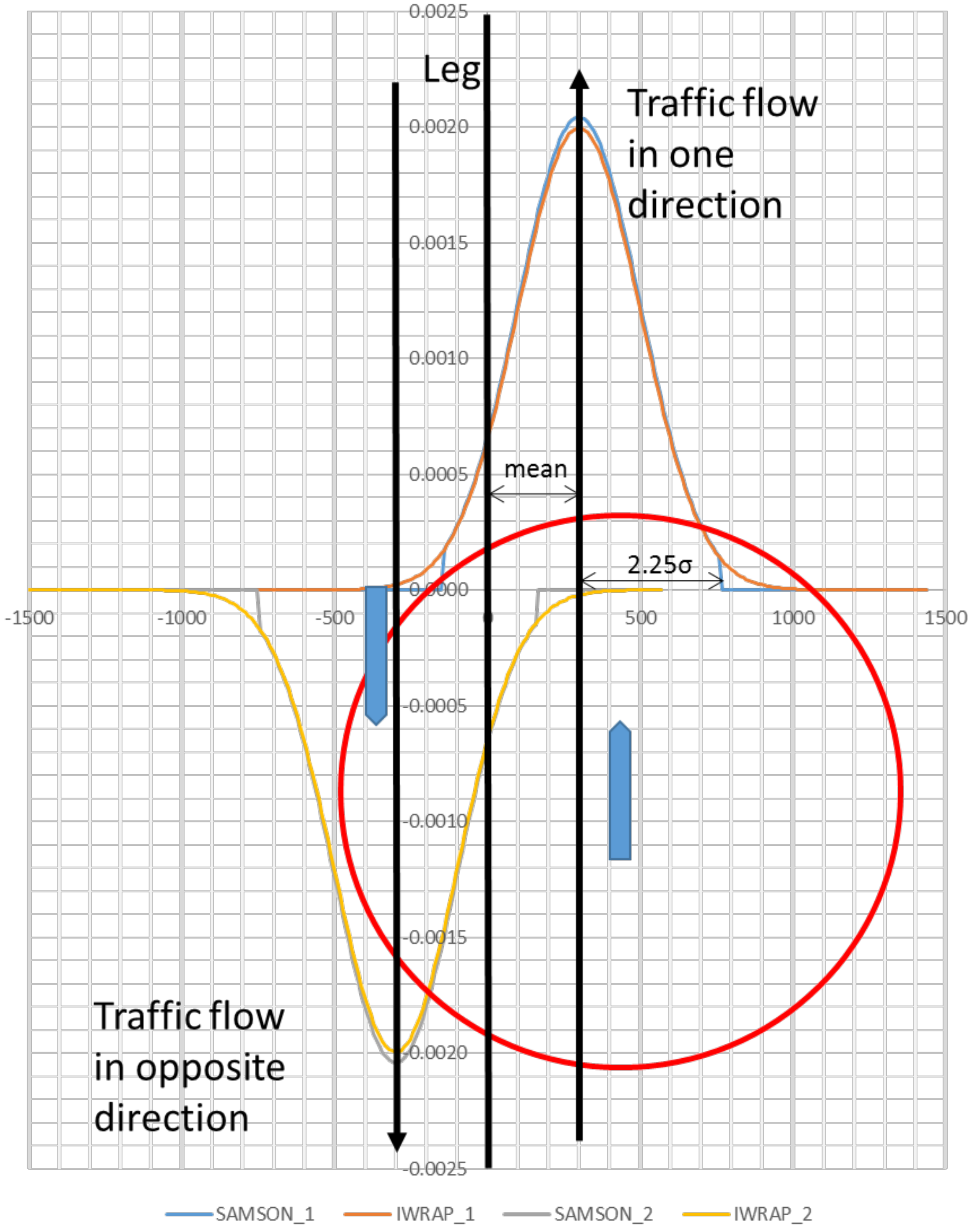

Figure 3-1 Elementary traffic situation

The normal distributions are shown. In SAMSON, the distribution is cut off at 2.25σ. Therefore, the other values are enlarged to get an overall probability of 1. Two tankers of 35m width are drawn and a ship domain with 1 nm used by SAMSON is plotted for one tanker. The figure makes clear that in this case in SAMSON nearly all ships sailing

in the opposite direction are met and counted as a potentially dangerous situation. In IWRAP the collision-candidates are the ships that will hit each other when both ships keep course. The number of expected collisions follows in SAMSON by multiplying the potentially dangerous situations with the CASRAT and in IWRAP by multiplying the collision-candidates with the causation factor. The difference in expected collisions is compared for a number of elementary traffic scenarios.
The number of collision-candidates or potentially dangerous situation is the product of:

- a factor depending on the lateral distribution;
- the speeds and dimensions of the ships;
- the number of ships on the links;
- the length of the links.

The factor due to the lateral distribution is independent on the other factors. This factor depends only on the lateral distributions of the two flows and the geometric width in IWRAP and the domain size in SAMSON. The ratio between this factor in SAMSON and IWRAP is not constant but depends on the mean and standard deviation of the two traffic flows. The change in this factor is the cause that the difference between the results of IWRAP and SAMSON varies. This ratio has been determined for a number of elementary traffic situations.

Head-on collisions
1000 tankers in each direction
Ship length=200m. Width=35m. Speed=15 knots

Table 3-1 Head-on collisions as the leg length changes

Leg length [m]	Normal distribution		IWRAP geometric width 70m			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	σ [m]	collision candi- dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
500	0	100	0.80	5.2E-05	4.20E-05	4.20	8.4E-06	3.53E-05	0.8
1000	0	100	1.61	5.2E-05	8.30E-05	8.40	8.4E-06	7.06E-05	0.9
5000	0	100	8.03	5.1E-05	4.12E-04	41.99	8.4E-06	3.53E-04	0.9
10000	0	100	16.06	5.1E-05	8.25E-04	83.99	8.4E-06	7.06E-04	0.9

Table 3-2 Head-on collisions as the standard deviation changes

Leg length [m]	Normal distribution		IWRAP geometric width 70m			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	σ [m]	collision candi- dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
10000	±300	100	0.00	4.7E-05	1.00E-07	83.34	8.4E-06	7.00E-04	7000.7
10000	±300	200	0.86	5.1E-05	4.40E-05	74.18	8.4E-06	6.23E-04	14.2
10000	±300	500	2.26	5.1E-05	1.16E-04	56.40	8.4E-06	4.74E-04	4.1
10000	±300	1000	1.48	5.1E-05	7.60E-05	38.76	8.4E-06	3.26E-04	4.3

Table 3-3 Head-on collisions as the mean changes (traffic separates)

Leg length [m]	Normal distribution		IWRAP geometric width 70m			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
10000	0	500	3.25	5.1E-05	1.67E-04	69.34	8.4E-06	5.82E-04	3.5
10000	±100	500	3.12	5.1E-05	1.60E-04	67.80	8.4E-06	5.69E-04	3.6
10000	±200	500	2.77	5.1E-05	1.42E-04	63.32	8.4E-06	5.32E-04	3.7
10000	±500	500	1.19	5.1E-05	6.10E-05	38.34	8.4E-06	3.22E-04	5.3
10000	±1000	500	0.06	5.1E-05	3.00E-06	4.74	8.4E-06	3.98E-05	13.3

The columns marked yellow have been the results of IWRAP provided by Erik Sonne Ravn. The collision-candidates and potentially dangerous situations have been calculated by MARIN and put in the tables. The causation factor used by IWRAP is determined by dividing the collisions by the encounters. In any case it has resulted in a constant causation factor which is in line with the published one in wiki/IWRAP.
The collisions in Table 3-1 are linear with the length of the leg, thus resulting in a fixed factor between SAMSON and IWRAP. The high SAMSON/IWRAP factor in the first row of Table 3-2 is caused by the large domain of SAMSON resulting in encounters in SAMSON. Encounters are counted in an area where ships that sail on the same lateral position in opposite direction (hard encounters) are negligible. The same occurs in the scenario of the last row of Table 3-3, where the distance between the two center lines is 4σ. Compared with the number of “collision-candidates” calculated by IWRAP, SAMSON calculates relatively many “potentially dangerous situations”. Chapter 4 (see Table 4-4) explains that this is due to the domain size that is used by SAMSON.

Overtaking collisions
1000 tankers. Length=200 m. Width=35 m. Speed=15 knots
1000 container ships. Length=200 m. Width=30 m. Speed=21 knots

Table 3-4 Overtaking collisions as the leg length changes

Leg length [m]	Normal distribution		IWRAP geometric width 65m			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
500	0	100	0.11	1.2E-04	1.30E-05	0.60	2.6E-06	1.56E-06	0.1
1000	0	100	0.21	1.2E-04	2.60E-05	1.20	2.6E-06	3.12E-06	0.1
5000	0	100	1.07	1.2E-04	1.29E-04	6.00	2.6E-06	1.56E-05	0.1
10000	0	100	2.13	1.2E-04	2.57E-04	12.00	2.6E-06	3.12E-05	0.1

Table 3-5 Overtaking collisions as the standard deviation changes

Leg length [m]	Normal distribution		IWRAP geometric width 65m			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
10000	±300	100	0.00	1.5E-04	4.00E-08	11.91	2.6E-06	3.10E-05	773.9
10000	±300	200	0.11	1.2E-04	1.40E-05	10.60	2.6E-06	2.76E-05	2.0
10000	±300	500	0.30	1.2E-04	3.60E-05	8.06	2.6E-06	2.09E-05	0.6
10000	±300	1000	0.20	1.2E-04	2.40E-05	5.54	2.6E-06	1.44E-05	0.6
10000	±300	2000	0.11	1.2E-04	1.30E-05	3.10	2.6E-06	8.06E-06	0.6

Table 3-6 Overtaking collisions as the mean changes (traffic separates)

Leg length [m]	Normal distribution		IWRAP geometric width 65m			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
10000	0	500	0.43	1.2E-04	5.17E-05	9.91	2.6E-06	2.58E-05	0.5
10000	±100	500	0.41	1.2E-04	4.96E-05	9.69	2.6E-06	2.52E-05	0.5
10000	±200	500	0.37	1.2E-04	4.40E-05	9.05	2.6E-06	2.35E-05	0.5
10000	±500	500	0.16	1.2E-04	1.90E-05	5.48	2.6E-06	1.42E-05	0.7
10000	±1000	500	0.01	1.2E-04	9.45E-07	0.68	2.6E-06	1.76E-06	1.8

The collisions in Table 3-4 are linear with the length of the leg, thus resulting in a fixed factor between SAMSON and IWRAP. For the same reason as for head-on, the SAMSON/IWRAP factor in the first row of Table 3-5 is very large. In fact, there is only a negligible number of collision-candidates. For a standard deviation of 500m and higher, the factor is constant.
MARIN has added Table 3-6 in order to present the same cases as for head-on. MARIN has determined the results for IWRAP. Therefore, the column with the collisions is not marked yellow.

Crossing collisions at different angles
1000 tankers. Length=200 m. Width=35 m. Speed=15 knots
1000 tankers. Length=200 m. Width=35 m. Speed=15 knots

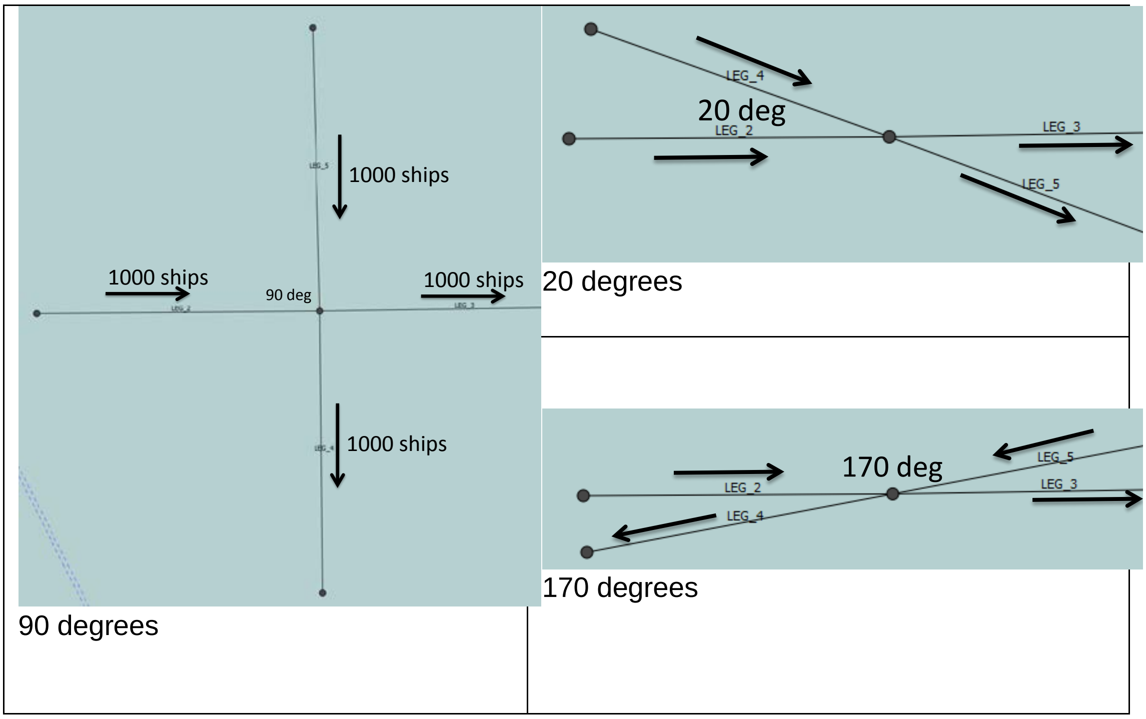

Figure 3-2 Definition of crossing angle

The total number of encounters for crossing flows is not dependent on the lateral distributions. The reason is that each ship can collide each other ship that crosses the leg. Only the location of the encounter point depends on the lateral distribution. Therefore Table 3-7 is the same for each value of mean and σ.

Table 3-7 Crossing collisions with fixed causation factor from wiki/IWRAP

Angle between legs [°]	**Normal distribution**		IWRAP geometric width depends on ship lengths, speeds and crossing angle			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	**σ [m]**	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT dependent on angle	collisions per year	
10			1.67	1.29E-04	2.15E-04	7.6	3.6E-06	2.74E-05	0.13
20			1.69	1.29E-04	2.19E-04	7.7	3.6E-06	2.77E-05	0.13
45			1.76	1.29E-04	2.27E-04	8.2	2.7E-05	2.26E-04	0.99
90			1.93	1.29E-04	2.49E-04	10.8	2.7E-05	2.95E-04	1.18
135			2.34	1.29E-04	3.02E-04	19.9	2.7E-05	5.45E-04	1.81
170			4.93	1.29E-04	6.36E-04	87.3	8.4E-06	7.33E-04	1.15

In SAMSON the crossing encounter calculation for angles less than 30° is replaced by an overtaking calculation and the situation with a crossing angle above 150° is replaced by a head-on calculation. The reason was that the crossing meeting area is spread over more than one grid cell. The encounter result is calculated per grid cell, thus, also in grid cells where the crossing between the centre lines does not take place, but in which the meeting area is partly located.

Table 3-7 shows the results of the calculations. MARIN has calculated again the number of encounters for IWRAP. Table 3-7 contains the expected collisions per year when the causation factor 1.29E-4 (from the wiki/IWRAP site) for crossing has applied to the encounters calculated by MARIN. The CASRAT used by SAMSON is not the same over all angles. For crossings <30° the CASRAT for overtaking is used and for crossings between 150° and 180° the head-on CASRAT is used.

The factor SAMSON/IWRAP is not constant. One reason is that the geometric width of IWRAP, calculated from the dimensions of the ships decreases with collision angles while this collision diameter is constant (1 nautical mile) in SAMSON. In Chapter 7 the use of a collision diameter of 1 nautical mile used by SAMSON is further explained.

4 IMPACT OF THE MEAN AND STANDARD DEVATION

4.1 Average mean and standard deviation

The main difference between IWRAP and SAMSON is due to the domain size of SAMSON which is much larger than the geometric width in IWRAP. Table 3-2 and Table 3-5 show that the SAMSON/IWRAP factor decreases from a very large value for a standard deviation of 100m to a more or less constant value for a standard deviation of 500m. This is because the domain diameter of 1 nm related to a standard deviation of 100m means that all other ships are met in SAMSON while this is not the case in IWRAP. At sea a standard deviation of 100m is not realistic. Such a standard deviation will only occur in restricted waters, for example when passing the bridge crossing the Great Belt. The range of the standard deviation and the distance between the two sailing directions at sea is further investigated.

Hereto, the traffic database of IWRAP for area North before the changes in the routes of August 2013 provided for the meeting of April 11th has been used. For each leg the mean and standard deviation factor has been determined. The average distance between the two directions belonging to one leg is put in classes of 0.1 nm width. The same is done with the standard deviation for one direction of the traffic on that link. The number of ships in that direction multiplied with the length of the leg is assigned to the belonging mean and standard deviation class. The result for the whole IWRAP traffic database North before, is presented in Table 4-1.

