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Acronym **EfficienSea**

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A tool that makes the link between Aids to Navigation, traffic volume and the associated risk

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Content

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1 Scope

The purpose of this report is to explain a method that can be used to evaluate the effect of the aids to navigation. An aid to navigation (AToN) is any device external to a vessel specifically intended to assist navigators in determining their position or safe course, or to warn them of dangers or obstructions to navigation. The effect of aids to navigation is here quantified by causation factors explained in the report. The method developed is closely linked to the IALA risk tool software IWRAP and the results from the method are a set of causation factors that can be used when creating a waterway model in IWRAP. The report outlines how the method has been derived and it presents a software tool for using the method. The modeling tool used is Bayesian networks.

2 Background

Today most risk models for estimating the grounding or collision frequency are routed in the approach defined by Fujii et al. and by MacDuff. That is, the potential number of ship grounding or ship-ship collisions is first determined as if no aversive maneuvers are made. This potential number of ship accidents is based on 1) an assumed or prespecified geometric distribution of the ship traffic over the waterway and 2) on the assumption that the vessels are navigating blindly as these are operating at the considered waterway. The thus obtained number of potential accident candidates (often called the geometric number of collision candidates) is then multiplied by a specified causation probability to find the actual number of accidents. The causation probability, which acts as a thinning probability on the accident candidates, is estimated conditional on the defined "blind navigation". The method has been refined by Petersen and Friis and implemented by Gatehouse in the software package IWRAP. The software has been thoroughly tested using models from all over the world, and it has been found to give results similar to historical data. The basic idea of the method is shown in Figure 1.

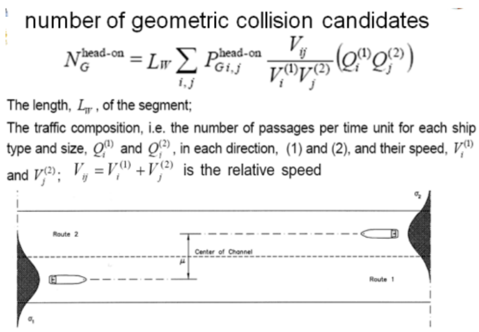

Figure 1: Sketch of the IWRAP method to estimate head-on collision frequency

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2.1 Causation factors

One of the cornerstones in the IWRAP model is the use of causation factors. A causation factor is the probability that a person does not act as he or she is supposed to. The causation factor depends on a range of factors from safety culture of the shipping company to the layout of the waterway. Causation factors are in the order of 10^{-4}, meaning that one out of 10000 times an operation is carried out wrongly. From the waterway authorities point of view it would be valuable to know what the effect of its aids to navigation has on the collision and grounding frequencies. In the figures below some causation factors for different parts of the world are showed. It is important to remember that the smaller a causation factor is the better. A causation factor on 1 means that the navigator always acts incorrectly. 0 means that he always acts correctly.

Ship-ship collisions			
Location	**P_c [$\times10^{-4}$]**	**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

Figure 2: Collision causation factors from the literature.

Vessel grounding			
Location	**P_c [$\times10^{-4}$]**	**Comment**	**Reference:** see [20] for ref.
Japanese Straits	[1.0; 6.3]	Collisions and grounding	Fujii
Japanese Straits	1.58		Fujii & Mizuki [9]
Japanese Straits	[0.8; 4.3]		Matsui
Dover Strait	1.55	No traffic separation	MacDuff [21]
Dover Strait	1.41	With traffic separation	MacDuff [21]
Strait of Gibraltar	2.2		COWIconsult
Øresund, Denmark	2.0		Karlson *et al.* [19]

Figure 3: Grounding causation factors from the literature.

3 Method for estimating causation factors

A good and simple method for estimating causation factors is to create a model of the waterway using IWRAP and then relate the number of calculated collisions and grounding to the actual number of historical collisions and grounding. This gives the causation factors. The problem with this method is that it requires the actual number of historical collisions and groundings on each leg and in each crossing point. Because the number of incidents in general is very low, we cannot apply this method leg by leg.

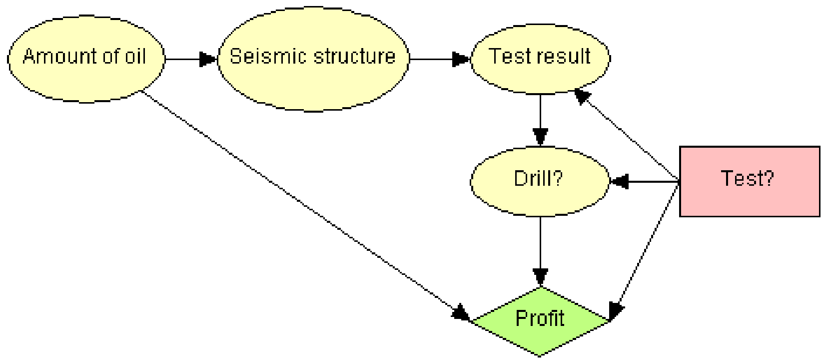
Instead we will try to model what actually goes on, on the bridge of the ship. This is attempted using Bayesian Networks. A Bayesian Network is a graphical representation of uncertain quantities (and decisions) that explicitly reveals the probabilistic dependence between the set of variables and the flow of information in the model. A Bayesian Network is designed as a knowledge representation of the considered problem and may therefore be considered as the proper vehicle to bridge the gap between analysis and formulation.

3.1 Example of a Bayesian network

The network below is a classic example called oil wildcatter. It tells an oil prospector whether or not to make a seismic test before drilling for oil. The ellipse shaped nodes are the probability nodes. The square nodes are decision nodes and the diamond shaped node is a utility node. The arrows indicate the dependence between the nodes.

The 'Test result'-node depends on whether we make a test or not and the actual structure of the underground.

The profit depends on the actual amount of oil in the underground, whether or not we drill and whether or not we make a test (A test cost money)



This Bayesian network can answer questions such as:

- If we do not make a test our expected profit will be $10
- If we do make a test then our expected profit will be $22.5

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The values inside the nodes look like this:

Amount of oil | Seismic structure | Test result | Test? | Drill? | Profit

dry	0.5
wet	0.3
soaking	0.2

The amount of oil in the ground is only known with a certain probability. For example half the time someone has drilled in the area they have not found anything. 20 % of the time they find oil in abundance.

Amount of oil | Seismic structure | Test result | Test? | Drill? | Profit

Amount of oil	dry	wet	soaking
none	0.6	0.3	0.1
open	0.3	0.4	0.4
closed	0.1	0.3	0.5

If the ground is soaking with oil then the ground has a closed structure in 50% of the incidents and there is only 10% chance that it has no structure at all. If the ground is dry then the probability that the structure is closed is only 10%

Amount of oil | Seismic structure | Test result | Test? | Drill? | Profit

Seismic stru...	none		open		closed	
Test?	do test	no test	do test	no test	do test	no test
none	1	0	0	0	0	0
open	0	0	1	0	0	0
closed	0	0	0	0	1	0
no result	0	1	0	1	0	1

The 'test result' node is a logical node because the values are either true or false. If the seismic structure is open and you do the test then the test result is also an 'open structure'. If you do not do the test then there is of course no result.

Amount of oil | Seismic structure | Test result | Test? | Drill? | Profit

do test	0.5
no test	0.5

The 'Test?' node is a decision node that can be true or false

Test?	do test				no test			
Test result	none	open	closed	no result	none	open	closed	no result
drill	0	1	1	0	0.5	0.5	0.5	0.5
do not drill	1	0	0	1	0.5	0.5	0.5	0.5

If we decide to do a test and it shows an open or a closed structure then we drill. If we do not make a test, then we toss a coin whether or not to drill.

Amount of oil | Seismic structure | Test result | Test? | Drill? | Profit

Drill?	drill						do not drill					
Amount of oil	dry		wet		soaking		dry		wet		soaking	
Test?	do test	no test	do test	no test	do test	no test	do test	no test	do test	no test	do test	no test
Utility	-80	-70	40	50	190	200	-10	0	-10	0	-10	0

The utility node assigns a value to the different outcomes.

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3.2 Bayesian network software

A number of software tools for creating Bayesian Networks exist. Here we use the open source tool GeNIe[1] developed at the University of Pittsburgh. This tool is good as long as you do not need to describe the probability tables using equations. GeNIe is only able to use equation nodes if the entire network consists of equation nodes. If equation nodes are required the commercial software package Hugin is a very good option.