Table 4-1 Ship miles of traffic database in area North before the changes in the route structure of August 2013, summarized per mean and standard deviation classes of 0.1 nm width

		Standard deviation in classes of 0.1 nm width (next row)											Grand Total
Average distance between the two flows in [m] ->		93	278	463	648	833	1019	1204	1389	1574	1759	1945	
Distance between the two flows in class [0.1 nm] ->		0	1	2	3	4	5	6	7	8	9	10	
[m]	class												
648	3				37,048							167	37,215
833	4	60	285		34,684	425						452	35,906
1019	5			3,015			47,510		348				50,874
1204	6			54	5,070								5,124
1389	7		2,670		36,065	36,383	80						75,199
1574	8			1,634	25,925	111	187						27,856
1759	9					35,141	416						35,557
1945	10			21,245	11,847	14,478	1,218	131	332				49,251
2130	11				41,101	203,454	1,516	1,928	1,339				249,338
2315	12					57,924	63,828	55,223	1,498				178,473
2500	13						407		388				795
2685	14						32,211	1,864		1,507	112		35,694
Grand Total		**60**	**2,956**	**25,948**	**191,740**	**347,915**	**147,373**	**59,145**	**3,906**	**1,507**	**112**	**619**	**781,282**

The table shows that the most ship-miles (203,405) are produced in mean class 11 and standard deviation class 4. When these values are transformed in de parameters of the elementary situation, this means that the mean=±1065 (=2130 of Table 4-1 /2) and σ=833m. This is mostly outside the range that is calculated through in the previous chapter.

The overall average parameters can be calculated with the values of Table 4-1. This delivers mean=±935m and σ=842m. The layout with these parameters is presented in Figure 4-1.

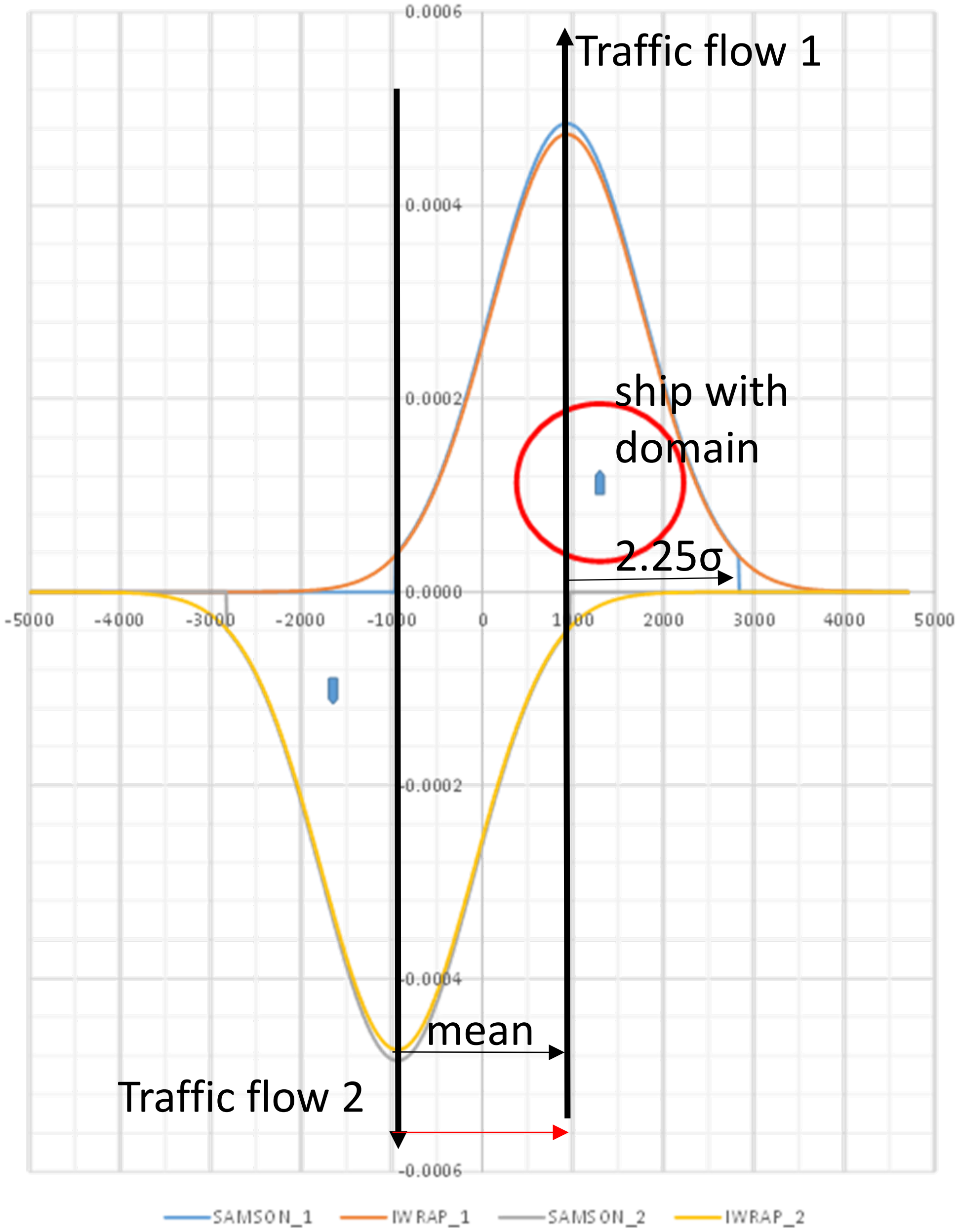

Figure 4-1 Elementary traffic situation for the average mean and standard deviation in the area

Table 3-1 and Table 3-4 were based on a standard deviation of 100m. This value is much too small for a traffic situations at sea. Therefore the tables are recalculated for a standard deviation of 850m, which delivers Table 4-2 and Table 4-3.

Table 4-2 Head-on collisions as the leg length changes

Leg length [m]	Normal distribution		IWRAP geometric width 70m			SAMSON domain diameter 1nm			SAMSON/ IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
500	0	850	0.095	5.10E-05	4.87E-06	2.35	8.40E-06	1.97E-05	4.0
1000	0	850	0.191	5.10E-05	9.74E-06	4.69	8.40E-06	3.94E-05	4.0
5000	0	850	0.955	5.10E-05	4.87E-05	23.46	8.40E-06	1.97E-04	4.0
10000	0	850	1.909	5.10E-05	9.74E-05	46.93	8.40E-06	3.94E-04	4.0

Table 4-3 Overtaking collisions as the leg length changes

Leg length [m]	Normal distribution		IWRAP geometric width 65m			SAMSON domain diameter 1nm			SAMSON /IWRAP
	mean [m]	σ [m]	collision candi-dates	causation factor	collisions per year	potentially dangerous situation	CASRAT	collisions per year	
500	0	850	0.013	1.2E-04	1.52E-06	0.34	2.6E-06	8.72E-07	0.6
1000	0	850	0.025	1.2E-04	3.04E-06	0.67	2.6E-06	1.74E-06	0.6
5000	0	850	0.127	1.2E-04	1.52E-05	3.35	2.6E-06	8.72E-06	0.6
10000	0	850	0.253	1.2E-04	3.04E-05	6.70	2.6E-06	1.74E-05	0.6

4.2 Varying domain sizes

The SAMSON domain is in Figure 4-1 relatively much smaller than in Figure 3-1, thus not longer, all meetings between ships are counted. It is expected that in the most common range of the parameters a more or less constant factor between the IWRAP and SAMSON will exist.
The expected number of collisions in SAMSON is the product of the number of potentially dangerous situations and the CASRAT. The expected collisions summarized over all traffic has to deliver the average number of collisions per year in the area. In case the domain is decreased within the calculations this leads to a smaller number of potentially dangerous situations. This means that in that case the CASRAT has to be increased to get the correct level of collisions. In case of a full linear relationship between the domain size and the number of potentially dangerous situations, the CASRAT has to be multiplied with 10 when the domain is decreased with a factor 10. This would mean, that the choice of the domain size is not so important. The relationship between the domain size and the number of potentially dangerous situations is investigated by varying the domain diameter in SAMSON from 0.01 nm to 1 nm for the average situation of Figure 4-2.

The number of collision-candidates or potentially dangerous situation is the product of:

- a factor depending on the lateral distribution;
- the speeds and dimensions of the ships;
- the number of ships on the links;
- the length of the links;
- the domain size in SAMSON

The factor due to the lateral distribution is independent on the other factors. This factor depends only on the lateral distributions of the two flows and the geometric width in IWRAP and the domain size in SAMSON. This “factor by lateral distribution”, thus only depends on the lateral distribution of the two traffic flows and the ship domain in SAMSON is determined as function of the size of the ship domain.

The factor delivered by the lateral distribution (y-axis) for a certain domain size (x-axis) is presented in Figure 4-2. The figure shows a nearly linear relationship between the factor by the lateral distribution and the domain diameter. The left red arrow shows the point for a “tanker meets tanker” (both 35m width) and the right arrow shows the 1 nm domain used by SAMSON. The domain size factor amounts 1852/(2*35)= 26.5 and the factor in the lateral distribution is (0.2055/0.00684) =30.1 which is 1.14*26.5. Thus with a factor 28.3 between the CASRAT of SAMSON and the causation factor of IWRAP the results would be very close to each other. However, this is not the case, because the real quotient ((Causation factor) / CASRAT) for tankers with width 35m is 5.1E-5/8.4E-6 = 6.1, which means that a factor of 4.7 remains, thus what SAMSON predicts above IWRAP for head-on collisions.

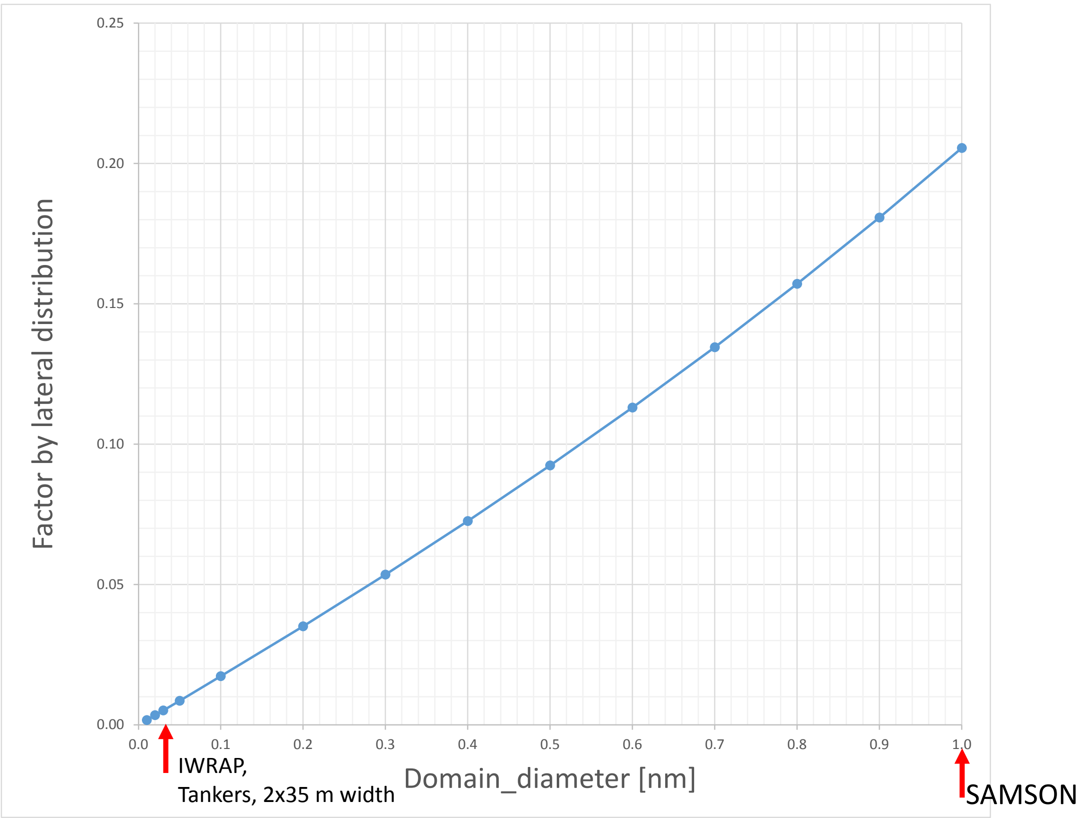

Figure 4-2 Factor for lateral distribution for head-on encounters for the average mean ±935m and average σ=832m when the domain diameter runs from 0 to 1 nautical mile

4.3 Ratio between the SAMSON and IWRAP predictions

The result of the analysis performed by the variation of the ship domain suggests that for larger values of the mean and standard deviation, there is a fairly constant factor between the predicted accident level by SAMSON and the predicted accident level of IWRAP. For this reason, the calculation with elementary traffic situations is performed for mean values between 0 and 2000m and standard deviations between 100 and 2000m, both in steps of 200m. The result is presented in Table 4-4 for head-on collisions and in Table 4-5 for overtaking collisions.

Both tables show the same shape. The cells left under contain “#DIV/0” which means that the distance between the two traffic flow (= 2 times de value of ±mean) is too much with relation to the standard deviation, so that the number of collision-candidates is 0. The value “0.00” means that there are no “potentially dangerous situations” counted by SAMSON because the 2*2.25*”standard deviation”+926 < 2*(±mean). In this range it is possible that IWRAP finds some collision–candidates because the lateral distribution is not cut off. The very large values in the upper left of the table are caused by the domain radius of 926m of SAMSON, causing that still potentially dangerous situations are counted, while IWRAP finds very few collision-candidates. For example a ±mean of 900 with standard deviation 200m means that the distance between the centre lines of the two traffic flows is 2*900/200=9 times the standard deviation. This means an extremely low value in the denominator of the quotient (SAMSON/IWRAP), thus extremely high value for the quotient, but the absolute value for the collision expected by SAMSON is not extremely high in this area.

The tables tell that globally SAMSON expects roughly 4.8 times more head-on collisions than IWRAP. For overtaking collisions is de ratio about 0.65. If possible, a validation with the latest casualty databases has to be performed.

Table 4-4 Expected head-on collisions by SAMSON divided by that of IWRAP for two traffic flows with tankers 35m width for a range of ±means and standard deviations

± mean in m \ Standard deviation in m	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
0	0.84	1.67	2.45	3.04	3.44	3.70	3.88	4.00	4.09	4.16	4.21	4.25	4.28	4.30	4.32	4.34	4.35	4.36	4.37	4.38
100	2.24	2.14	2.68	3.16	3.50	3.73	3.90	4.01	4.10	4.16	4.21	4.25	4.28	4.30	4.32	4.34	4.35	4.36	4.37	4.38
200	42.34	4.40	3.51	3.53	3.68	3.83	3.95	4.05	4.12	4.18	4.22	4.25	4.28	4.31	4.32	4.34	4.35	4.36	4.37	4.38
300	5664.37	13.85	5.33	4.22	4.00	4.00	4.05	4.11	4.16	4.20	4.24	4.27	4.29	4.31	4.33	4.34	4.35	4.37	4.37	4.38
400	########	60.49	9.14	5.34	4.49	4.24	4.18	4.19	4.21	4.23	4.26	4.28	4.30	4.32	4.33	4.35	4.36	4.37	4.38	4.38
500	########	330.94	17.16	7.10	5.16	4.57	4.36	4.29	4.27	4.27	4.29	4.30	4.31	4.33	4.34	4.35	4.36	4.37	4.38	4.39
600	########	2055.09	34.27	9.78	6.06	4.98	4.58	4.42	4.35	4.32	4.32	4.32	4.33	4.34	4.35	4.36	4.37	4.37	4.38	4.39
700	#DIV/0!	12889.96	70.63	13.79	7.24	5.49	4.84	4.56	4.44	4.38	4.36	4.35	4.35	4.35	4.36	4.36	4.37	4.38	4.38	4.39
800	#DIV/0!	65586.61	144.15	19.66	8.74	6.10	5.13	4.73	4.54	4.44	4.40	4.38	4.37	4.36	4.37	4.37	4.37	4.38	4.38	4.39
900	#DIV/0!	78373.36	273.10	27.79	10.58	6.80	5.47	4.91	4.64	4.51	4.44	4.40	4.39	4.38	4.38	4.38	4.38	4.38	4.39	4.39
1000	#DIV/0!	0.00	419.85	37.95	12.71	7.58	5.83	5.11	4.76	4.58	4.48	4.43	4.41	4.39	4.38	4.38	4.38	4.39	4.39	4.39
1100	#DIV/0!	0.00	281.62	47.96	14.94	8.40	6.21	5.31	4.87	4.65	4.53	4.46	4.42	4.41	4.39	4.39	4.39	4.39	4.39	4.39
1200	#DIV/0!	0.00	0.00	51.43	16.87	9.19	6.58	5.51	4.98	4.72	4.57	4.49	4.44	4.42	4.40	4.39	4.39	4.39	4.39	4.39
1300	#DIV/0!	#DIV/0!	0.00	34.17	17.69	9.80	6.89	5.68	5.08	4.78	4.61	4.51	4.46	4.43	4.41	4.40	4.39	4.39	4.39	4.39
1400	#DIV/0!	#DIV/0!	0.00	0.00	16.11	10.06	7.10	5.82	5.16	4.83	4.63	4.53	4.46	4.43	4.41	4.40	4.39	4.39	4.39	4.39
1500	#DIV/0!	#DIV/0!	0.00	0.00	10.24	9.68	7.14	5.89	5.20	4.86	4.65	4.54	4.47	4.43	4.41	4.39	4.39	4.38	4.38	4.38
1600	#DIV/0!	#DIV/0!	0.00	0.00	0.00	8.32	6.91	5.86	5.20	4.86	4.65	4.54	4.46	4.43	4.40	4.39	4.38	4.38	4.38	4.38
1700	#DIV/0!	#DIV/0!	0.00	0.00	0.00	5.54	6.31	5.69	5.13	4.82	4.62	4.52	4.45	4.41	4.39	4.38	4.37	4.37	4.37	4.37
1800	#DIV/0!	#DIV/0!	0.00	0.00	0.00	0.89	5.21	5.34	4.98	4.74	4.57	4.48	4.42	4.39	4.37	4.36	4.35	4.36	4.36	4.36
1900	#DIV/0!	#DIV/0!	#DIV/0!	0.00	0.00	0.00	3.50	4.76	4.72	4.61	4.48	4.42	4.37	4.35	4.34	4.34	4.33	4.34	4.34	4.35
2000	#DIV/0!	#DIV/0!	#DIV/0!	0.00	0.00	0.00	1.05	3.91	4.33	4.40	4.35	4.33	4.31	4.30	4.30	4.31	4.31	4.32	4.32	4.33