3.3 Method

In a number of workshops navigators and risk analysts came up with the network showed in Figure 4. The nodes have been colored so that:

- Orange nodes: Inputs that can be influenced by the maritime authorities.
- Dark orange nodes: Inputs that cannot be influenced by the maritime authorities.
- Yellow nodes: estimated probability tables.
- Green nodes: Final probability tables for the causation factors.
- Dark green nodes: calculation nodes for the causation factors.

By changing the orange input nodes the causation factors can be read in the green nodes.

<u>Overall description of the network</u>

The network calculates the causation factors for a single leg or single junction point. It can be divided into three parts. The left part models how well the ship copes with the situation. The outcome of this side is the node 'Bridge team management'. The right side of the network models the complexity of the network and the outcome of this side is the node 'Waterway complexity'. The two outcome nodes are combined in the causation factor nodes. High waterway complexity increases the causation factors. High 'Bridge team management' decreases the causation factors.

[1] http://genie.sis.pitt.edu/

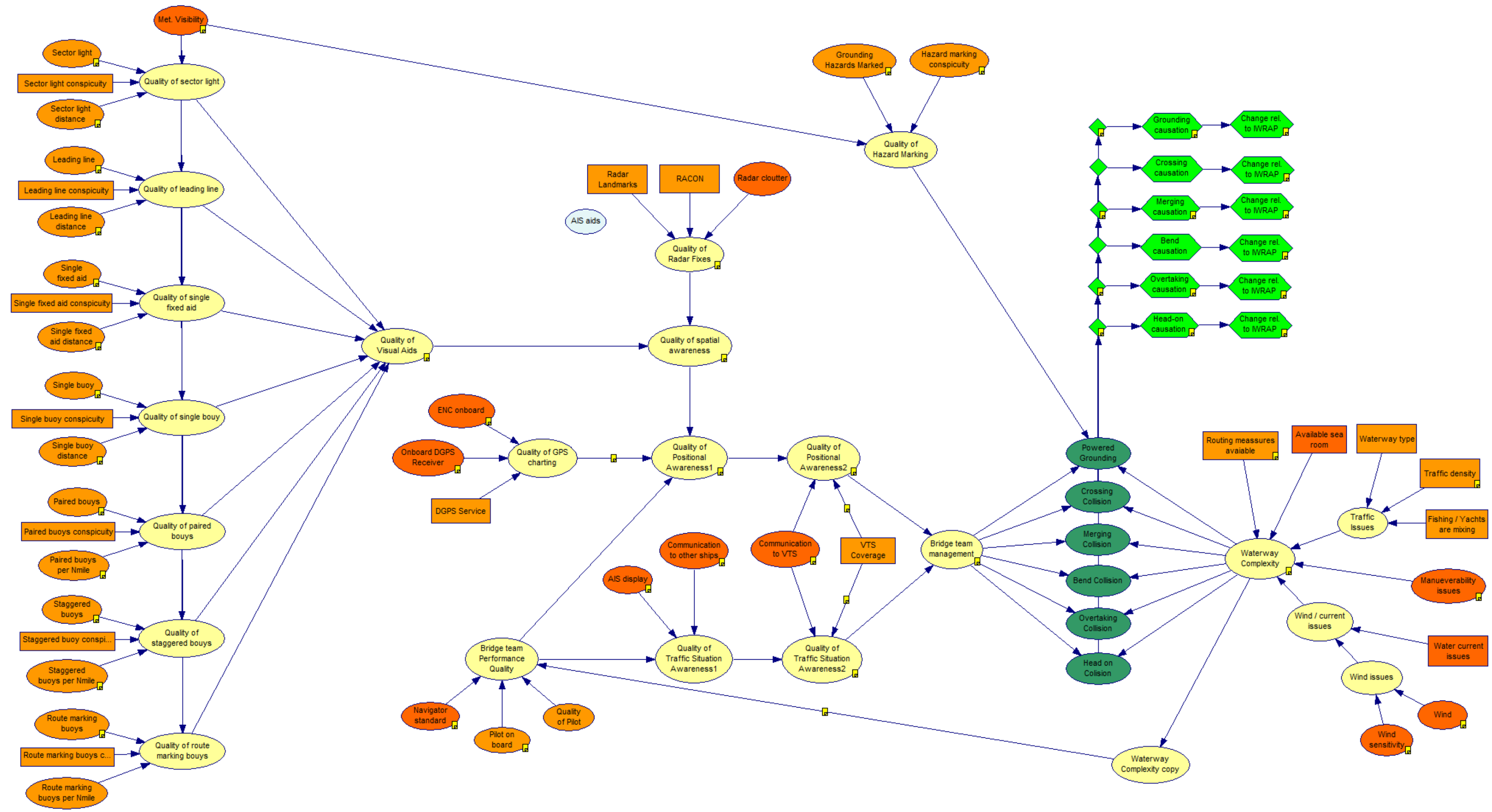

Figure 4: The Bayesian network for estimating the causation factor

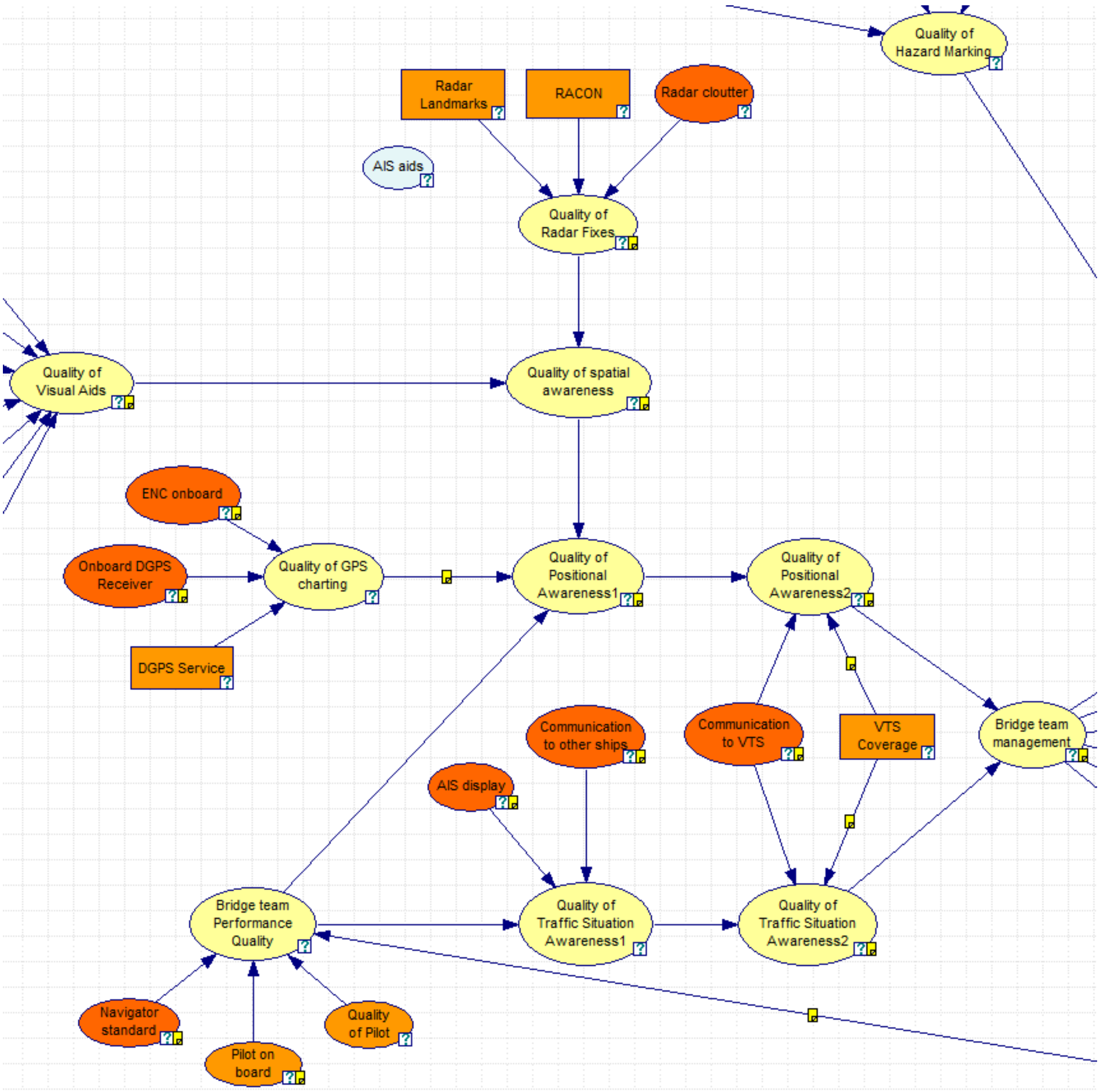

Figure 5: Left side of the network. When the 'Bridge team management' node is in a high state the causation factors are decreased (Good) and vice versa