Table 4-5 Expected overtaking collisions by SAMSON divided by that of IWRAP for a traffic flow with tankers 35m width and a traffic flow with container ships 30m width

± mean in m \ Standard deviation in m	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
0	0.12	0.24	0.35	0.43	0.49	0.52	0.55	0.57	0.58	0.59	0.60	0.60	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62
100	0.32	0.30	0.38	0.45	0.50	0.53	0.55	0.57	0.58	0.59	0.60	0.60	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62
200	6.05	0.62	0.50	0.50	0.52	0.54	0.56	0.57	0.58	0.59	0.60	0.60	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62
300	820.31	1.96	0.75	0.60	0.57	0.57	0.57	0.58	0.59	0.59	0.60	0.60	0.61	0.61	0.61	0.62	0.62	0.62	0.62	0.62
400	666286.45	8.59	1.29	0.76	0.64	0.60	0.59	0.59	0.60	0.60	0.60	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62	0.62
500	########	47.07	2.43	1.01	0.73	0.65	0.62	0.61	0.60	0.61	0.61	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62	0.62
600	########	292.84	4.86	1.39	0.86	0.71	0.65	0.63	0.62	0.61	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62	0.62	0.62
700	#DIV/0!	1840.81	10.02	1.95	1.03	0.78	0.69	0.65	0.63	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
800	#DIV/0!	9389.80	20.46	2.79	1.24	0.86	0.73	0.67	0.64	0.63	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
900	#DIV/0!	11251.81	38.79	3.94	1.50	0.96	0.78	0.70	0.66	0.64	0.63	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
1000	#DIV/0!	0.00	59.67	5.38	1.80	1.07	0.83	0.72	0.67	0.65	0.64	0.63	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
1100	#DIV/0!	0.00	40.06	6.80	2.12	1.19	0.88	0.75	0.69	0.66	0.64	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62	0.62
1200	#DIV/0!	0.00	0.00	7.30	2.39	1.30	0.93	0.78	0.71	0.67	0.65	0.64	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62
1300	#DIV/0!	#DIV/0!	0.00	4.85	2.51	1.39	0.98	0.81	0.72	0.68	0.65	0.64	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62
1400	#DIV/0!	#DIV/0!	0.00	0.00	2.28	1.43	1.01	0.82	0.73	0.68	0.66	0.64	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62
1500	#DIV/0!	#DIV/0!	0.00	0.00	1.45	1.37	1.01	0.83	0.74	0.69	0.66	0.64	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62
1600	#DIV/0!	#DIV/0!	0.00	0.00	0.00	1.18	0.98	0.83	0.74	0.69	0.66	0.64	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62
1700	#DIV/0!	#DIV/0!	0.00	0.00	0.00	0.79	0.89	0.81	0.73	0.68	0.65	0.64	0.63	0.62	0.62	0.62	0.62	0.62	0.62	0.62
1800	#DIV/0!	#DIV/0!	0.00	0.00	0.00	0.13	0.74	0.76	0.71	0.67	0.65	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62	0.62
1900	#DIV/0!	#DIV/0!	#DIV/0!	0.00	0.00	0.00	0.50	0.67	0.67	0.65	0.63	0.63	0.62	0.62	0.61	0.61	0.61	0.61	0.62	0.62
2000	#DIV/0!	#DIV/0!	#DIV/0!	0.00	0.00	0.00	0.15	0.55	0.61	0.62	0.62	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61

4.4 Location of the collisions

The ship domain in SAMSON means that the location at which ships can collide in SAMSON is different than in IWRAP. This different location is illustrated in Figure 4-3 for the traffic flows of Figure 3-1 in which the domain of SAMSON is relatively large with respect to the mean and standard deviation and in Figure 4-4 for the traffic flows of Figure 4-1 based on the average values for the mean and standard deviation in the northern area before the route change. The y-axis in both figures belongs to the lateral traffic distribution. The axis on the right is for the expected collisions. The expected head-on collisions by IWRAP are multiplied with the factor 4.8 which is the general factor between the head-on collisions between SAMSON and IWRAP.

Figure 4-3 shows the difference in locations and the total collision level between IWRAP and SAMSON. Because the large size of the domain in SAMSON with respect to ±mean and standard deviation, the locations where collisions are expected differs between the two models. The distribution in IWRAP is symmetric around 0. The distribution in SAMSON is asymmetric due to the ship domain. The total number of expected collisions is the area under the collisions curves. For this situation the area under the SAMSON collision curves is larger, namely 13.85/4.8 (13.85 can be found in Table 4-4). As mentioned before, this standard deviation is not realistic for sea areas.

Figure 4-4 shows the collision locations for the average mean and standard deviation at sea. The figure shows that there is a little shift of the locations of the ships that are involved in a collision. In IWRAP the distribution is always symmetric around 0. In SAMSOM the distribution is asymmetric due to the domain. For this situation the location and the total number of collisions (after the general factor) correspond quite well.

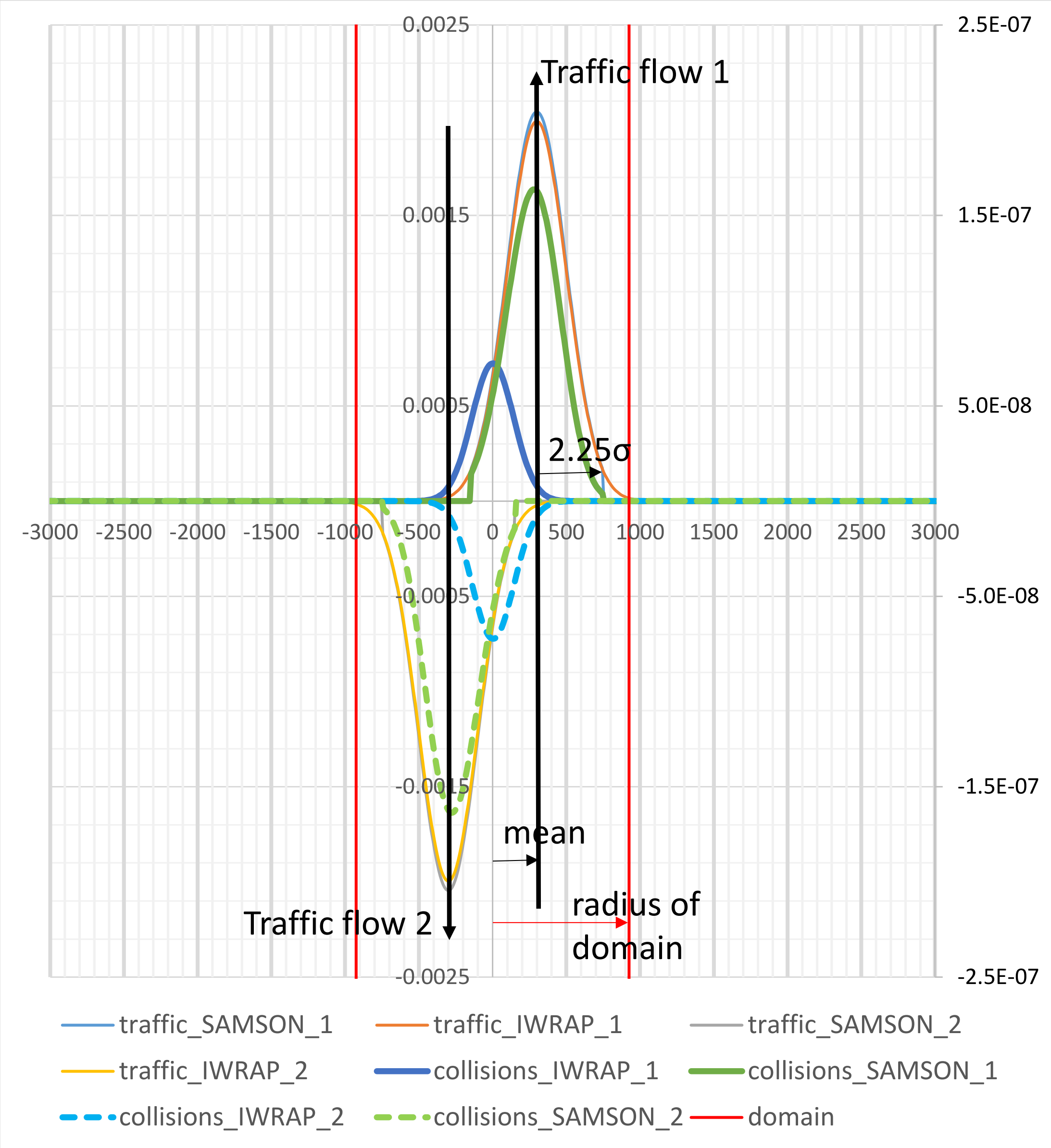

Figure 4-3 Distribution of collisions for head-on with ±mean=300m and σ=200m

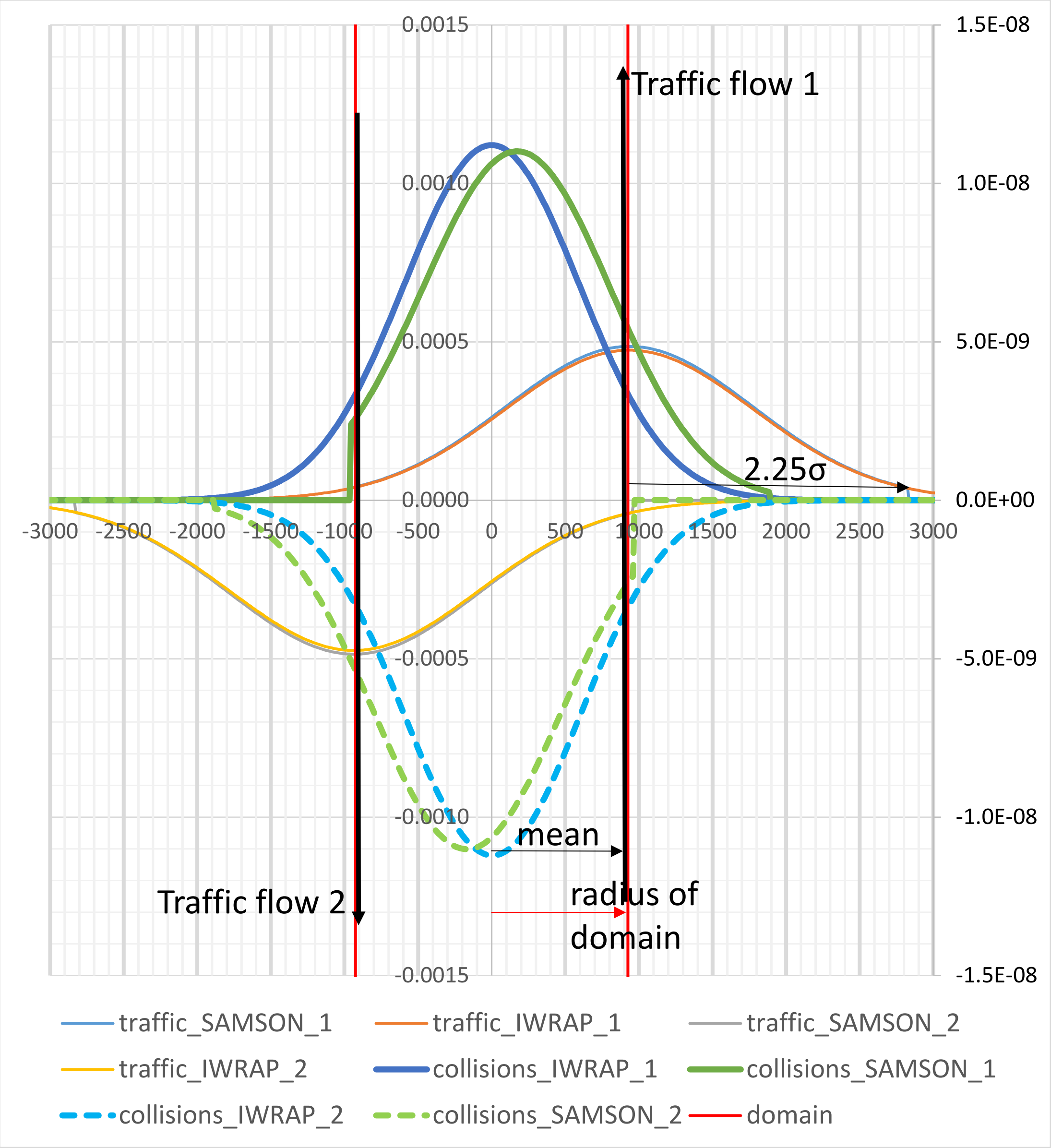

Figure 4-4 Distribution of collisions for head-on with ±mean=935m and σ=842m

5 CAUSATION FACTOR VERSUS CASUALTY RATE

In IWRAP the same causation factor has been used for all ships for head-on and overtaking collisions. The difference in collision risk between ships is incorporated by the dimensions of a ship. There is no difference between the causation factors of different ship types. The wiki/IWRAP page shows a variety in causation factors for ship-ship collisions used in different sea areas.

Table 5-1 Causation factors for ship-ship collision on /www.iala-aism.org/wiki/iwrap/images/f/fc/20090405_Fig_Pc_Ship_Ship_Collisions

Ship-ship collisions			
Location	**P_c** $[\times 10^{-4}]$	**Comment**	**Reference:** see [20] for ref.
Dover Strait	5.18	Head-on, no traffic separation	MacDuff [21]
Dover Strait	3.15	Head-on, with traffic separation	MacDuff [21]
Øresund, Denmark	0.27	Head on	Karlson *et al.* [19]
Japanese Straits	0.49	Head on	Fujii & Mizuki [9]
Japanese Straits	1.23	Crossings	Fujii & Mizuki [9]
Dover Strait	1.11	Crossings, no traffic separation	MacDuff [21]
Dover Strait	0.95	Crossings, with traffic separation	MacDuff [21]
Strait of Gibraltar	1.2		COWIconsult
Japanese Straits	1.10	Overtaking	Fujii & Mizuki [9]
Great Belt, Denmark	1.30	At bends in lanes	Pedersen *et al.* [24]
Danish waters	3.0	Head-on and overtaking Crossings also?	COWIconsult Oil and Chemical Spills, 2007

In SAMSON the casualty rate (CASRAT) is different for each ship type and ship size class but not on the sea area. The CASRAT increases with the ship size and models the same effect as the width of the ships in the “hard” encounter calculation of IWRAP.

The worldwide casualty database with about 25000 casualties in the period 1990-2007 has been used for the determination of the difference in collision proneness between ship types and ship sizes. The absolute level is determined by relating the number of encounters calculated with SAMSON for the whole North Sea with the collisions that have occurred in the North Sea.

6 IMPACT OF THE TAILS OF THE LATERAL DISTRIBUTION

The tails of the lateral distribution can play a significantly role in the collision risk. For example, the first rows of Table 3-2 and Table 3-5 contain a mean of ±300m and a σ of 100 and 200m. Figure 3-1 shows the situation for the second row (σ = 200m). This means that there is a difference between the centre lines of the traffic flows of respectively 6σ and 3σ. To reduce the impact of the tails of the lateral distribution, SAMSON cuts the distribution of at 2.25 σ. This means that in situation where the centre lines between the traffic flows are 6σ apart, the distributions between the traffic flows are cut off in SAMSON. Thus, there is a shipping free zone of 1.5σ=150m between the sailing directions in SAMSON. In IWRAP the distributions are not cut off and this will be a nearly shipping free zone. In fact, this means that only ships with a summarized width of 300m would be on collision risk. These ships do not exist, thus the collision risk would be 0 in SAMSON and very low in IWRAP. However, due to the domain diameter of 1 nm used by SAMSON, encounters are still counted which results in a collision risk. For this reason, the factor SAMSON/IWRAP is so high for situations where σ is much smaller than the mean distance of the two flows towards the centre line.

The tail of the lateral distribution plays not only in role in the calculation of the collision risk, but it also plays a dominant role in the determination of the grounding risk and the contact risk with an offshore installation. Because the tail of a lateral distribution is the most inaccurate part of the distribution, the prediction of the grounding and contact risk cannot be determined accurately based on this tail. Without deleting the tails of the distribution, changing the shape of the lateral distribution from, for example, a normal distribution to the sum of a number of other distributions, the grounding and contact risk can change an order of magnitude due to the resulting changes in the tails of the distribution.

Cut off of lateral distribution

In IWRAP, the lateral distribution is determined by assigning the AIS data to predetermined links. All ships within a predefined area around the predefined link with a course within an area around the course of the link are assigned to the link. The lateral distribution parameters mean and σ are determined from the positions of the assigned AIS data. These parameters are used for predicting the collision, grounding and contact risk. As described in section 2.3, the IWRAP traffic database for the northern area before the route change was imported in SAMSON. The resulting traffic database is shown in Figure 2-7. The xml-file that was obtained contained information about the distance range and the course range for each leg.

In Figure 6-1 the situation is schematized for a leg from WP001 to WP0492. The AIS targets within a range of 5000m and a course difference of less than 15° are included in the assignment process. The black targets of Figure 6-1 are included and the red targets are ignored because they are located outside the range of 5000m or have a course difference > 15°. The mean and standard deviation for the leg are calculated from the targets included (black ones). This delivers a mean=974m and σ=978m. With these values, the lateral range limits are located on -3.55σ (portside) and 1.59σ (starboard). Thus, ships sailing in the tail on starboard side on a distance of more than 1.59σ are not included in the determination of the parameters of the lateral distribution. However, the grounding and contact risk in the IWRAP approach are only delivered by ships in those tails of the distribution.

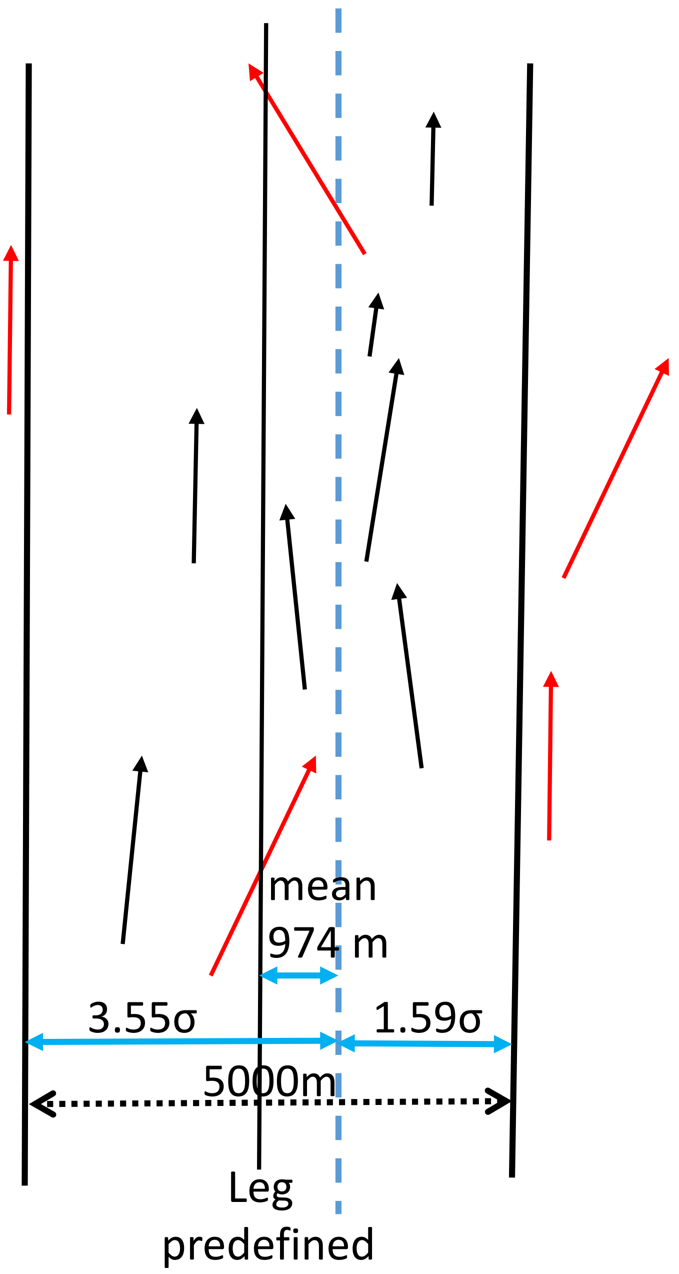

Figure 6-1 Leg with AIS targets

In SAMSON the lateral distribution is cut off at 2.25σ on both sides. However, the grounding and contact risk are not only based on the tails of the lateral distribution. Instead, these risks are based on the whole lateral distribution of the leg/link that runs closely to the object. The contribution to the risk decreases with the distance to the object expressed in ship lengths.

7 WHY A DOMAIN DIAMETER OF ONE NAUTICAL MILE

History

The circle domain with a radius of 0.5 nm is taken at a certain moment to incorporate the behaviour of the ships. It is based on the wish of masters to keep an area around the own ship free from other ships. This area is not equal to all sides. Aft of the ship a smaller area is kept clear than before the ship and also on the starboard side the master will try to keep freely larger area clear. This was the result of the research of Goodwin in the seventies of the previous century [1]. The domain of Goodwin could be best represented by an ellipse with the ship in the focal point and the long axis of the ellipse a little turned to starboard. This shape has been used by van der Tak and Spaans in a “Model to calculate a Maritime Risk criterium number” presented at the International Navigational Congress in Boston in 1976, [2]. The paper was also published in the English and American Journal of the Institute of Navigation. Later the elliptical domain has been replaced by a circular domain because that was easier to deal with and delivered practically the same results.

Thus the circular domain has been used in all studies by MARIN since the eighties. The Casualty Rates (CASRATs) thus the transition factors from encounters to collisions have been determined from the casualty databases. In the first period, the casualty rates were only based on North Sea and European casualty databases. Since 1990 the world wide casualty database is collected by purchasing data from LRF. From time to time updates of the CASRATs took place based on new data.

Recent research

Until ten years ago, only very few data was available for studying the behaviour of shipping. The main source was the expert opinion. The introduction of AIS made it possible to analyse shipping traffic in a more objective way.

Within MARIN continuously studies are executed in order to improve the knowledge of the behaviour of shipping. The objectives are to improve the Quantitative Risk Assessment (QRA) studies executed by MARIN. In some cases the QRA could be based on AIS only while in other cases the risk was determined applying additional calculations with SAMSON.

Within this framework, the behaviour of shipping has recently been researched in near miss situations. This is done by following the DCPA (predicted distance at the closest point of approach) and TCPA (time to the CPA) of the ships. Some of the results are presented in the next figures. Figure 7-1 gives the tracks by (DCPA, TCPA) points of the other ship. The figure should be read from right to left, so for decreasing TCPA. The own ship is located in point (0,0). The own ship is passed when TCPA=0. The figure shows that ships start a manoeuvre roughly at 12 minutes before the meeting point in order to pass on a certain distance. The minimum distance other ships pass is roughly 0.5 nm. Due to the sign conventions, the figure is identical for both ships that pass each other.

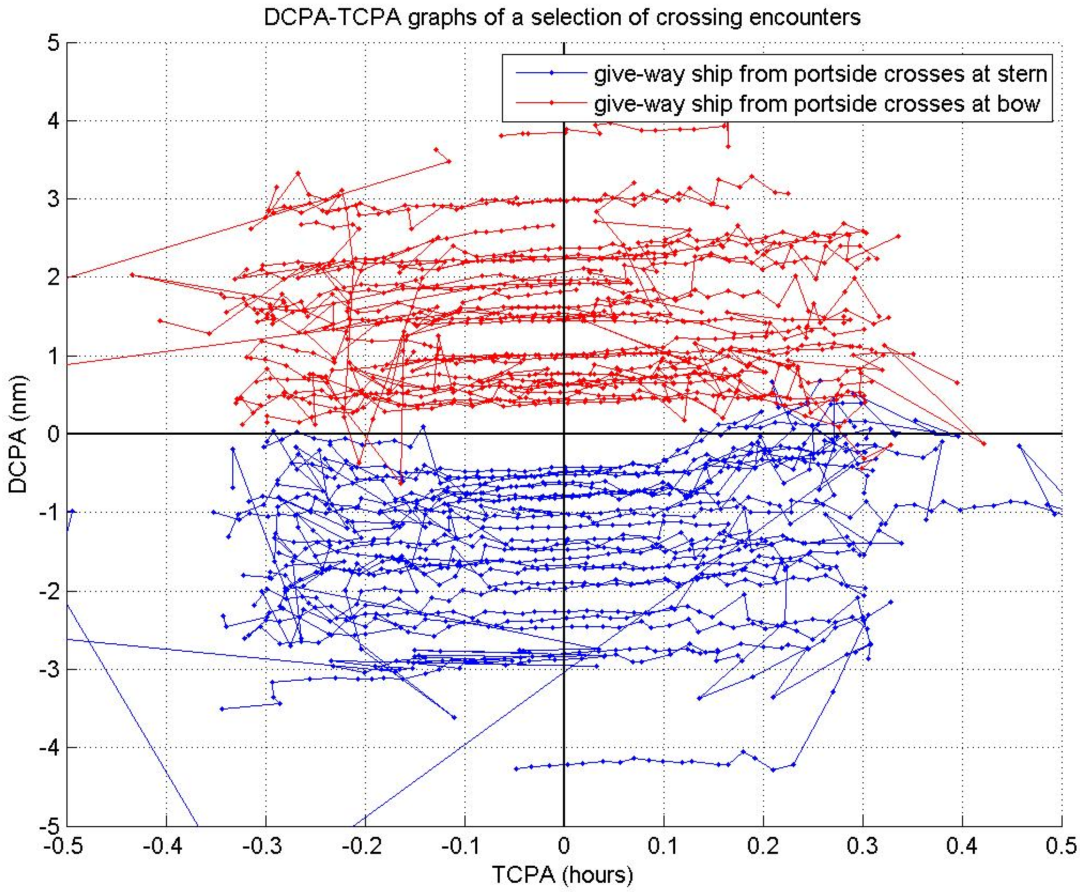

Figure 7-1 Observed (DCPA,TCPA) tracks of crossing ships

Figure 7-2 shows the density (DCPA,TCPA) for ships at portside crossing at the stern, Figure 7-3 the density of ships at portside crossing at the bow and Figure 7-4 the density plot for overtaking ships. The density plot for meeting is not yet determined. These figures show that ships will pass each other on a distance. Crossing ships will take manoeuvres to realize a distance of roughly 0.5 nm. Crossing at bow a little bit more than crossing at stern. In case of overtaking the distance is sometimes a little smaller.

Based on these figures it can be concluded that ships try to cross each other on at least 0.5 nautical mile.