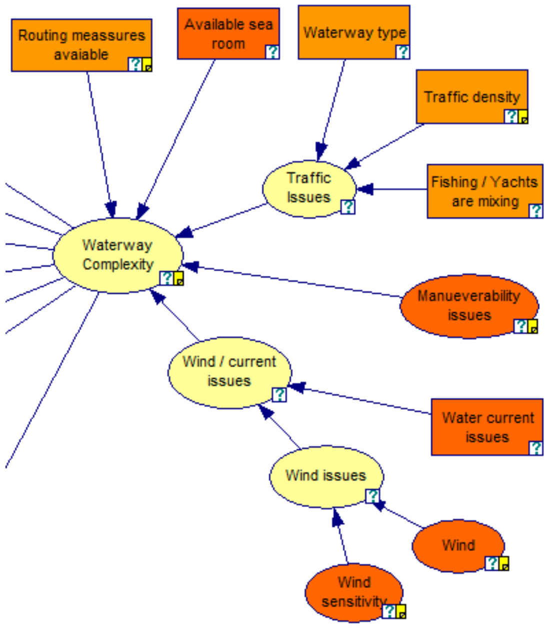

Figure 6: The right side of the network where the water way properties are defined. When the waterway complexity is high the causation factors are increased (bad) and vice versa

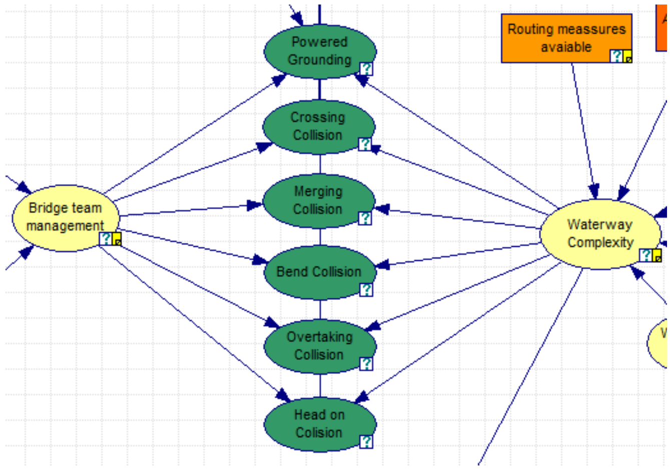

Figure 7: The central part of the network where the two sides are combined and the six causation factors are calculated

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3.4 Verifying the network

The network and the results from it, has only been verified as to their overall value. The actual values which are valid for a single leg are quite difficult to verify. A workshop in which several persons do a number of cases is required to verify it.

4 Implementing the network

In order to test the network for people not familiar with GeNIe, a Windows application has been developed. This allows the user to play with the input nodes and see how the causation factors are affected.
The program is started by executing the file Effect of AtoNs.exe. Each tab in Figure 8 represents a part of the network's input nodes. After giving the input, return to the Menu-tab and press the Calculate-button. Now the causation factors are shown. The case can be saved by pressing the save-button. The grid at the bottom shows The Iterate-button makes it possible to choose one or more input nodes. The program then automatically assign values to the nodes and calculate the causation factors. The result is saved in a csv-file.

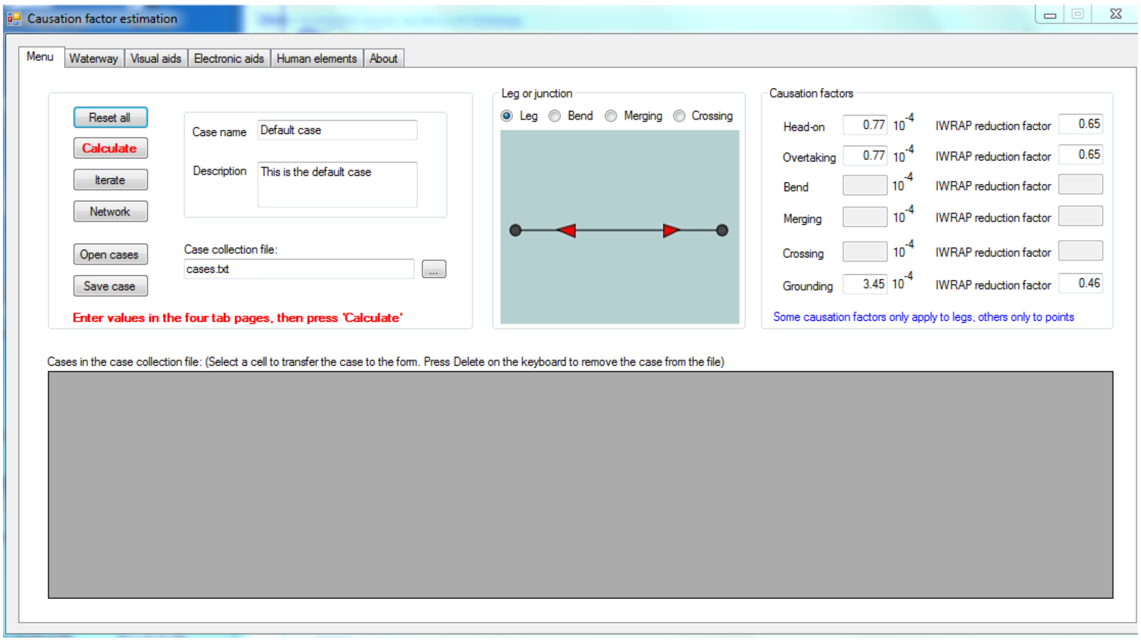
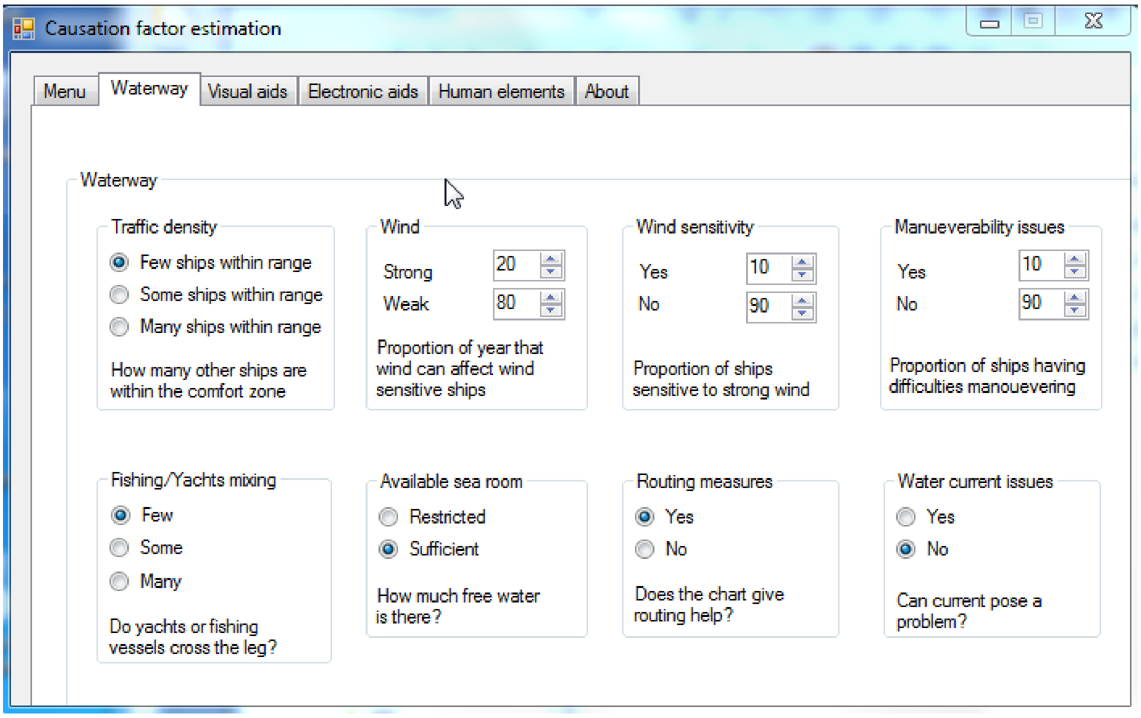


Figure 8: User interface for testing the network

5 Detailed description of the input parameters

In the following each input node/parameter is described. The node/parameter name is underlined.