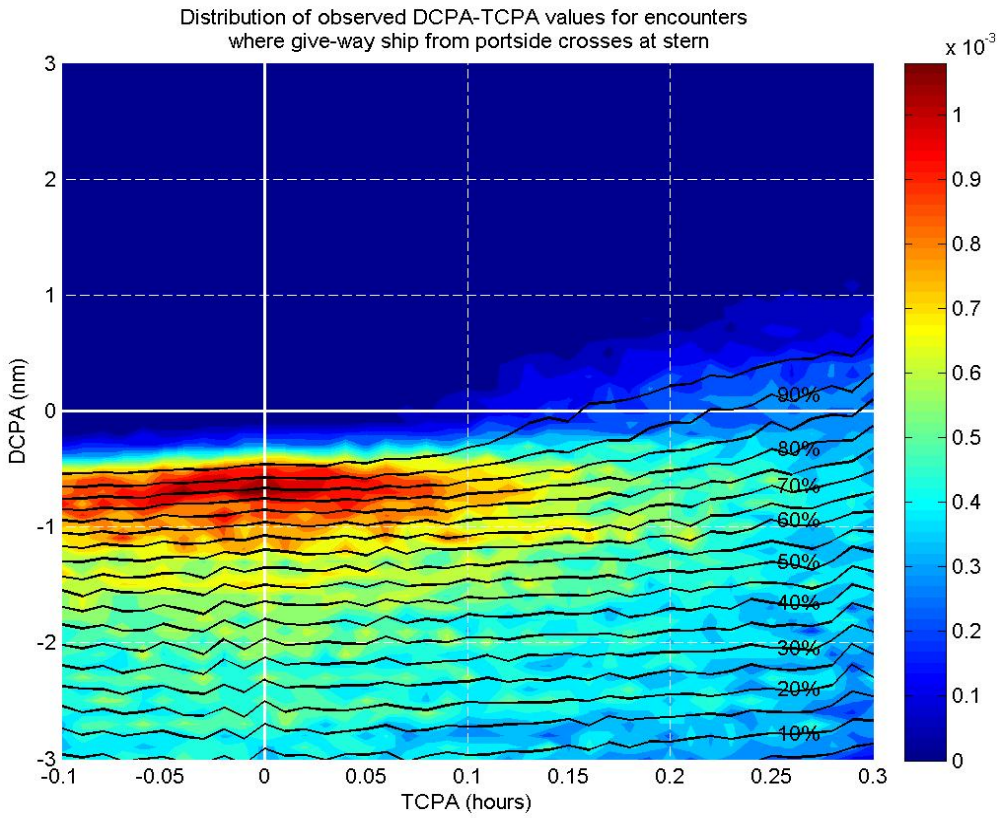

Figure 7-2 Observed DCPA-TCPA for crossing at stern

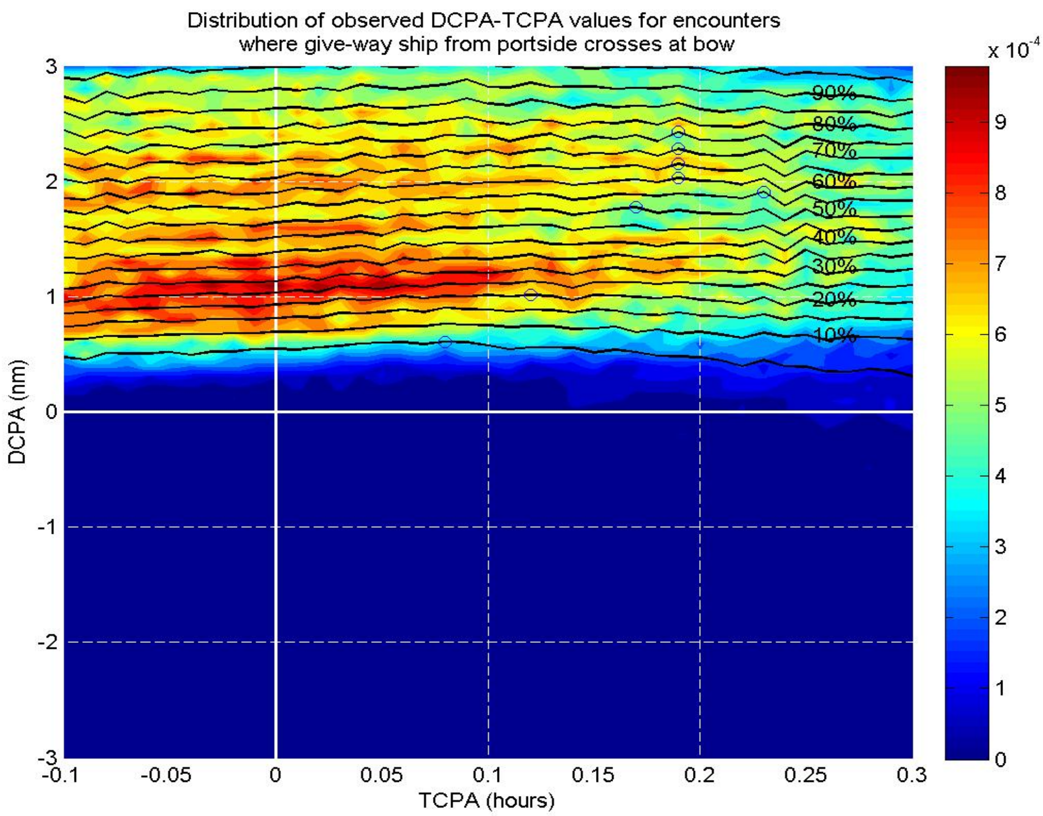

Figure 7-3 Observed DCPA-TCPA for crossing at bow

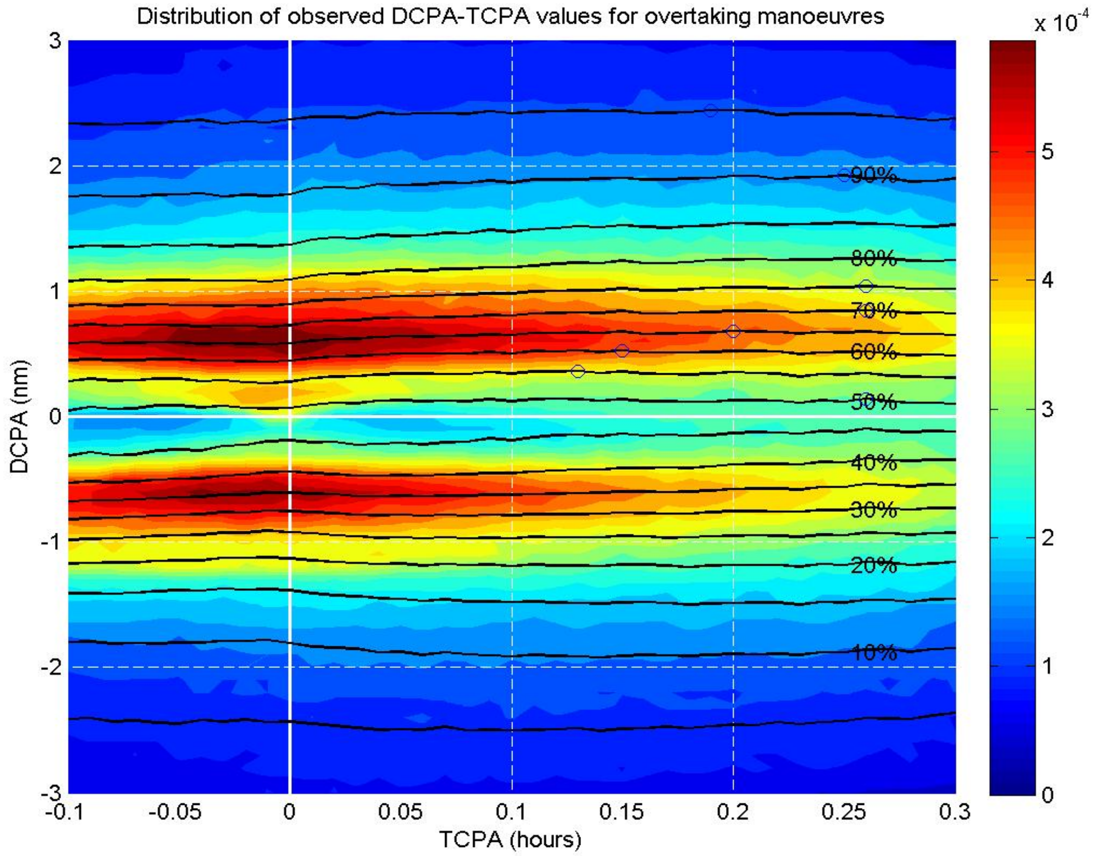

Figure 7-4 Observed DCPA-TCPA for overtaking

Collisions that have occurred

The collisions that occur nowadays are replayed with AIS. One of the collisions that occurred is presented in Figure 7-5. The ships are plotted with a domain that is equal to six times the ship length in forward and backward direction and two times the ship length to starboard and portside. A fast container ship with a length of 365m and a speed of 22.5 knots wants to overtake two slower ships. The track distances are respectively 500m and 800m (thus in IWRAP modelling very far away from a dangerous situation). However, the container ship seems to be not willing to overtake both vessels by continuing her present track between these ships, due to too small passing distances. Therefore, a turning manoeuvre is initiated to overtake also the first ship on portside. By a misinterpretation of the very low speed of the first ship, the initiated turn resulted in a collision to the first ship.

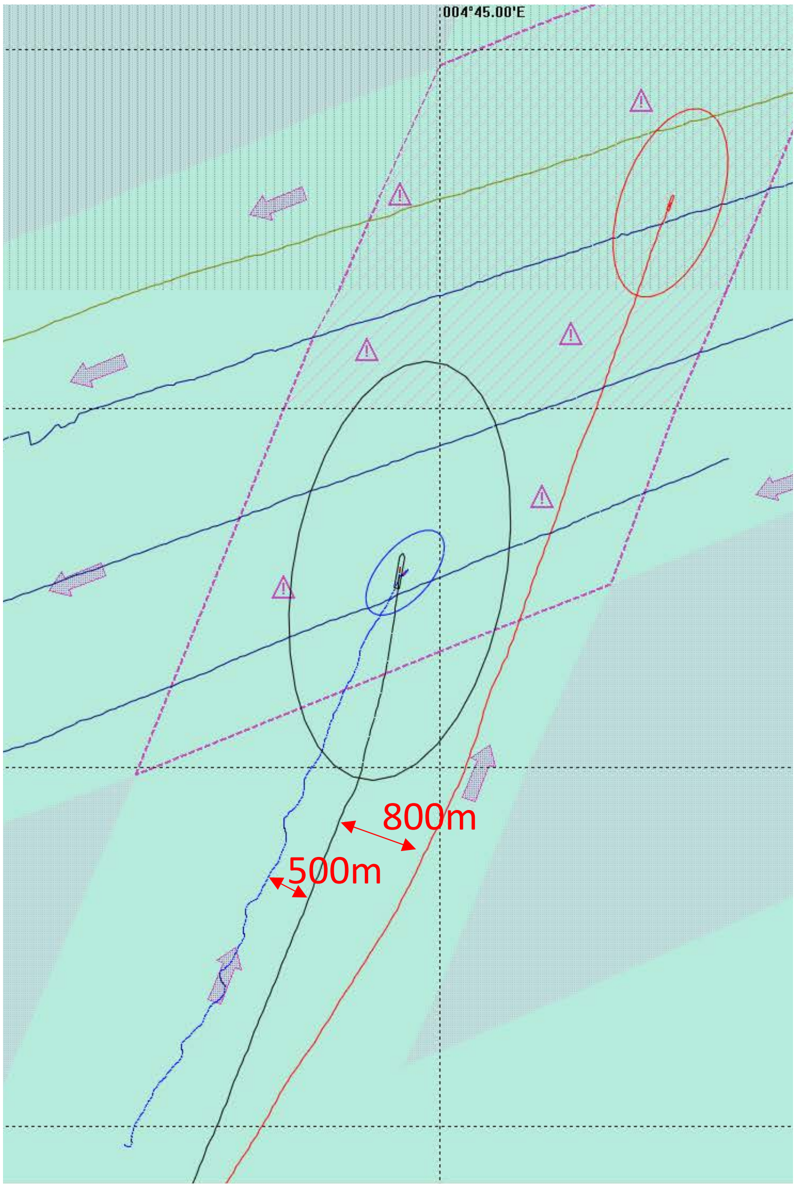

Figure 7-5 Overtaking collision in TSS Vlieland

Conclusions

The considerations in this chapter give no reason to change our approach of using a circular domain with radius 0.5 nautical mile in QRA collision studies.

8 CONCLUSIONS

The main conclusions is that IWRAP and SAMSON use different methods to determine the risk in a quantitative way. Despite the fact that the same processes are followed the results can vary significantly. This has its reasons in the choice of the ship's domain and the use of the causation factor in IWRAP and the casualty rate in SAMSON. Furthermore, the model used by SAMSON is much less sensitive to the shape of the tails of distributions that are dominantly in the determination of the grounding and contact risk in IWRAP.

A number of goals have formulated in the previous meeting of April 11th. Based on the work done and the results achieve, the notes of MARIN are added.

What is our goal?

- That both models produce the same risk for the same situation (or that the difference is explainable)
  Note: The results remain different. The source of the difference is clear.

- That both models indicate the same change in risk as a result of changes in the situation
  Note: Because the calculated risk differs, also the change in risk will differ. It is expected that the direction of the change in risk will be the same.

- It is desirable to have a tool that is not very sensitive to input parameters with a very uncertain value. On the other hand it should respond in a plausible (expert opinion? AIS data analysis? Near-miss reports?) manner to changes in those parameters.
  Note: As far as possible results of other (research) projects are used. Generally the results of SAMSON are less sensitive for changes in the location and width of shipping routes. Furthermore the grounding and contact risk for offshore platforms method used by SAMSON is less sensitive than the method in which the very uncertain tails of the lateral distributions dominate the grounding and contact risk.

- If there are large differences it might be impossible to decide which result is closest to reality.
  Note: This is the largest challenge. The number of shipping accidents that occur are so scarce that it is nearly impossible to figure out which model is most realistic.

REFERENCES

[1] E. Goodwin
A statistical study of ship domains
Thesis, London Polytechnic, 1975

[2] C. van der Tak, J.A. Spaans
A model for calculating a maritime risk criterion number
Journal of Navigation, Vol 30, No. 2, May 1977

APPENDIX D INVESTIGATION COLLISIONS FROM 2005-2013

To	:	IALA Risk Management Steering Group
From	:	Anke Cotteleer, Kees van der Tak
CC	:	
Date	:	November, 17, 2014
Project No	:	27656.600
Subject	:	Investigation collisions from 2005-2013

Introduction

There is a difference in the modelling of IWRAP and SAMSON. The expected number of collisions in IWRAP is calculated from the collision candidates multiplied with the causation factor. The expected number of collisions in SAMSON is calculated from the number of ship domain penetrations times the casualty rate.
To enlarge the insight in what happens in reality, this memo describes an in depth study that has been performed of collisions that occurred in reality.

In all known casualty databases an extensive description of the situation just before the collision is lacking. However, AIS data is available to replay collisions. The tracks, courses and positions in time, give insight in what has really happened. Questions that can be answered by these replays are:

1. Can the collision be qualified as a head-on, overtaking or crossing collision?
2. Were the ships on collision course or not?

Summarized over a large area and a long time period, it is possible to compare the model predictions (of SAMSON and IWRAP) with the reality. For the current investigation, the collisions from 2005 through 2013 in the Dutch Sector of the North Sea have been replayed.

However, not all collisions could be replayed, because:

- especially in the first years, the AIS coverage was not complete;
- sometimes AIS data was missing, just at the time of the collision;
- the number of fishing vessels that are obliged to have an AIS transponder on board has increased over the years.

Collisions in the Dutch sector of the North Sea

Two sources have been used to extract the collisions from 2005-2013, namely:

- the worldwide casualty database of Lloyd's Register Fairplay (LRF) and
- the national database containing all shipping incidents (SOS = ScheepsOngevallen Systeem) in the Dutch waters.

In previous investigations, some collisions were found in only one of the databases. This time, all collisions in the Dutch sector found in LRF were also present in the SOS database, and the SOS database contains additional collisions. Therefore, the SOS database is most representative for the collisions in the Dutch sector of the North Sea.

Because of the large sea area and the long timeframe, the collision can only be found when the ship names, position and collision date and time are known. With this information it is possible to zoom in to the location of the collision and to follow the progresses of the ships from about one hour before the collision to the collision.

The SOS database contained 73 incidents in which more than one ship was involved. Not all incidents were collisions between sailing ships. Some incidents described damages by waves excited by passing ships. Further, a number of collisions occurred with ships at anchor. In SAMSON, this type of collision is modelled differently than a collision between sailing ships. The 73 incidents are classified as:

- 45 collisions between two sailing ships;
- 13 collisions in which a sailing ship hits a ship at anchor;
- 3 collisions (damages) during boarding of a pilot or crewmember;
- 12 incidents were not used by different reasons, (double records, waves, not located in the Dutch sector of the North Sea, collisions by two recreational vessels).

Collisions between sailing vessels

Domain or collision candidate approach

Table 0-1 gives a summary of the results of the investigation of the 45 collisions between sailing ships. The collision type is given in the first column. A question mark (?) is used when the collision type could not be obtained from the AIS data or the casualty databases. RR means a collision between two route bound ships, RN a collision between a route and a non-route bound ship and NN between two non-route bound ships.
The number of ships involved in the collisions of which AIS was available is given under “number of ships in AIS replay”. Because R-ships are required to be equipped with AIS, in nearly all RR collisions, 2 ships could be followed in the replay. In case of RN collisions, the data of the N-ship was often missing, because most N-ships were not required to use AIS. For the same reason, most NN collisions could not be replayed with AIS.

In case 2 ships could be followed with AIS, it is indicated in the columns of Table 0-1 whether the ships have taken: no action, a collision avoidance action (not always according to the colregs) or a wrong action.

- “no” action represents blind sailing. An example is presented in Figure 0-1.
- the collision “avoidance” action is initiated in case a collision threatens. In nearly all cases, the collision avoidance manoeuvre has success, but not in the cases ending in a collision. Furthermore, in the cases that the avoidance action has failed, no collision would have occurred when ships would have kept course and speed. This type is illustrated in Figure 0-2.
- collisions also occurred, because a ship initiated a non-expected (wrong) manoeuvre while another ship was sailing in the vicinity, making a collision unavoidable. This occurs most often in overtaking situations. This type is illustrated in Figure 0-3.

When looking at the RR collisions of Table 0-1, there are 7 collisions in which no action was taken, thus between collision candidates (IWRAP model) and 8 (5 avoidance + 3 wrong) collisions in which the ships initially were no collision candidates, but would have caused domain penetrations in the SAMSON modelling. It can be concluded that roughly 50% of the collisions are between ships being collision candidates while in the others 50% the action initiated by one or both ships results in the collision.

Table 0-1 Classification of collisions

Collision type	Number of ships in AIS replay					AIS hole at time of collision	Grand Total
	0	1	2				
			Action taken				
			No	Avoidance	wrong		
Head_on RR	1		1				2
Overtaking RR			3		3		6
Crossing RR			3	5			8
? RR	1						1
Overtaking RN			1				1
Crossing RN		1	1	2			4
? RN	2	6				1	9
Head-on NN	1			1			2
Crossing NN	1		1				2
? NN	8	2					10
Grand Total	14	9	10	8	3	1	45

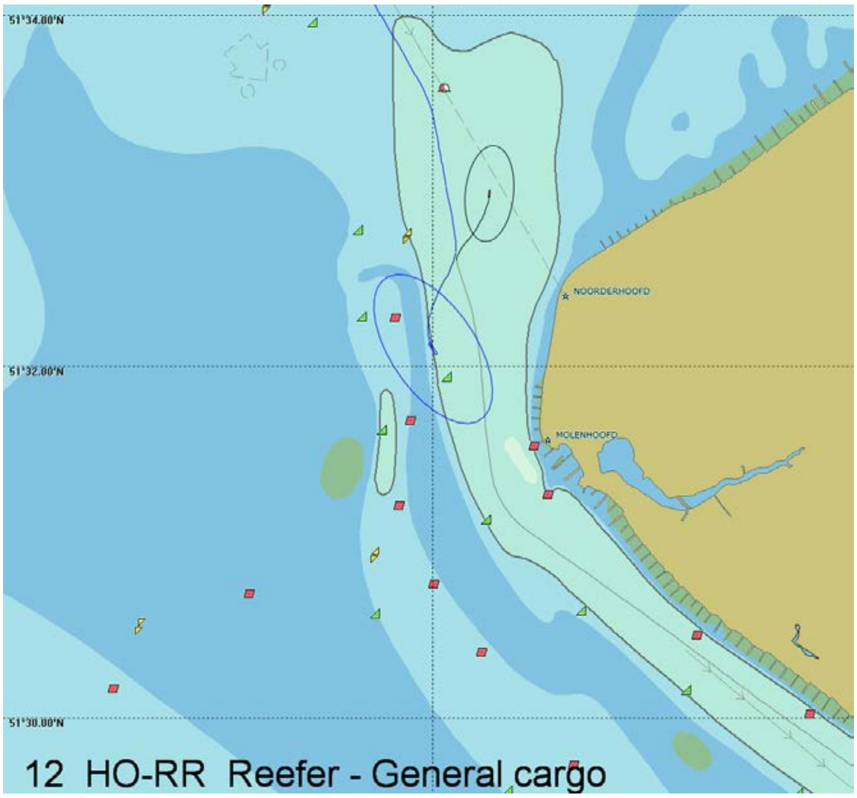

Figure 0-1 Head-on collision that occurred without any collision avoidance was taken, thus between two collision candidates

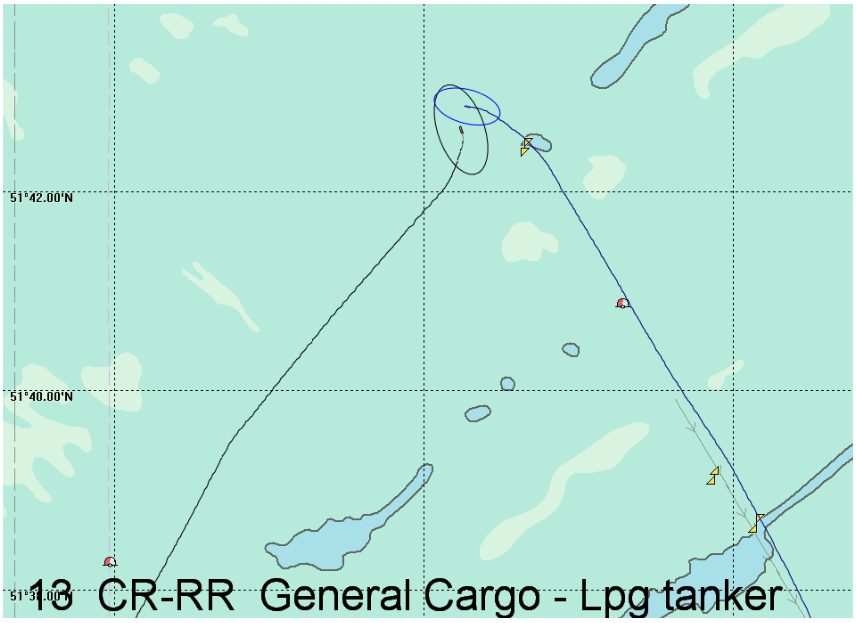

Figure 0-2 *Collision between two ships by the avoidance manoeuvres; ships were no collision candidates*

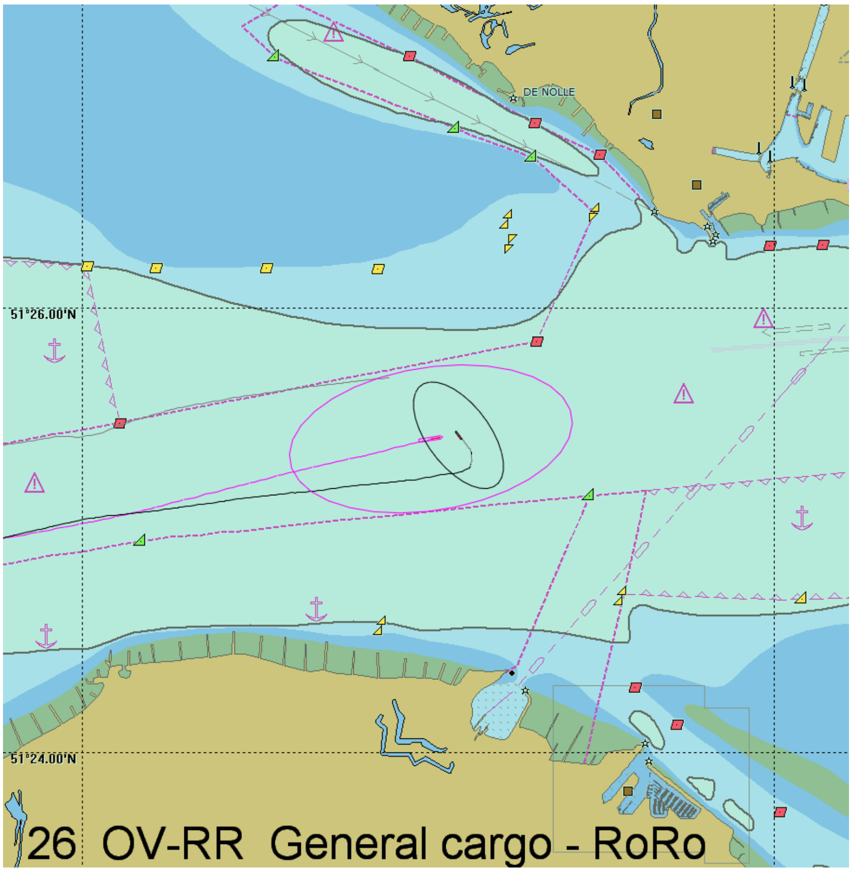

Figure 0-3 *Wrong manoeuvre leading to a collision*

Ernst Bolt has described the main difference between IWRAP and SAMSON in his "considerations.doc" of June 2014 as follows:

> The 'potentially dangerous situation' or PRETS[1] (exposure) as used by SAMSON differs from the 'number of collision candidates' used in IWRAP. This is not only a matter of definition but also a different way of modelling.
>
> The modelling behind IWRAP is that, if all ships would ignore other traffic and follow the tracks with the prescribed lateral distribution, this would mathematically result in a number of hits. Because there is intelligence on the bridge this number is reduced by the causation factor to get the expected number of collisions.
>
> In SAMSON it is rather the other way around. Although mariners will try to pass each other at a safe distance, it might happen that they fail to take the appropriate actions (due to lack of attention, human error, mechanical failure or whatever). The probability that such an error occurs and is not discovered in time to save the situation is represented by the casualty rate. For a number of course deviations the probability that such an error would occur is combined with the time available for corrective action, before the other vessel (or obstacle or coastline) is hit.

The replay of the collisions on the Dutch sector of the North Sea showed that roughly 50% of the collisions occurred by collision candidates thus modelled by IWRAP with collision candidates times the causation factor. The remaining 50% of the collisions occurred by ships penetrating the other ship's domain, thus included in the SAMSON modelling, originally not on collision course, but still colliding by wrong and/or erroneous avoidance manoeuvres. These are also modelled by SAMSON by the number of domain penetrations times the casualty rate,
But even after this investigation it is impossible to conclude which model is better suited for which purpose, because the causation factor and the casualty rate implicitly correct for shortcomings.

Comparison with division over collision types in SAMSON

In Table 0-1, the collisions are divided over the collision types used in SAMSON. The collisions with a "?" are assigned proportionally to the known types within the RR, RN and NN collisions. The result is presented in Table 0-2 for one year. The expected number of collisions per year is 5 (= 45 of Table 0-1 / 9 years).

Table 0-2 Number of collisions per year between sailing vessels in the Dutch sector based on the collisions occurred between 2005-2013

collision type	ships involved in collisions					collisions
	R-ships in		N-ships in		total	
	RR- collisions	RN-collisions	NR-collisions	NN-collisions		
Head-on	0.47			1.56	2.03	1.01
Overtaking	1.42	0.31	0.31		2.04	1.02
Crossing	1.89	1.24	1.24	1.56	5.93	2.97
All	3.78	1.56	1.56	3.11	10.00	5.00

[1] "Potentially Risky Elementary Traffic Situation"

Table 0-3 contains the expected frequencies calculated by SAMSON with the traffic database for route-bound traffic of 2008 and the density database for non-route-bound ships of 2009. These databases are representative for the traffic on the North Sea in the period 2005-2013.

Table 0-3 Expected number of ships involved in collisions per year between sailing vessels in the Dutch sector of the North Sea for the traffic database of 2008 for R-ships and the traffic database of 2009 for the N-ships

collision type	ships involved in collisions					collisions
	R-ships in		N-ships in		total	
	RR- collisions	RN-collisions	NR-collisions	NN-collisions		
Head-on	1.363	0.191	0.191	0.383	2.13	1.06
Overtaking	0.704	0.064	0.064	0.059	0.89	0.45
Crossing	2.453	1.508	1.508	2.501	7.97	3.99
All	4.520	1.764	1.764	2.943	10.99	5.49

In Table 0-4 the predicted values of SAMSON of Table 0-3 are divided by the observed collisions of Table 0-2.

Table 0-4 Expected number of SAMSON divided by the observed frequencies (Table 0-3/Table 0-2)

collision type	ships involved in collisions					collisions
	R-ships in		N-ships in		total	
	RR- collisions	RN-collisions	NR-collisions	NN-collisions		
Head-on	2.89			0.25	1.05	1.05
Overtaking	0.50	0.21	0.21		0.44	0.44
Crossing	1.30	1.21	1.21	1.61	1.34	1.34
All	1.20	1.13	1.13	0.95	1.10	1.10

Table 0-4 shows that the total collision frequency predicted by SAMSON is 10% higher than the frequency observed in reality. This factor is not the same for the different collision types. This is partly caused by the small number of observations in the different cells of the table. For example the factor 2.89 for head-on ships involved in RR collisions is based on only 2 head-on collision in 9 years.

The occurrence of a collision follows more or less a Poisson process. The estimate for the parameter μ of the Poisson distribution is based on the number of collisions observed $n_{observed}$. The lower limit μ_{lower} and upper limit μ_{upper} for the of the 95% interval follows from:

$$\sum_{n_{obsereved}}^{\infty} e^{\mu_{lower}} \frac{\mu_{lower}{}^{n}}{n!} = 0.025$$

$$\sum_{0}^{n_{obsereved}} e^{\mu_{upper}} \frac{{\mu_{upper}}^{n}}{n!} = 0.025$$

This means that the 95% confidence interval for 2 collisions is between 0.25 and 7.22 collisions, which means 0.125 for the lower and 3.61 for the upper limit for the collision probability based on 2 collisions. The lower and upper limit presented as factor of the observed number of collision approach to 1. Figure 0-1 shows the factors based on the Poisson distribution as function of the number of collisions.

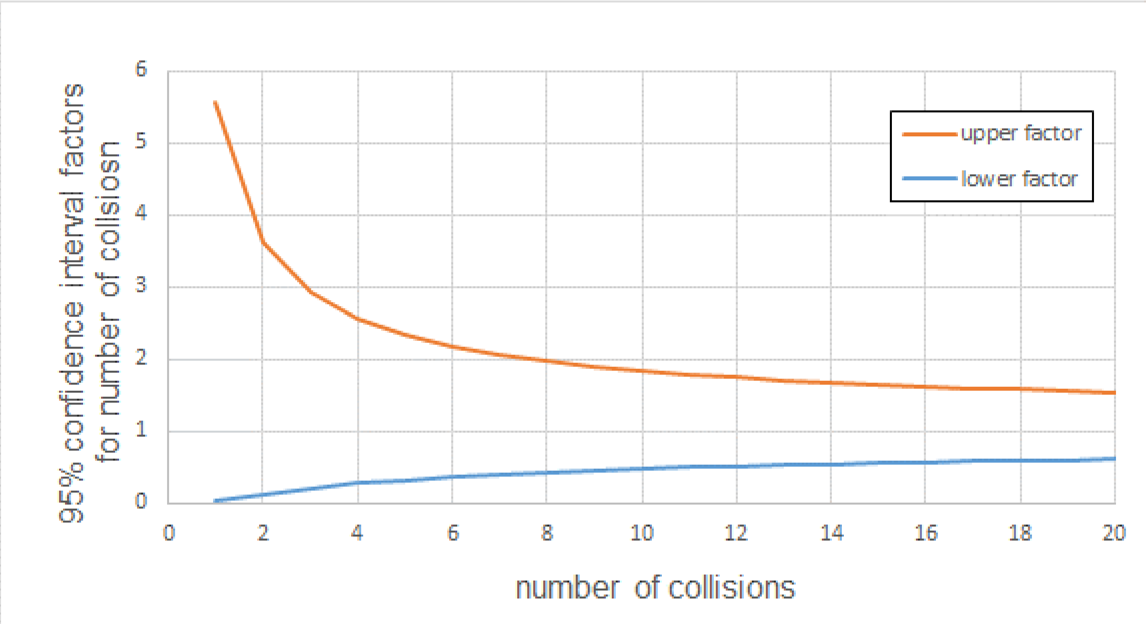

Figure 0-4 95% confidence interval as factor f the number of collisisons.

Thus the 0.47 (inclusive the assignment of the "? RR" collision of Table 0-1) based on 2 collisions observed, means a confidence interval between 0.125*0.47=0.060 and 3.61*0.47=1.704. The 1.363 (of Table 0-3) predicted by SAMSON is located within the confidence interval. This example shows that it is difficult to draw conclusions from the tables.

The soft conclusions taken from Table 0-4 are:

- the number of head-on collisions predicted by SAMSON seems to be a little too high for RR collisions;
- the number of overtaking collisions predicted by SAMSON seems to be too low for all type of collisions;
- the crossing collisions seems to be a little overestimated by SAMSON.

Collisions; a sailing vessel collides with a ship at anchor

There are 13 collisions observed in the period 2005-2013 where a ship hits a ship at anchor. Table 0-5 gives the number of collisions per collision type. Figure 0-4 contains a typical case of a non-route bound ship that collides a route-bound ship at anchor in an anchorage area.

The colliding ship does not take any collision avoidance action. In fact, this ship was all the time on a collision course with the ship at anchor.

Table 0-5 Collisions with ships at anchor in the Dutch sector of the North Sea

Collision type	In anchorage area	In open sea	Grand Total
Ramming N ship with R ship at anchor	3	1	4
Ramming R ship with N ship at anchor		2	2
Ramming N ship with N ship at anchor		2	2
Drifting: Sailing R ship meets failure and drifts to R ship at anchor	1		1
Anchor failure: R ship at anchor drifts to R ship at anchor	1		1
Anchor failure: R ship at anchor drifts to N ship at anchor	1		1
Manoeuvring failure: R ship at anchor rams R-ship at anchor when leaving anchorage area	2		2
Grand Total	8	5	13

The table shows whether the collision has occurred to a ship at anchor in an anchorage area or somewhere else at sea. Four of the five collided ships at anchor in open sea were non-route bound ships.

The collisions described in Table 0-5 are not modelled with the encounter model, but with other models available in SAMSON. For now it is important to indicate that collisions with ships at anchor cannot be neglected.

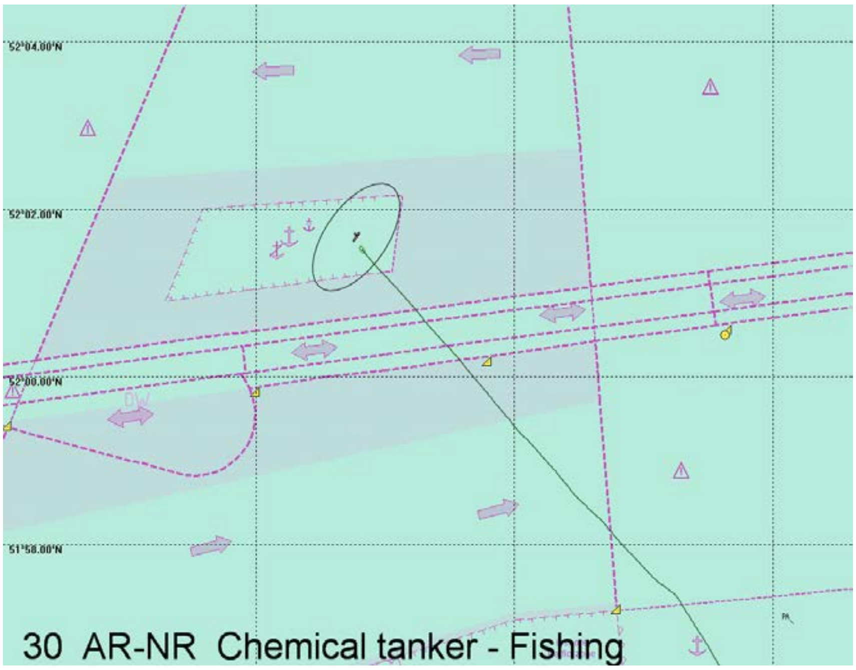

Figure 0-5 Fishing vessel collides a ship in an anchorage area

Non-route bound traffic

The tables with the collisions show that the non-route bound ships takes care for a considerable share of the collisions. In SAMSON, the non-route bound traffic is presented by densities on a grid. It is assumed that these ships sail randomly in these cells. The collision risk is calculated by encounters between route and non-route bound ships.

Conclusions

The main conclusion of the investigation are:

Collisions between sailing ships

- roughly 50% of the collisions are between ships being collision candidates while in the other 50% the collision occurs by the action initiated by one or both ships
- the overall collision risk between sailing ships by SAMSON is 10% higher than is observed;
- the number of head-on collisions predicted by SAMSON seems to be a little too high for RR collisions;
- the number of overtaking collisions predicted by SAMSON seems to be too low for all type of collisions;
- the crossing collisions seems to be a little overestimated by SAMSON.

Collisions by a sailing ship with a ship at anchor

- All incidents occurred by collision candidates.

Remark

SAMSON does not use the encounter model for collisions with objects, such as ships at anchor, offshore platforms and wind turbines, but has developed a different model. A comparison between the observed and calculated collisions with ships at anchor has not been made yet.