5.1 Waterway tab



<u>Traffic density</u>

Few ships within range:	So few ships comes within the comport zone that the navigators might relax too much.	Baltic, Kattegat
Some ships within range:	1-3 ship comes within the ships comport zone every hour	Great Belt
Many ships within range:	Almost constantly others ships within the comport zone	Dover, Malacca, Oresund, Bosperus

<u>Wind</u>
Proportion of the year that wind may be a problem for wind sensitive ships.

<u>Wind sensitivity</u>
Proportion of ships that are sensitive to strong wind. Typical ships with a high super structure.

<u>Maneuverability issues</u>
Proportion of ships that have difficulties in deviating from their course.

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Fishing/Yachts mixing

Few:	Almost never an issue	Kattegat
Some:	Can be an issue	Great Belt
Many:	Constantly an issue	Oresund

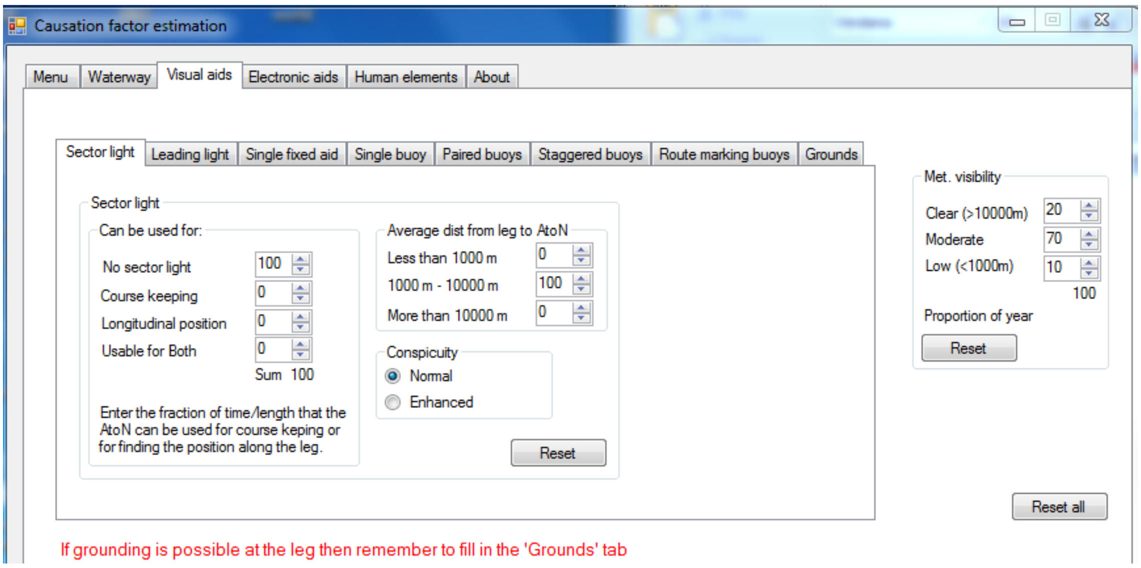
Available sea room
Restricted: Ships will not be able to make a turn

Routing measures
Does the chart offer help in navigating the waterway?

Water current issues
Is it necessary for the ships to account for current in the area?

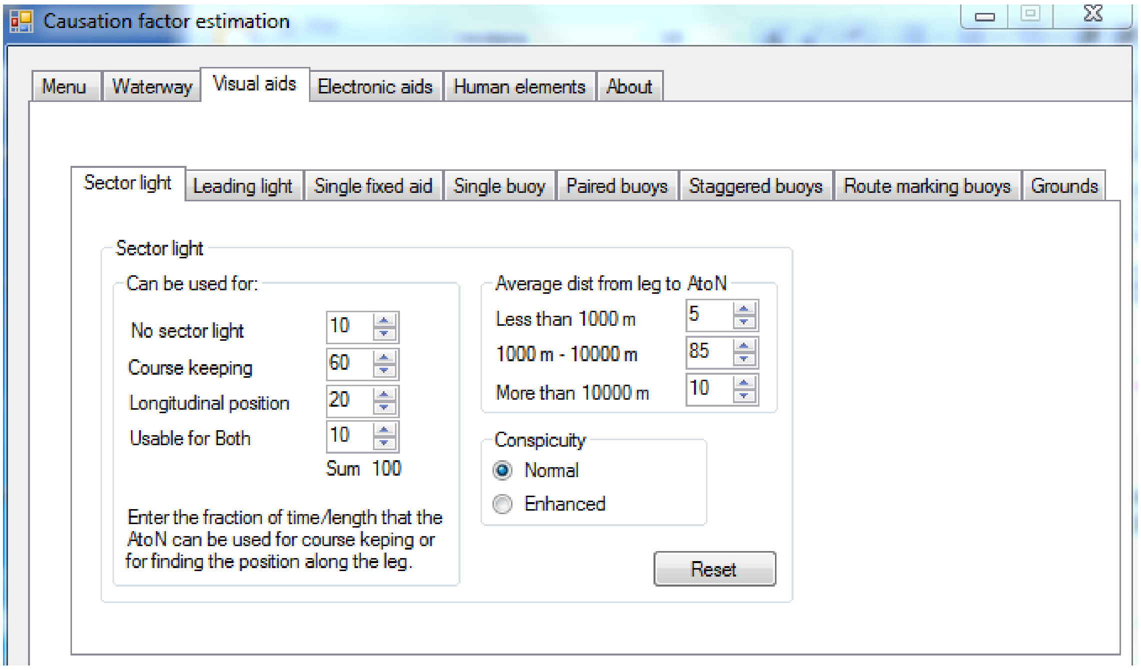
5.2 Visual aids

The idea here is that visual aids can be used for course keeping or for fixing the position if sailing along a row of buoys.



Met. visibility
The proportion of the year that the meteorological visibility in the area is more than 10 km, 1-10 km, less than 1km.

Sector light example

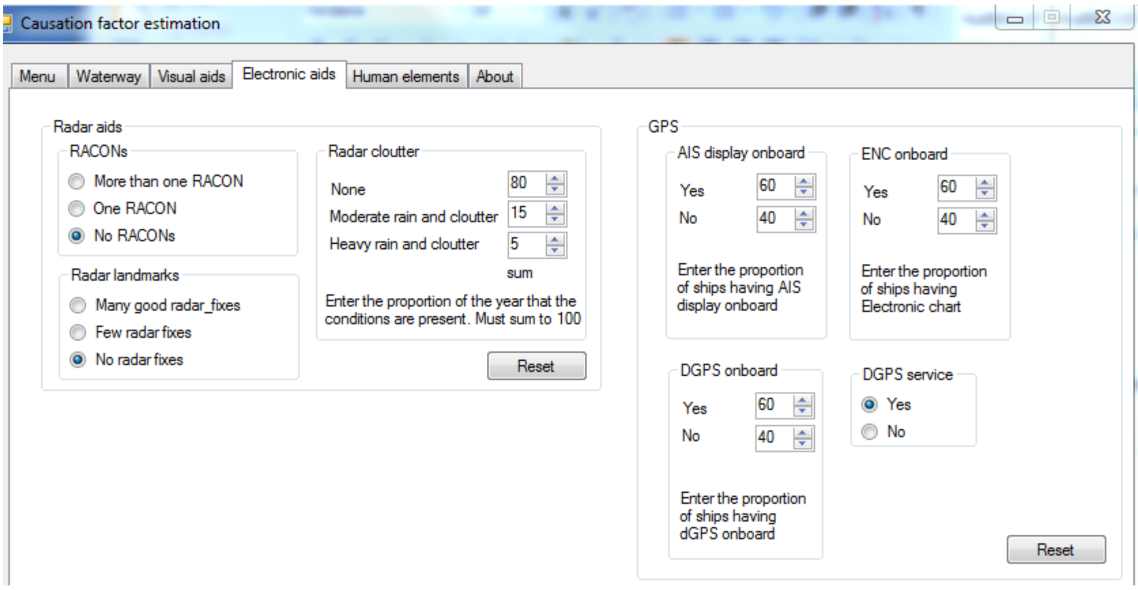


<u>Can be used for</u>
In the example above the sector light cannot be used/seen for 10 % of the leg/point. During 60 % length of the leg it can only be used for course keeping. During 20 % of the leg it can only be used for fixing the position. In 10 % of the length of the leg it can be used for both. This is a constructed example. In most cases one of the text boxes can be assigned 100.

<u>Average distance</u>
During 5 % of the length of the leg, the ship is less than 1000 m from the sector light. During 85 % of the length of the leg the ship is between 1000 and 10000 m from the sector light. In 10 % of the length of the leg the ship is more than 10000 m. from the sector light.

<u>Conspicuity</u>
Conspicuity is here set to Normal. If something extra has been done to the sector light it can be set to Enhanced.

5.3 Electronic aids



<u>RACONS's</u>
The number of RACONs that can be used at this leg/point.

<u>Radar landmarks</u>
This indicates how easy the coast line is seen on the radar screen.

<u>Radar cloutter</u>
This indicates how often the atmospheric conditions can yam the radar.

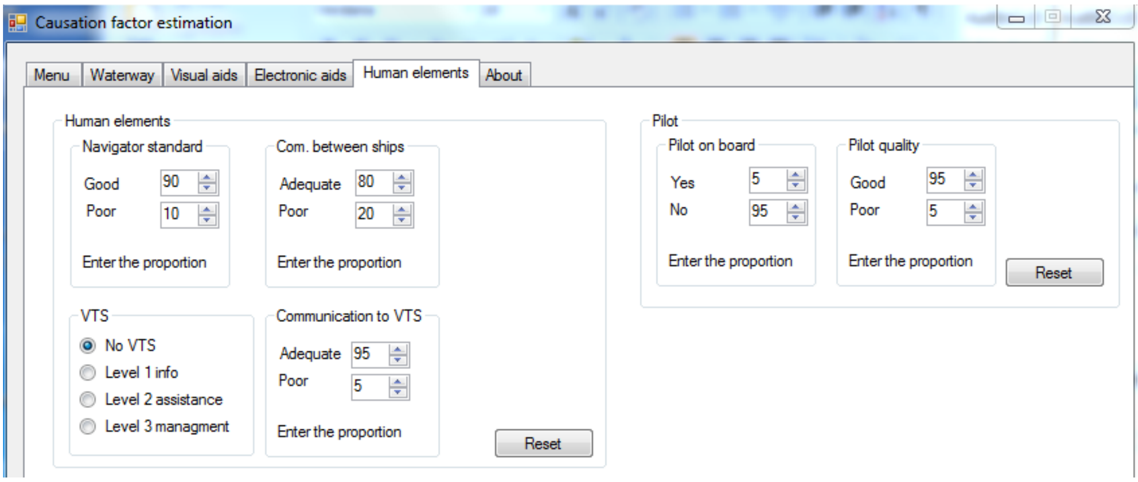
<u>AIS display onboard</u>
On how many ships are the AIS signals showed graphically on a monitor?

<u>ENC onboard</u>
How many ships have electronic charting onboard?

<u>DGPS onboard</u>
How many ships are able to use a DGPS service?

<u>DGPS service</u>
Is there a Differential Global Positioning System service in the area. DGPS can improve the precision from 20 m to 1 m.

5.4 Human elements



<u>Navigator standard</u>
The proportion of navigators that cannot navigate safely.

<u>Communication between ships</u>
The proportion of ships that is able to understand each other.

<u>Communication to VTS</u>
The proportion of ships that can communicate with the VTS.

<u>VTS</u>
Is there a VTS service in the area?

<u>Pilot</u>
How many ships have a pilot onboard

<u>Pilot quality</u>
How qualified are the pilots in the area?

6 Example. Drogden channel in the Sound, Denmark

In the chart below we will calculate the causation factors for the leg (blue) going through the Drogden channel. On the following pages the input parameters are shown. The results are that the collision causation factors are increased by 8 % compared to the IWRAP default causation factors. The grounding causation factor is increased by 56 %. When comparing these factors to the causation factors in table, we see that we get within 50% of the observed values. It is important to note that we should not expect to get the same values as the values in table x is an average value of the area, where the calculated values are specific for a single leg.