APPENDIX E OIL OUTFLOW DISTRIBUTION

MARIN

MEMO

To	:	IALA Risk Management Steering Group
From	:	Kees van der Tak
CC	:	
Date	:	September, 1st, 2015
Project No	:	27656.600
Subject	:	Oil outflow distribution

Introduction

MARIN has prepared some tables, which belong to the SAMSON model, that describe the outflow of:

- cargo oil from cargo tanks of tankers;
- fuel oil from fuel tanks of all ships.

These tables are made available to IALA for implementation in IWRAP.

The basis for the tables are the worldwide casualty statistics of Lloyd's Register Fairplay and the presence of oil and chemicals in ships. The worldwide casualty database contains the ships involved in casualties and information about the type and consequence of the casualty. The initial event is called the incident. Succeeding events, as for example sinking or fire can be the consequence of the first incident. One casualty record in the database describes the first incident and all succeeding events as result of the incident. The casualties are categorized by the first incident. The most frequently ones are, CN for collision, CT for contact, FD for foundered, FX for fire/explosion, WS for wrecked/stranded. Information is available about oil outflow, sinking of ships and hull penetration. Further, the damage distribution functions of IMO are applied.

This memo first gives a description of the contents of the outflow tables. Then, it describes the preparation of the tables.

Outflow tables

The outflow tables are given separately for bunker oil and cargo oil. The presence of cargo oil and the resulting maximum outflow is based on the reports of dangerous goods in Rotterdam in 2008 and contains the carriage of:

- Crude oil (UN number 1267);
- Oil products (UN numbers 1202, 1203, 1223, 1268, 1300 and 1863);
- HFO;

The outflow volume classes in cubic meters are:

1. >0 - < 20 m^3
2. 20 - < 150 m^3
3. 150 – < 750 m^3
4. 750 – < 3,000 m^3
5. 3,000 – < 10,000 m^3
6. 10,000 – < 30,000 m^3
7. 30,000 – < 100,000 m^3
8. 100,000 m^3 and more

The size classes of the ships are given in Table 1. This table presents size classes for both route-bound ships and for non-route-bound ships.

Table 1 Size classes of ships

Size class	Route-bound ships	Non-route-bound ships
1	100 - < 1,000 GT	0 - < 50 GT
2	1,000 - < 1,600	50 - < 100 GT
3	1,600 – < 5,000 GT	100 - < 500 GT
4	5,000 – < 10,000 GT	500 - < 1,000 GT
5	10,000 – < 30,000 GT	1,000 - < 1,600 GT
6	10,000 – < 30,000 GT	1,600 - < 5,000 GT
7	60,000 – < 100,000 GT	5,000 – 10,000 GT
8	100,000 GT and more	10,000 and more

The output files contain:

- type of outflow from casualty*
- type number of the ship
- size class
- type name of the ship
- expon(I,j) = fraction of ships with cargo on board
- average quantity on board in case of cargo on board
- pflow(I,j,1) probability of none outflow
- pflow(I,j,2) probability of outflow in volume class 1
- pflow(I,j,3) probability of outflow in volume class 2
- pflow(I,j,4) probability of outflow in volume class 3
- pflow(I,j,5) probability of outflow in volume class 4
- pflow(I,j,6) probability of outflow in volume class 5
- pflow(I,j,7) probability of outflow in volume class 6
- pflow(I,j,8) probability of outflow in volume class 7
- pflow(I,j,9) probability of outflow in volume class 8
- pflow(I,j,10) sum of probability of outflow in volume classes 1-8
- xflow(I,j,1) volume of outflow in case of none outflow, thus always 0
- xflow(I,j,2) outflow in m3 in class 1
- xflow(I,j,3) outflow in m3 in class 2
- xflow(I,j,4) outflow in m3 in class 3
- xflow(I,j,5) outflow in m3 in class 4
- xflow(I,j,6) outflow in m3 in class 5
- xflow(I,j,7) outflow in m3 in class 6
- xflow(I,j,8) outflow in m3 in class 7
- xflow(I,j,9) outflow in m3 in class 8
- xflow(I,j,10) sum of outflow in m3 in classes 1-8

* type of outflow from a casualty
The following codes are used:

colcargo	for cargo oil from collisions
fxscargo	for cargo oil from fire/explosions
fd_cargo	for cargo oil from foundering
hmhcargo	for cargo oil from hull failure
dricargo	for cargo oil from contact
prscargo	for cargo oil from wrecked/stranding
colbunke	for bunker oil from collisions
fxsbunke	for bunker oil from fire/explosions
fd_bunke	for bunker oil from foundering
hmhbunke	for bunker oil from hull failure
dribunke	for bunker oil from contact
prsbunke	for bunker oil from wrecked/stranding

The outflow distribution is determined based on a loaded ship. In the SAMSON model, the fraction of the ships with dangerous goods on board (expon) is extracted from what is found for the ships calling Rotterdam. Therefore, each casualty has to be multiplied with the given expon to determine whether or not the ship is loaded. In case, for example, in a simulation, you know exactly if the ships is loaded or not. Expon has the value 1 for a loaded ship and 0 for an unloaded ship.

Thus the average outflow in a certain volume class is xflow(I,j,k) / pflow(I,j,k).and the probability of an outflow in volume class k for a ship type I and size j = expon(I,j) * pflo(I,j,k).

Please note that the outflow distributions provided are worldwide average values. For example, for use of the outflow tables in Dutch waters, the outflow for a wrecked/stranded incident (prscargo and prsbunke) is changed. These values set to zero, because of the sandy bottom around the Netherlands gives a negligible change of an oil spill.

The outflow tables have been delivered for the outflow of cargo and bunker oil separately.

Preparation of outflow tables

In http://www.iala-aism.org/wiki/iwrap/images/8/84/Outflow.pdf, the outflow model is described based on the worldwide casualty statistics from 1990 to 2002. Since then, important developments have taken place. The most important one is the transition of single hull oil tankers to double hull oil tankers, which has considerably reduced the probability of an outflow after a casualty. Therefore, the outflow distributions have been updated in 2015 based on the worldwide casualties of 2003 to 2012.

The same method is used to determine the outflow distributions for bunker and cargo oil. For both, first, it has to be determined whether a tank is penetrated or not and, next, whether the tank is loaded or not and whether it is loaded with cargo oil or with fuel oil. Two parameters play a dominant role in the determination of the outflow distribution, namely:

- the probability that a ship sinks after the incident;

- the probability that the damage is such that the hull of a ship is penetrated. In case the damage location is a tank, this tank is penetrated. For a tank within a double hull, also the inner hull has to be penetrated for an outflow. The damage distribution functions as described in the referenced model are still used for this purpose.

In case the vessel sinks after the incident, all oil is assumed to flow out. This is both the oil lost to the environment and the oil that in reality remains in the vessel that is sunken. This principle is also used by the International Tanker Owners Pollution Federation (ITOPF).

In case a cargo tank is penetrated above the waterline, it is modelled that all oil above the underside of the hole flows out. In case of a hole below the waterline, it is assumed that all oil of the cargo tank flows out.

These are worst case scenarios, because in reality the outflow can often be a mitigated. In case of penetrated tanks, this can be done by pumping the oil to another tank and in case of a sunken ship, the oil tanks can be emptied by salvage ships without any spill.

The casualty database of Lloyd's Register Fairplay does not contain 100% of all casualties. This became clear when the LRF casualty database was compared with the Dutch national database. For each casualty type, a multiplier has been determined to achieve the correct level of casualties. It is assumed that the missing casualties are casualties with minor damage, thus casualties that not contribute to the outflow of substances.

The next two chapters describe how the two above mentioned main parameters for an outflow are determined based on the worldwide casualty database of LRF of the period of 2003-2012.

In the chapter thereafter, a validity check is performed by comparing the predicted number of spills by using the calculated outflow distributions with the observed number of spills in the casualty database.

The outflow distributions have been determined for casualties at sea. In the last chapter it is tested and concluded that the outflow distributions determined for at sea can also be used in restricted waters and port areas.

The outflow of bunker oil for non-route-bound ships could not be determined similar to the route-bound ships, because casualties with non-route-bound ships (often less than 100GT) are not included in the casualty database of LRF. Therefore, the outflow of bunker oil from non-route-bound ships is taken over from the dry cargo ships.

Determination of the probability of sinking as result of a casualty

This chapter describes how the probability that a ship sinks after being involved in a casualty is determined based on the worldwide casualty database of LRF of the period of 2003-2012.

The largest spill for a certain ship type and size occurs when the ships sinks, because in that case all fuel oil and/or cargo oil will be spilt. Therefore, it is essential to know the fraction of ships that will sink/founder after the initial incident. For casualty type "foundered' the fraction is 1, but for the other types of casualties the fraction has to be determined from the casualty database. Because of the very few sinkings after an incident this cannot be done by simply dividing the number of sinkings by the number of casualties.

The process to determine the probability that a ship sinks after a casualty that is followed instead, is described here for oil tankers. The same approach has been followed for determining the probabilities of sinking after a casualty for the other ship types. The ship type oil tanker is chosen as example, because it is, of course, the ship type with the largest contribution to spills. The fraction "sunken after the incident" has been determined for each ship type and size class separately, as it varies strongly over these classes. For example, ship types designed as one-compartments ships, sink very often after a severe damage while ship types designed as multi-compartment ships, such as tankers, sink seldom after an incident.

First, for each ship type it is determined how many incidents occurred in the period 2003 to 2012. For ship type “Oil” (oil tankers) at sea this is 243, see Table 2. (For the definition of the ship size classes refer to the chapter “Outflow tables”.)

Next, it is determined how many “Oil” ships sunk after the incident, see Table 3.

*Table 2 Incidents for ship type **oil in de period 2003-2012***

Year	(Multiple Items)	2003- 2012
Pollution Type	(All)	
Foundered_after_casualty	(All)	
Smain2006	Oil	Oil tankers
Severity Ind	(All)	
EnvLocCode	S	At sea

Type of casualty	**Ship size classes**								**Grand Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
CN (Collision)	17	4	9	5	14	22	16	13	100
CT (Contact)	1		2	1	4		1	1	10
FD (Foundered)	6	2	1	1					10
FX (Fire / Explosion)	3		3	4	9	3	6	4	32
H (Hull failure part of HM Hull/Machinery)	3	1	3	1	2	4	4	5	23
WS (Wrecked / Stranded)	14	4	16	3	8	18	4	1	68
Grand Total	**44**	**11**	**34**	**15**	**37**	**47**	**31**	**24**	**243**

Table 3 Incidents after which the ship sunk after the incident, for oil tankers in the period 2003-2012

year	(Multiple Items)	2003-2012
Pollution Type	(All)	
Foundered_after_collision	(Multiple Items)	Only cases that sunk
Smain2006	Oil	Oil tankers
EnvLocCode	S	At sea

Type of casualty	**Ship size classes**				**Grand Total**
	1	**2**	**3**		
CN	1	2			3
FX	1		1		2
Grand Total	**2**	**2**	**1**		**5**

The probability of sinking after an incident is much lower for a large ship than for a small ship. It is assumed that the ratio over the size classes for sinking after an incident is similar to the ratio over the size classes for spontaneous sinking (thus casualty type FD). The casualty probability for FD is derived from the worldwide casualty database for the period 2003-2012 and for oil tankers given in Table 4.

*Table 4 Probability of foundering per million year at sea (= CASRATFD * nms per year at sea)*

	Ship size class							
	1	2	3	4	5	6	7	8
Foundered per 10^6 year at sea	639.76	575.74	441.77	267.89	112.22	27.97	27.49	27.45

Table 5 contains the number of incidents of Table 2 multiplied with the probability of foundering of Table 4 per million year at sea used as foundering sensitivity after an incident. Only a scaling factor has still to be applied to get the right level. The column "1-8" of Table 5 contains the sum of the values per size class. The last column column "FD_after_[]" contains the number of founderings after that incident found in the casualty database for the period 2003-2012. In case that none incidents were found a value of 0.4 is taken, preventing the conclusion that such an incident will never occur in the future. The scaling factor for the probability of sinking, is the number observed, divided by the value in column "1-8", thus 3/21477 for foundered_after_CN (sinking after being involved in a collision). Table 6 with the sinking probability after an incident is derived by multiplying the foundering sensitivity of Table 4 with the scale factor derived from Table 5. For example "factor FD_after_CN" for an oil tanker in size class 1 of Table 6 is 639.76 * 3 / 21477 = 0.089632.

Table 5 Number of incidents for ship type oil multiplied with the probability of foundering per million year at sea

Foundered_after_...	CASRATFD * nms * incidents per ship size class									FD_ after_[]
	1	2	3	4	5	6	7	8	1-8	
foundered_after_CN	10876	2303	3976	1339	1571	615	440	357	21477	3
foundered_after_CT	640	0	884	268	449	0	27	27	2295	0.4
foundered_after_FX	1919	0	1325	1072	1010	84	165	110	5685	2
foundered_after_H	1919	576	1325	268	224	112	110	137	4672	0.4
foundered_after_WS	8957	2303	7068	804	898	504	110	27	20670	0.4

Table 6 Probability of sinking after an incident for ship type oil tanker

Foundered_after_...	Casrat FD after incident per ship size class							
	1	2	3	4	5	6	7	8
factor FD_after_CN	0.089362	0.080421	0.061707	0.037419	0.015675	0.003907	0.003840	0.003835
factor FD_after_CT	0.111504	0.100347	0.076997	0.046690	0.019559	0.004875	0.004792	0.004785
factor FD_after_FD	1	1	1	1	1	1	1	1
factor FD_after_FX	0.225077	0.202556	0.155422	0.094246	0.039481	0.009841	0.009672	0.009658
factor FD_after_H	0.054776	0.049296	0.037825	0.022936	0.009608	0.002395	0.002354	0.002351
factor FD_after_WS	0.012380	0.011141	0.008549	0.005184	0.002172	0.000541	0.000532	0.000531

The foundering rate varies considerably over the different ship types. Therefore, the process described here for oil tankers has been repeated for all other ship types. Table 7 for all ship types is the equivalent of Table 3 for oil tankers only.

The validity of the approach followed, can be shown by comparing the observed number of sinkings after an incident at sea (presented in Table 7, which is the equivalent of table 2 for oil tankers) with the predicted number from this approach in Table 8. Table 8 contains the predicted number of casualties (thus sinking and not sinking after the incident) multiplied with the corresponding factor FD-after_[]. Table 7 and Table 8 are reasonable in line with each other.

Only for the larger ship size classes 6 and 8, the predicted number of sinkings after an incident is considerably lower than observed. Of course, the model can be less correct for this size class, but it can also be caused by the small numbers. In size class 7 and 8 respectively, 1 and 2 incidents were observed. The statistical results from such low numbers will be inaccurate. This can be proven by the 95% confidence interval. Around an observation of 1 this can vary from 0.03 to 5.57 and for an observation of 2 the interval runs from 0.25 to 7.22.

To check for other reasons that can explain the lower number of predicted incidents with large ship size classes, the ship types of these 13 incidents are looked up in the casualty database. It was found that there were 7 bulkers, 3 container ships, 1 roro ship, 1 passenger ship and 1 semi-submersible platform. It was concluded that these are all ships that sink relatively fast due to the minor number of compartments. Among these sunken ships there were no oil tankers, thus, a possible underestimation for these ships in these size classes will only have negligible impact on the outflow of oil, in fact only on the outflow of bunker oil.
To account for this very small effect, it is decided to multiply the factors for foundering after an incident for the size classes 6, 7 and 8 with 2.

Table 7 Incidents at sea after which the ship sinks found in the casualty database in the period 2003-2012, summarized over all ship types

Casualty type	Ship size class								Total
	1	2	3	4	5	6	7	8	
CN	47	19	32	6	9	3	1	1	118
CT	7	3	8	1					19
FX	31	5	9	2	5	1			53
H	21	1	10	3	1	2			38
WS	16	2	8	7	7	4		1	45
Grand Total	**122**	**30**	**67**	**19**	**22**	**10**	**1**	**2**	**273**

Table 8 Predicted Incidents at sea in which the ship sinks, by multiplying the number of incidents with the corresponding factor FD_after_[] for the period 2003-2012, summarized over all ship types

Casualty type	Ship size class								Total
	1	2	3	4	5	6	7	8	
CN	48.81	14.54	36.09	10.50	8.06	1.45	0.39	0.14	119.97
CT	9.92	2.02	6.43	1.59	0.65	0.07	0.03	0.01	20.71
FX	30.09	4.67	10.94	4.30	2.95	0.80	0.15	0.08	53.97
H	18.38	3.81	11.20	2.87	2.48	0.38	0.23	0.04	39.39
WS	19.45	5.23	13.67	4.17	3.63	0.71	0.33	0.02	47.21
Grand Total	126.64	30.27	78.33	23.43	17.76	3.41	1.13	0.29	281.26

Determination of the probability of penetration of the hull

This chapter describes how the probability that the damage is such that the hull of a ship is penetrated is determined based on the worldwide casualty database of LRF of the period of 2003-2012.