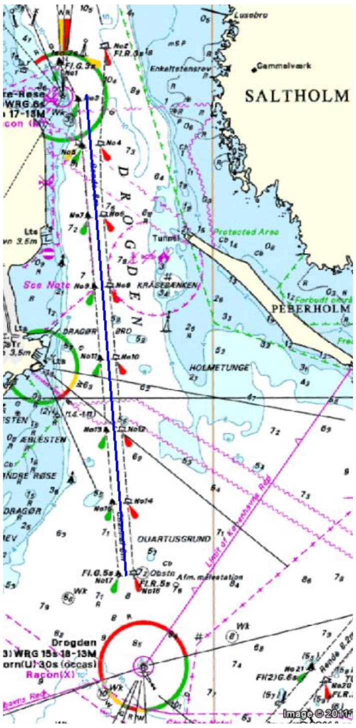


Figure 9: Example leg through Drogden channel

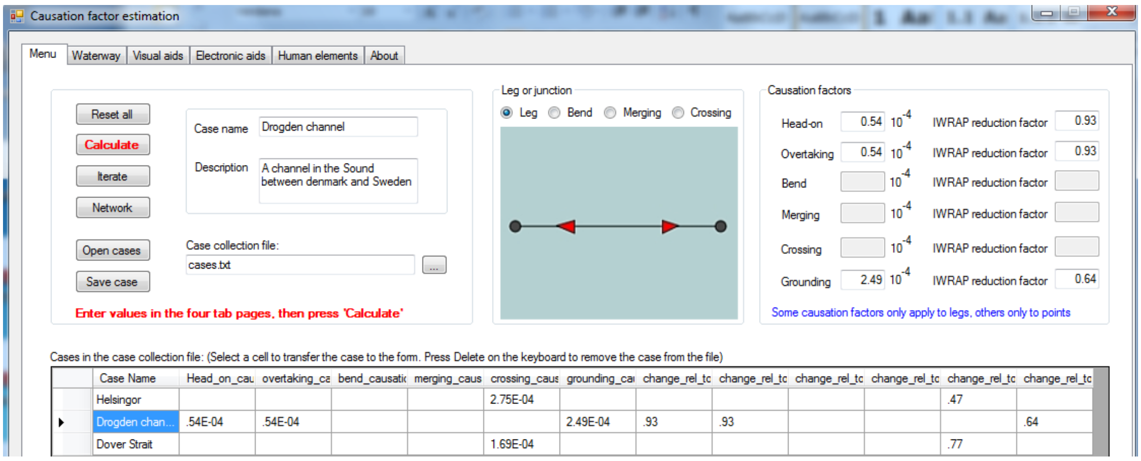


Figure 10: example results. The factors fit well with Figure 2 and Figure 3

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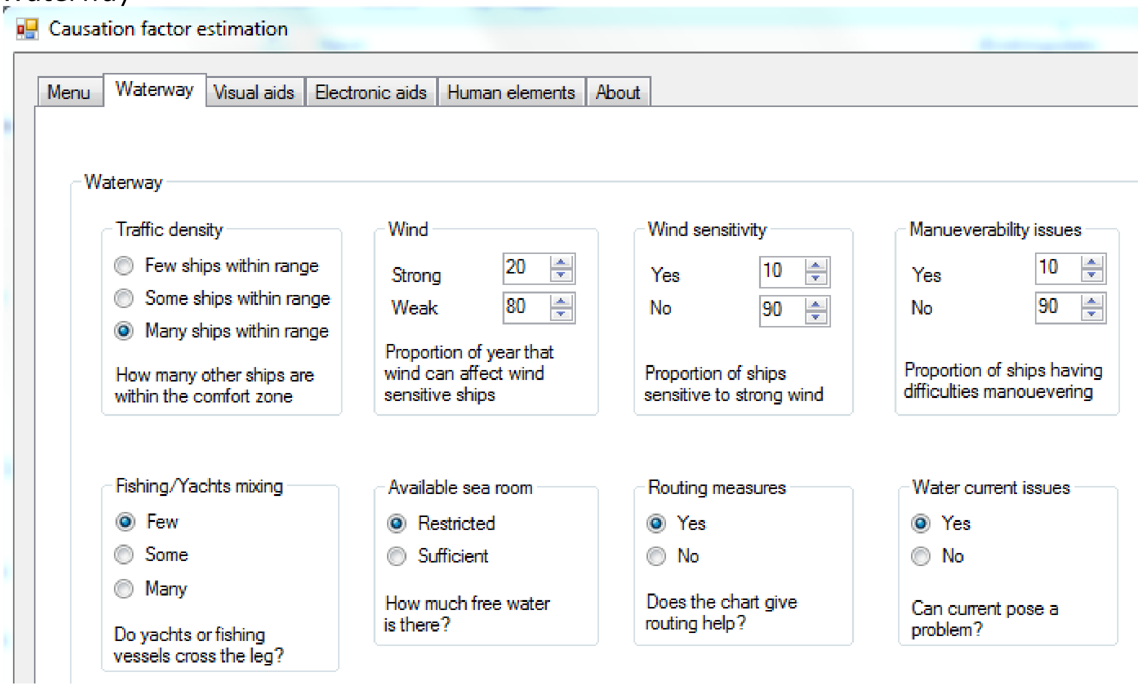
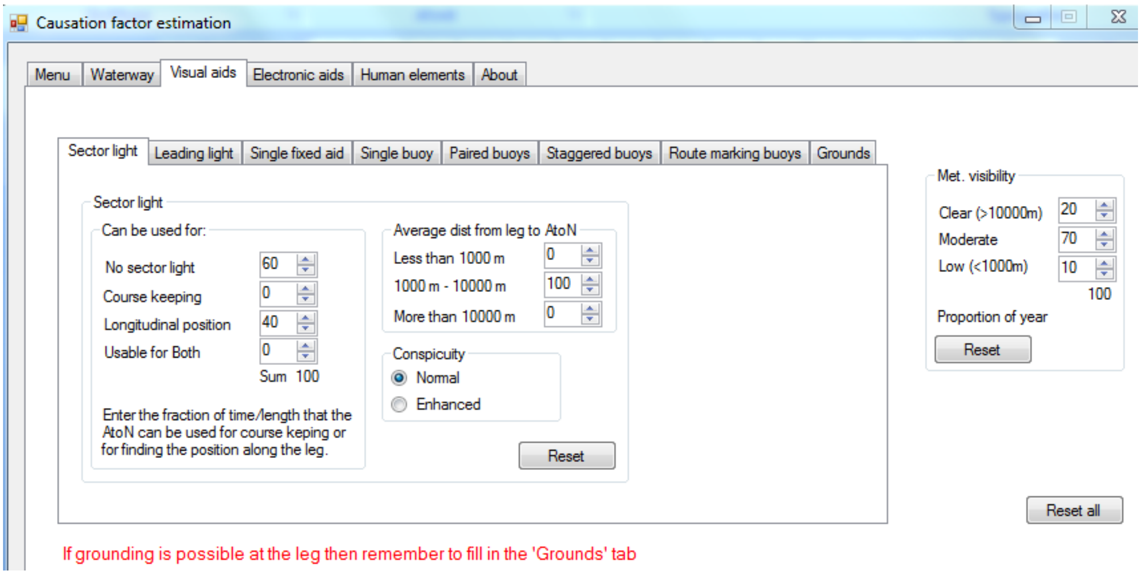
Waterway



Visual aids



Sector light can be used 40% of the leg for positioning

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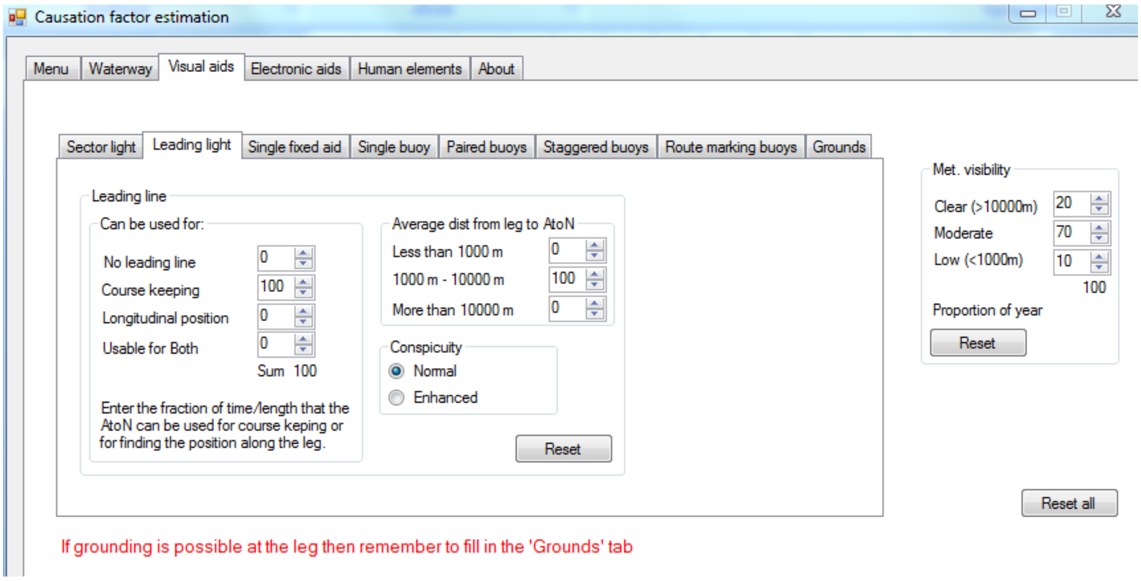
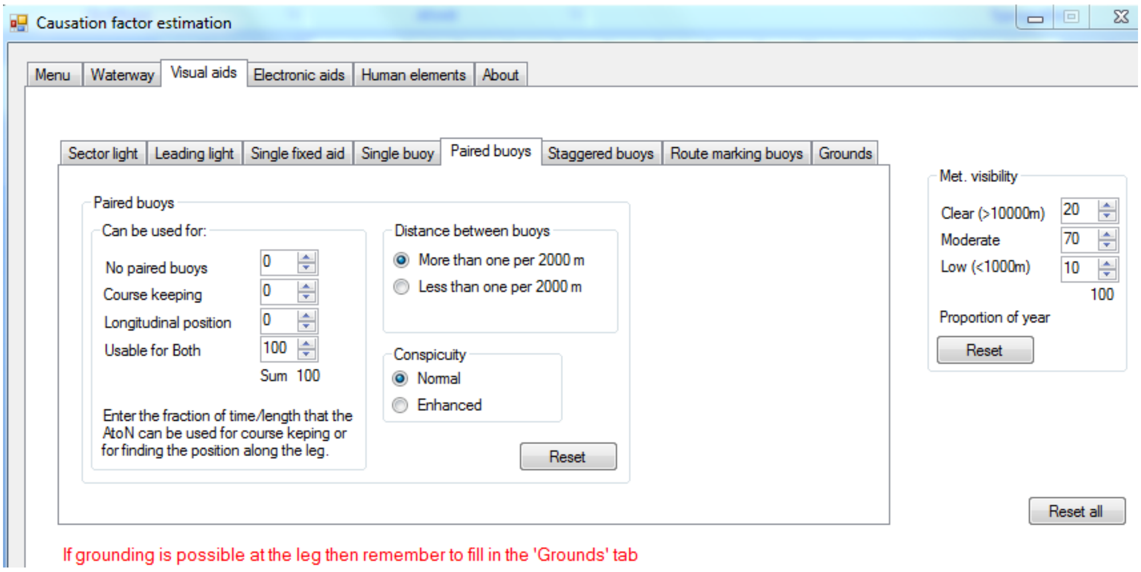
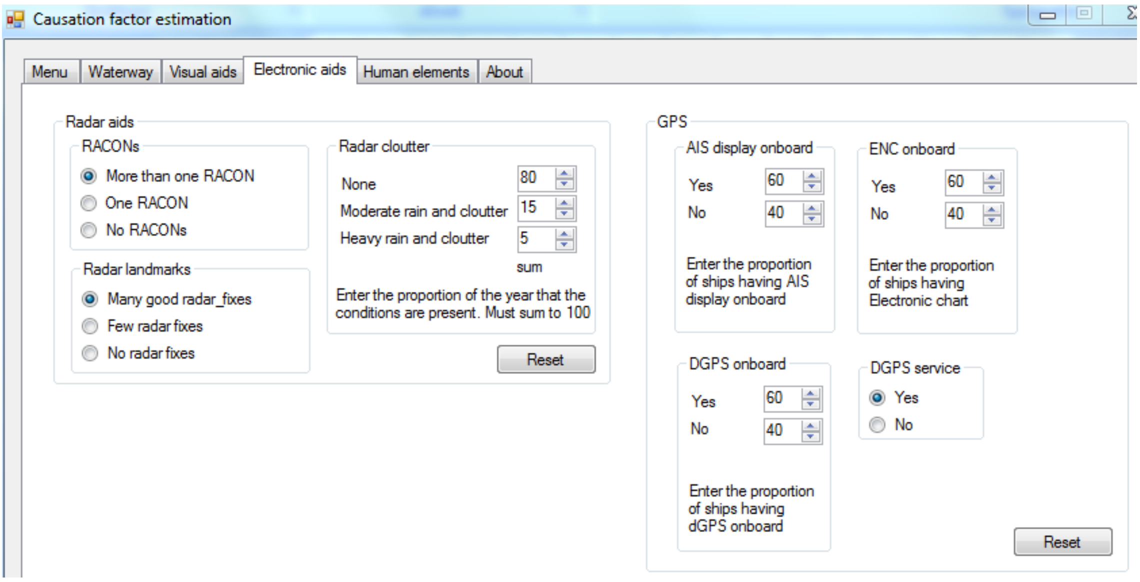


The leading light can be used 100% of the time for course keeping

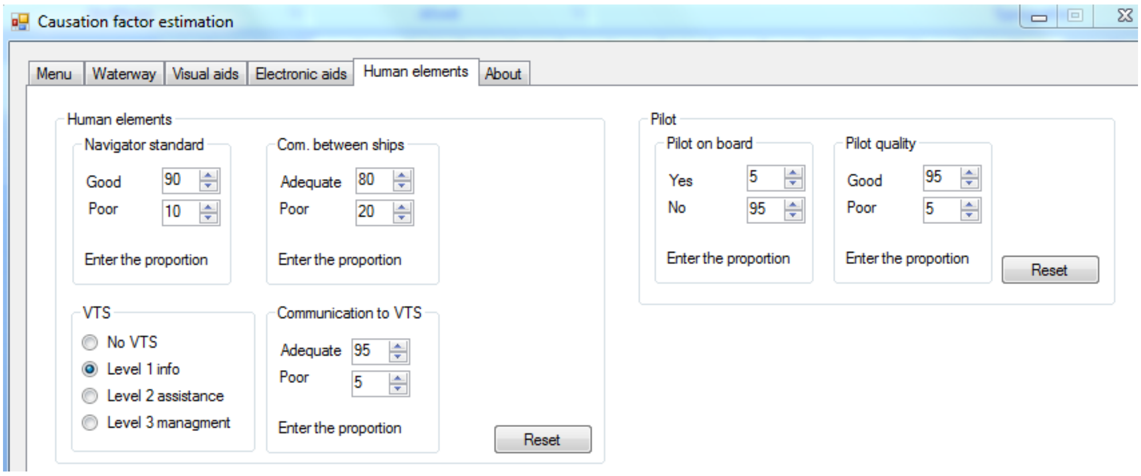


Paired buoys can be used 100 % of the leg

Electronic aids



Human elements



7 Detailed description of the network

The input nodes of the network has already been described in section x. In this section the internal nodes are describes. Many nodes have the states high, adequate and low. These are of course not very precise descriptions. In general low means that the situation is not acceptable. Adequate means that the situation is acceptable and high means that the situation is above what is required.

<u>Bridge team management</u>

This models the combined effectiveness of the people on the bridge

Quality of Positional Awareness2	High			Enough			Inadequate		
Quality of Traffic Situation Awareness2	High	Enough	Inadequate	High	Enough	Inadequate	High	Enough	Inadequate
High	1	0.5	0	0.5	0	0	0	0	0
Enough	0	0.5	0.5	0.5	1	0.3	0.5	0.3	0
Inadequate	0	0	0.5	0	0	0.7	0.5	0.7	1

<u>Quality of positional awareness2</u>

This node captures the effect of VTS. Even though the positional awareness1 is low, then a VTS can correct this.

VTS Coverage	NoVTS						Level1_info					
Quality of Positional Awareness1	High		Enough		Inadequate		High		Enough		Inadequate	
Communication to VTS	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor
High	1	1	0	0	0	0	1	0.9	0.5	0	0	0
Enough	0	0	1	1	0	0	0	0	0.5	0.8	0.5	0.1
Inadequate	0	0	0	0	1	1	0	0.1	0	0.2	0.5	0.9

VTS Coverage	Level2_assistance						Level3_management					
Quality of Positional Awareness1	High		Enough		Inadequate		High		Enough		Inadequate	
Communication to VTS	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor
High	1	0.9	0.75	0	0	0	1	0.9	0	0	0	0
Enough	0	0	0.25	0.75	0.75	0.1	0	0	1	0.5	1	0.1
Inadequate	0	0.1	0	0.25	0.25	0.9	0	0.1	0	0.5	0	0.9

<u>Quality of positional awareness1</u>

This node gives the probability that the bridge team knows where they are.

Bridge team Performance Quality	High								
Quality of spatial awareness	Position_can_be_established_easily			Position_cannot_be_established_e...			Position_cannot_be_established		
Quality of GPS charting	ENC_high_...	ENC_low_...	Position_se...	ENC_high_...	ENC_low_...	Position_se...	ENC_high_...	ENC_low_...	Position_se...
High	1	0.95	0.9	1	0.9	0	1	0.85	0
Enough	0	0.05	0.1	0	0.1	0.8	0	0.15	0.6
Inadequate	0	0	0	0	0	0.2	0	0	0.4

Bridge team Performance Quality	Average								
Quality of spatial awareness	Position_can_be_established_easily			Position_cannot_be_established_e...			Position_cannot_be_established		
Quality of GPS charting	ENC_high_...	ENC_low_...	Position_se...	ENC_high_...	ENC_low_...	Position_se...	ENC_high_...	ENC_low_...	Position_se...
High	0.9	0.85	0.8	0.85	0.8	0	0.8	0.75	0
Enough	0.1	0.15	0.2	0.15	0.2	0.7	0.2	0.25	0.5
Inadequate	0	0	0	0	0	0.3	0	0	0.5

Bridge team Performance Quality	Below_average								
Quality of spatial awareness	Position_can_be_established_easily			Position_cannot_be_established_e...			Position_cannot_be_established		
Quality of GPS charting	ENC_high_...	ENC_low_...	Position_se...	ENC_high_...	ENC_low_...	Position_se...	ENC_high_...	ENC_low_...	Position_se...
High	0.8	0.75	0.7	0.75	0.7	0.2	0.75	0.7	0
Enough	0.2	0.25	0.2	0.25	0.3	0.5	0.25	0.2	0.5
Inadequate	0	0	0.1	0	0	0.3	0	0.1	0.5

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Quality of Traffic Situation Awareness2

This node captures the effect of VTS. Even though the traffic situation awareness1 is low, then a VTS can correct this.

VTS Coverage	NoVTS						Level1_info					
Quality of Traffic Situation Awareness1	High		Enough		Inadequate		High		Enough		Inadequate	
Communication to VTS	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor
High	1	1	0	0	0	0	1	0.9	0.5	0	0	0
Enough	0	0	1	1	0	0	0	0	0.5	0.5	1	0.1
Inadequate	0	0	0	0	1	1	0	0.1	0	0.5	0	0.9

VTS Coverage	Level2_assistance						Level3_management					
Quality of Traffic Situation Awareness1	High		Enough		Inadequate		High		Enough		Inadequate	
Communication to VTS	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor	Adequate	Poor
High	1	0.9	0.75	0	0	0	0.9	0.8	1	0	1	0
Enough	0	0	0.25	0.75	0.75	0.1	0	0.2	0	0.8	0	0.1
Inadequate	0	0.1	0	0.25	0.25	0.9	0.1	0	0	0.2	0	0.9

Quality of Traffic Situation Awareness1

The probability that the bridge team understand the traffic around them

AIS display	Yes					
Communication to other ships	Adequate			Poor		
Bridge team Performance Quality	High	Average	Below_ave...	High	Average	Below_ave...
High	1	0.2	0	0.7	0.1	0
Enough	0	0.8	0.4	0.2	0.7	0.2
Inadequate	0	0	0.6	0.1	0.2	0.8