The IMO penetration functions (see referenced document of the SAMSON model) are still used to determine the probability of one or more penetrated cargo or fuel tanks. The functions are applied to ships of which it is known that the outer hull is penetrated. The fraction of ships of which the hull is penetrated is determined from the casualty database for the period 2003-2012 for casualties at sea. The casualties with penetrations are found by searching in different fields. The casualty record contains a field that indicates whether or not outflow of substances has occurred. It also contains fields that describe the damage in terms of text such as “broke in two” or “holed”. And the last field that helps to conclude whether the casualty resulted in penetration or not is the textual description of the casualty.

The method described is applied to all ships. Again, oil tankers have been used as example to describe the method.

Table 9 contains the number of hull penetrations for oil tankers in the period 2003 to 2012. Please note that this does not mean that all these incidents result in oil outflow, because the inner hull can be undamaged or the penetration can be outside the cargo part.

Table 9 Incidents in which the ship hull is penetrated after the incident, for oil tankers at sea in period 2003-2012

Type of casualty	Ship size classes								
	1	2	3	4	5	6	7	8	Grand Total
CN (Collision)	3	2	2	1		2	4	3	17
CT (Contact)			1		2				3
FD (Foundered)	6	2	1						9
FX (Fire / Explosion)	1		1						2
H (Hull failure part of HM Hull/Machinery)	1			1		2	3	2	9
WS (Wrecked / Stranded)		3	2	1	2		1		9
Grand Total	**11**	**7**	**7**	**3**	**4**	**4**	**8**	**5**	**49**

Thus, Table 9 divided by the total number of casualties of Table 2 gives the fraction of casualties in which the hull of the oil tanker is penetrated.

Tables, similar to Table 2 and Table 9 for oil tankers, were determined also for all other ship types. It can be observed that the penetration probability strongly depends on the ship size, but is not so dependent on the ship type. This corresponds to the expectations because the penetration strength of the hull is related to the size of the ship.
By using all ship types, the fraction of penetration could be determined with higher accuracy, because the numbers were larger as shown in Table 10 and Table 11. This approach after some smoothing has resulted into Table 12 with the fraction of ships that will be penetrated in case of a casualty. Table 12 is used in the calculations of the outflow distributions.

Table 10 Incidents for all ship types in the period 2003-2012

Type of casualty	Ship size classes								
	1	2	3	4	5	6	7	8	Grand Total
CN (Collision)	162	74	267	160	250	134	63	25	1135
CT (Contact)	35	11	44	21	26	12	3	2	154
FD (Foundered)	186	54	117	38	29	4	1		429
FX (Fire / Explosion)	56	34	104	81	130	75	29	11	520
H (Hull failure part of HM Hull/Machinery)	64	24	94	41	71	45	26	8	373
WS (Wrecked / Stranded)	239	104	375	127	197	106	25	4	1177
Grand Total	**742**	**301**	**1001**	**468**	**703**	**376**	**147**	**50**	**3788**

Table 11 Incidents in which the ship hull is penetrated after the incident, for all ships at sea in the period 2003-2012

Type of casualty	Ship size classes								
	1	2	3	4	5	6	7	8	Grand Total
CN (Collision)	39	24	57	20	36	17	12	8	213
CT (Contact)	10	3	14	3	6	2	1		39
FD (Foundered)	183	52	114	37	28	3	1		418
FX (Fire / Explosion)	10		9	6	8	4			37
H (Hull failure part of HM Hull/Machinery)	39	11	62	17	27	22	13	4	195
WS (Wrecked / Stranded)	55	23	83	36	50	17	7	1	272
Grand Total	**336**	**113**	**339**	**119**	**155**	**65**	**34**	**13**	**1174**

Table 12 Fraction of the incidents in which the ship hull is penetrated after the incident, for all ships at sea in the period 2003-2012

Type of casualty	Ship size classes							
	1	2	3	4	5	6	7	8
CN (Collision)	0.267	0.320	0.211	0.124	0.144	0.127	0.227	0.227
CT (Contact)	0.293	0.357	0.320	0.136	0.231	0.176	0.176	0.176
FD (Foundered)	1	1	1	1	1	1	1	1
FX (Fire / Explosion)	0.119	0.076	0.061	0.047	0.036	0.034	0.020	0.020
H (Hull failure part of HM Hull/Machinery)	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
WS (Wrecked / Stranded)	0.232	0.232	0.232	0.232	0.232	0.232	0.232	0.232

The penetration probability of Table 12 for each ship type and size together with the probability of sinking after an incident are input data for the outflow calculation. The distribution of the outflow volume classes, is still obtained from the damage distributions of IMO.

Validity check of the models used

The outflow distributions can now be calculated with a module of SAMSON. First, a summary of the input and output is given. Thereafter, the validity check is performed by applying the outflow distributions to the casualties of 2003 to 2012 in the casualty database. The number of casualties is first multiplied with the incompleteness factor for that type of casualties. Then, the predicted number of outflows can be checked with the reported number of outflows in the same casualty database from 2003 to 2012. This can be done for the number of outflows and the distribution of the volume of the outflow.

Calculation of the outflow distributions
The input for the outflow calculation in exists of:

For each ship type and size class:

- the typical tank layout of a ship, thus number and position of fuel, ballast and cargo tanks;
- fraction of ships that founder after being involved in a casualty (updated, see before);
- fraction of ships that are penetrated for each type of casualty (updated, see before);
- the dangerous goods reports in Rotterdam of 2008 to determine which fraction of the ships carry oil ;

and the general input:

- 8 volume size classes;
- the damage distribution functions to predict the number of penetrated tanks;

The output of the calculation is casualty type, ship type, size class and the probabilities and amounts of outflow in the eight given volume classes (see Outflow tables).

The calculated outflow distribution with the updated parameters is validated by comparing the predicted outflows with the reported outflows. The predicted outflows per ship type are obtained when all casualties are multiplied with the outflow distribution for that ship type.
As an example, this comparison is performed in this chapter for oil tankers at sea. The reported outflows are taken from the worldwide casualty database of 2003 to 2012.

Comparison of number of outflows
Table 13 contains the result for the probability of an outflow of cargo oil, Table 14 for the outflow of bunker oil and Table 15 contains the sum of the probabilities of the two tables. For the casualty FD always bunker oil is spilt. Therefore, the total probability for FD in Table 15 is equal to the probability of an outflow of bunker oil Table 14.

Table 13 Cargo oil spills based on casualties with oil tankers at sea in the database multiplied with outflow probabilities

Type of casualty	Cargo oil spills per size class of ship								Total
	1	2	3	4	5	6	7	8	
CN	1.43	0.05	0.15	0.15	0.50	0.82	1.13	1.11	5.34
CT	0.06	0.00	0.03	0.03	0.13	0.00	0.03	0.04	0.31
FX	0.18	0.00	0.02	0.06	0.13	0.03	0.06	0.05	0.53
H	0.02	0.00	0.01	0.01	0.02	0.04	0.08	0.12	0.31
WS	1.03	0.03	0.28	0.16	0.44	1.20	0.30	0.10	3.54
Total	2.72	0.09	0.50	0.41	1.22	2.10	1.61	1.41	10.04
FD	3.00	0.17	0.11	0.33	0.00	0.00	0.00	0.00	3.61

Table 14 Bunker oil spills based on casualties with oil tankers at sea in the database multiplied with outflow probabilities

Type of casualty	Bunker oil spills per size class of ship								total
	1	2	3	4	5	6	7	8	
CN	1.70	0.37	0.62	0.21	0.30	0.28	0.26	0.21	3.94
CT	0.12	0.00	0.18	0.05	0.12	0.00	0.02	0.02	0.51
FX	0.36	0.00	0.18	0.19	0.33	0.06	0.12	0.08	1.31
H	0.11	0.04	0.07	0.01	0.02	0.03	0.05	0.06	0.38
WS	0.26	0.07	0.25	0.04	0.08	0.14	0.03	0.01	0.89
Total	2.55	0.49	1.30	0.49	0.85	0.51	0.47	0.38	7.03
FD	6.00	2.00	1.00	1.00	0.00	0.00	0.00	0.00	10.00

Table 15 Cargo + bunker oil spills based on casualties with oil tankers at sea in database multiplied with outflow probabilities

Type of casualty	Cargo +bunker oil spills per size class of ship								total
	1	2	3	4	5	6	7	8	
CN	3.13	0.42	0.77	0.36	0.79	1.09	1.39	1.33	9.28
CT	0.54	0.00	0.20	0.25	0.45	0.10	0.18	0.12	1.84
FX	0.14	0.04	0.08	0.02	0.04	0.07	0.13	0.18	0.69
H	0.18	0.00	0.21	0.08	0.25	0.00	0.05	0.05	0.82
WS	1.29	0.11	0.54	0.20	0.52	1.34	0.33	0.11	4.43
Total	5.27	0.57	1.80	0.90	2.06	2.60	2.08	1.79	17.07
FD	6.00	2.00	1.00	1.00	0.00	0.00	0.00	0.00	10.00

The casualty type FD is mentioned separately because in most cases no oil spill was reported in the casualty database, while in our approach a spill always occurs, namely at least the fuel oil is spilt when a ship founders. The casualty database reports only spills that actually occur, thus when a ship sinks with oil in undamaged tanks this is not reported as a spill. Therefore, the comparison between predicted and actual numbers will show a large overestimation for the casualty type foundering. For the other casualty types this is only a small difference because the probability of sinking after an incident is relatively small.

The number of cargo and/or fuel oil spills at sea by oil tankers at sea in the period 2003-2012 reported in the worldwide casualty database is presented in Table 16. In the ideal case, Table 15 and Table 16 would be equal. However this is statistically impossible, certainly due to the very low occurrences. Table 16 has to be seen as one realization of the Poisson distributions with the mean values of Table 15.

Table 16 Cargo + bunker oil spills reported in casualty database

Type of casualty	Cargo +bunker oil spills per size class of ship								Total
	1	2	3	4	5	6	7	8	
CN	3					1	2		6
CT					1				1
FX	1								1
H									
WS		1							1
Total	4	1			1	1	2		9
FD	3								3

The prediction for the number of spills for oil tankers at sea is 17.07 for the casualty types without foundering (FD) while the reported number of spills is 9. This means that the conservative assumptions indeed result in an overall overestimation.
There are 10 oil tankers foundered, see Table 15, (thus 10 spills of at least bunker oil) of which only three has reported a spill (see Table 16).

It can be concluded that the predicted outflow probabilities are in line with the reported probabilities.

Comparison of the outflow volumes

Table 17, Table 18 and Table 19 contain the outflow per volume size class. In the tables, the distribution for bunker and cargo oil outflow are classified separately for FD. Table 20 contains the distribution based on the oil amount spilt as reported in the casualty database. Thus, Table 19 has to be compared with Table 20. In 50% of the cases the volume spilt is not reported. In the other 50%, the reported volumes seem to be less than predicted. This is the effect of mitigating measures in reality which are not included in the outflow figures. Furthermore, the number of spills on which the judgement has to be done is very low.

Table 17 Cargo oil spills based on casualties with oil tankers at sea in database multiplied with outflow probabilities

Type of casualty	Cargo oil spills per spill size class in m^3								total
	<20	<150	<750	<3,000	<10,000	<30,000	<100,000	<999,000	
CN	0.13	0.47	0.86	1.42	1.05	0.92	0.32	0.18	5.34
CT	0.00	0.00	0.02	0.06	0.12	0.09	0.01	0.01	0.31
FX	0.00	0.00	0.03	0.15	0.03	0.16	0.06	0.11	0.53
H	0.00	0.00	0.01	0.03	0.04	0.22	0.00	0.01	0.31
WS	0.00	0.60	0.47	0.39	0.59	1.34	0.15	0.01	3.54
Total	0.13	1.07	1.39	2.05	1.83	2.72	0.54	0.32	10.04
FD	0.00	0.00	0.54	2.63	0.13	0.31	0.00	0.00	3.61

Table 18 Bunker oil spills based on casualties with oil tankers at sea in database multiplied with outflow probabilities

Type of casualty	Bunker oil spills per spill size class in m^3								Total
	<20	<150	<750	<3,000	<10,000	<30,000	<100,000	<999,000	
CN	0.59	2.38	0.48	0.42	0.07	0.00	0.00	0.00	3.94
CT	0.00	0.30	0.10	0.10	0.02	0.00	0.00	0.00	0.51
FX	0.00	0.54	0.19	0.50	0.08	0.00	0.00	0.00	1.31
H	0.01	0.21	0.04	0.07	0.04	0.00	0.00	0.00	0.38
WS	0.06	0.56	0.13	0.13	0.01	0.00	0.00	0.00	0.89
Total	0.66	3.99	0.94	1.22	0.22	0.00	0.00	0.00	7.03
FD	0.00	9.00	1.00	0.00	0.00	0.00	0.00	0.00	10.00

Table 19 Cargo + bunker oil spills based on casualties with oil tankers at sea in database multiplied with outflow probabilities

Type of casualty	Cargo +bunker oil spills per spill size class in m^3								Total
	<20	<150	<750	<3,000	<10,000	<30,000	<100,000	<999,000	
CN	0.72	2.85	1.33	1.84	1.13	0.92	0.32	0.18	9.28
CT	0.00	0.30	0.13	0.25	0.04	0.16	0.06	0.11	1.04
FX	0.00	0.54	0.20	0.54	0.12	0.22	0.00	0.01	1.62
H	0.01	0.81	0.52	0.46	0.64	1.34	0.15	0.01	3.93
WS	0.06	0.56	0.15	0.19	0.12	0.09	0.01	0.01	1.20
Total	0.80	5.06	2.33	3.27	2.04	2.72	0.54	0.32	17.07
FD	0.00	9.00	1.54	2.63	0.13	0.31	0.00	0.00	13.61

Table 20 Cargo + bunker oil spills from oil tankers reported in the casualty database

Type of casualty	Cargo +bunker oil spills per spill size class in m^3								Total
	Spill size not reported	<20	<150	<750	<3,000	<10,000	<30,000	<100,000	
CN	1	1	2		2				6
CT	1								1
FX	1								1
H									
WS	1								1
Total	4	1	2		2				9
FD	2	1							3

Outflow distribution in restricted water and in port area

The outflow distributions have been determined for casualties at sea. This chapter tests whether the outflow distributions determined for at sea can also be used in restricted waters and port areas.

In the preceding chapters, the outflow is calculated for the casualties “At Sea”, because it was expected that the damage for casualties at sea is larger than for casualties in restricted water or in a port area. This hypothesis is checked with Table 17 and Table 18. Table 17 contains all casualties with oil tankers in the three areas. The right part of the table contains the number of spills reported in the database divided by the number of casualties. For the three areas, number of spills per type of casualty are of the same order of magnitude. Only in case of casualty type H (sub part of Hull/Machinery) the outflow in the port area seems to be much higher. However, in the casualty database, the reason was found. The damage in the port area was the effect of contacts with an object after a Hull/Machinery failure, while at sea the damage is caused by the adverse weather conditions. This type of casualty is modelled by an engine failure resulting in a contact. Hull damage by adverse weather conditions does not occur in a port area.
Table 22 contains the number of spills in each area reported in the casualty database and the predicted spills out of the number of casualties when the same distribution functions are applied as at sea. Comparing the right and left part of Table 22, it can be concluded that the same distribution functions can be used in the three areas.

Table 21 Number of incidents and fraction of incidents with oil tankers resulting in a spill for the different areas

Type of casualty	Number of incidents in 2003-2012				Number of spills / number of incidents			
	Port	Restricted waters	At Sea	Total	Port	Restricted waters	At Sea	Total
CN	94	48	100	242	0.064	0.104	0.060	0.070
CT	34	18	10	62	0.088	0.222	0.100	0.129
FX	65	12	32	109			0.031	0.009
H	20	1	23	44	0.150			0.068
WS	54	99	68	221	0.074	0.030	0.015	0.036
Total	267	178	233	678	0.060	0.067	0.039	0.055
FD	5	3	10	18	0.400	0.333	0.300	0.333

Table 22 Reported and prediction number of incidents with oil tankers resulting in a spill for the different areas

Type of casualty	Number of incidents with spill in 2003-2012				Predicted number of spills based on the number of incidents in 2003-2012				Predicted/observed
	Port	Restricted waters	At Sea	Total	Port	Restricted waters	At Sea	Total	
CN	6	5	6	17	7.91	4.51	9.28	21.70	1.28
CT	3	4	1	8	4.49	0.79	1.84	7.12	0.89
FX			1	1	0.51	0.03	0.69	1.24	1.24
H	3			3	2.63	1.52	0.82	4.97	1.66
WS	4	3	1	8	3.28	6.10	4.43	13.81	1.73
Total	16	12	9	37	18.82	12.95	17.07	48.84	1.32
FD	2	1	3	6	5.00	3.00	10.00	18.00	3.00