AIS display	No					
Communication to other ships	Adequate			Poor		
Bridge team Performance Quality	High	Average	Below_ave...	High	Average	Below_ave...
High	0.9	0	0	0.5	0	0
Enough	0.1	1	0.2	0.3	0.7	0
Inadequate	0	0	0.8	0.2	0.3	1

Bridge team performance quality

Quality of Pilot	Good											
Navigator standard	Good						Poor					
Pilot on board	Yes			No			Yes			No		
Waterway Complexity ...	High	Normal	Low	High	Normal	Low	High	Normal	Low	High	Normal	Low
High	0.7	0.8	0.6	0.4	0.5	0.7	0.64	0.59	0.49	0	0	0
Average	0.3	0.2	0.4	0.4	0.5	0.25	0.35	0.4	0.5	0.1	0.2	0.5
Below_average	0	0	0	0.2	0	0.05	0.01	0.01	0.01	0.9	0.8	0.5

Quality of Pilot	Poor											
Navigator standard	Good						Poor					
Pilot on board	Yes			No			Yes			No		
Waterway Complexity ...	High	Normal	Low	High	Normal	Low	High	Normal	Low	High	Normal	Low
High	0.3	0.4	0.6	0.4	0.5	0.7	0	0	0	0	0	0
Average	0.4	0.4	0.3	0.4	0.5	0.25	0.05	0.1	0.4	0.1	0.2	0.5
Below_average	0.3	0.2	0.1	0.2	0	0.05	0.95	0.9	0.6	0.9	0.8	0.5

Quality of GPS charting

ENC onboard	Yes				No			
Onboard DGPS Receiver	Yes		No		Yes		No	
DGPS Service	Yes	No	Yes	No	Yes	No	Yes	No
ENC_high_pos_acc	1	0	0	0	0	0	0	0
ENC_low_pos_acc	0	1	1	1	0	0	0	0
Position_set_in_paperchart	0	0	0	0	1	1	1	1

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Quality of spatial awareness

Quality of Visual Aids	Position_can_be_established_easily		
Quality of Radar Fixes	Position_can_be_established_easily	Position_cannot_be_established_easily	Position_cannot_be_stablished_by_radar
Position_can_be_established_easily	1	1	1
Position_cannot_be_established_easily	0	0	0
Position_cannot_be_established	0	0	0

Quality of Visual Aids	Position_cannot_be_established_easily		
Quality of Radar Fixes	Position_can_be_established_easily	Position_cannot_be_established_easily	Position_cannot_be_stablished_by_radar
Position_can_be_established_easily	0.5	0	0
Position_cannot_be_established_easily	0.5	0.8	1
Position_cannot_be_established	0	0.2	0

Quality of Visual Aids	Position_cannot_be_established_visually		
Quality of Radar Fixes	Position_can_be_established_easily	Position_cannot_be_established_easily	Position_cannot_be_stablished_by_radar
Position_can_be_established_easily	0.3	0	0
Position_cannot_be_established_easily	0.6	0.5	0
Position_cannot_be_established	0.1	0.5	1

Quality of radar fixes

RACON	More_than_one								
Radar Landmarks	Many_good_radar_fixes_in_several_dire...			Few_good_radar_fixes_one_direction			No_radar_fixes		
Radar cloutter	None	Moderate_rain...	Heavy_rain_...	None	Moderate_r...	Heavy_rain...	None	Moderate_r...	Heavy_rain...
Position_can_be_established_easily	1	0.8	0.5	1	0.8	0.5	1	0.8	0.4
Position_cannot_be_established_easily	0	0.2	0.4	0	0.2	0.4	0	0.2	0.5
Position_cannot_be_stablished_by_radar	0	0	0.1	0	0	0.1	0	0	0.1

RACON	One								
Radar Landmarks	Many_good_radar_fixes_in_several...			Few_good_radar_fixes_one_direction			No_radar_fixes		
Radar cloutter	None	Moderate_r...	Heavy_rain...	None	Moderate_r...	Heavy_rain...	None	Moderate_r...	Heavy_rain...
Position_can_be_established_easily	1	0.8	0.5	1	0.8	0.5	0	0	0
Position_cannot_be_established_easily	0	0.2	0.4	0	0.2	0.4	1	0.9	0.6
Position_cannot_be_stablished_by_radar	0	0	0.1	0	0	0.1	0	0.1	0.4

RACON	None								
Radar Landmarks	Many_good_radar_fixes_in_several...			Few_good_radar_fixes_one_direction			No_radar_fixes		
Radar cloutter	None	Moderate_r...	Heavy_rain...	None	Moderate_r...	Heavy_rain...	None	Moderate_r...	Heavy_rain...
Position_can_be_established_easily	1	0.8	0.5	0	0	0	0	0	0
Position_cannot_be_established_easily	0	0.2	0.4	1	0.9	0.6	0	0	0
Position_cannot_be_stablished_by_radar	0	0	0.1	0	0.1	0.4	1	1	1

Quality of hazard markings

Grounding Ha...	All						None					
Hazard markin...	Enhanced			Normal			Enhanced			Normal		
Met. Visibility	Clear	Moderate	Low	Clear	Moderate	Low	Clear	Moderate	Low	Clear	Moderate	Low
Very_Good	1	0.8	0.4	0	0	0	0	0	0	0	0	0
Average	0	0.2	0.5	1	0.9	0.8	0	0	0	0	0	0
Poor	0	0	0.1	0	0.1	0.2	1	1	1	1	1	1

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Dark green nodes

Head-on collision (Dark green node)

Waterway Complexity	High			Moderate			Low		
Bridge team management	High	Enough	Inadequate	High	Enough	Inadequate	High	Enough	Inadequate
x1	0	0	1	0	0	0	0	0	0
x2	0	0	0	0	0	0	0	0	0
x4	0	1	0	0	0	1	0	0	0
x8	1	0	0	0	1	0	0	0	1
x16	0	0	0	1	0	0	0	1	0
x32	0	0	0	0	0	0	1	0	0
x64	0	0	0	0	0	0	0	0	0

Powered grounding (dark green node)

Waterway Complexity	High								
Bridge team management	High			Enough			Inadequate		
Quality of Hazard Marking	Very_Good	Average	Poor	Very_Good	Average	Poor	Very_Good	Average	Poor
x1	0	0	0.5	0	0	0	0	0	0
x2	0	0.5	0.5	0	0	0.5	0	0	0
x4	0	0.5	0	0	0.5	0.5	0	0	0.5
x8	1	0	0	0	0.5	0	0	0.5	0.5
x16	0	0	0	1	0	0	0	0.5	0
x32	0	0	0	0	0	0	1	0	0
x64	0	0	0	0	0	0	0	0	0

Waterway Complexity	Moderate								
Bridge team management	High			Enough			Inadequate		
Quality of Hazard Marking	Very_Good	Average	Poor	Very_Good	Average	Poor	Very_Good	Average	Poor
x1	0	0	0.75	0	0	0	0	0	0
x2	0	0.75	0.25	0	0	0.75	0	0	0
x4	0	0.25	0	0	0.75	0.25	0	0	0.75
x8	1	0	0	0	0.25	0	0	0.75	0.25
x16	0	0	0	1	0	0	0	0.25	0
x32	0	0	0	0	0	0	1	0	0
x64	0	0	0	0	0	0	0	0	0

Waterway Complexity	Low								
Bridge team management	High			Enough			Inadequate		
Quality of Hazard Marking	Very_Good	Average	Poor	Very_Good	Average	Poor	Very_Good	Average	Poor
x1	0	0	1	0	0	0	0	0	0
x2	0	1	0	0	0	1	0	0	0
x4	1	0	0	0	1	0	0	0	1
x8	0	0	0	1	0	0	0	1	0
x16	0	0	0	0	0	0	1	0	0
x32	0	0	0	0	0	0	0	0	0
x64	0	0	0	0	0	0	0	0	0

Bright green Nodes
The bright green nodes contain an initial causation factor which is multiplied by the outcome of the dark green nodes.

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8 Conclusions

A Bayesian network for estimating the causation factors at specific legs or junction points has been established. The overall structure of the network is thought to model the dependences of the causation factors well. However the actual probability tables within the network are based on judgment. They can most likely be improved.

An application for testing the network has been created. This means that one does not have to use the GeNie software in order to use the network.

9 References/Literature

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