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1 Index

2 Introduction and Description to the Workpackage

2.1 Introduction

Shipping is of great importance for trade and prosperity around the world and thus also the Baltic Sea region benefits from shipping. Moreover, shipping in itself is a complex system with many actors and components displaying variations in space and time. Manoeuvrability, crew competence and navigational equipment are different from vessel to vessel. The vessels themselves vary in length, draught and width as well as directions and speed. Waterways and aids to navigations are crucial for shipping and are adjusted to the natural settings and the maritime traffic. Due to the array of maritime accidents experienced worldwide throughout the years and up to present date, it is clear that shipping, although relatively safe in general, never takes place without some risk.

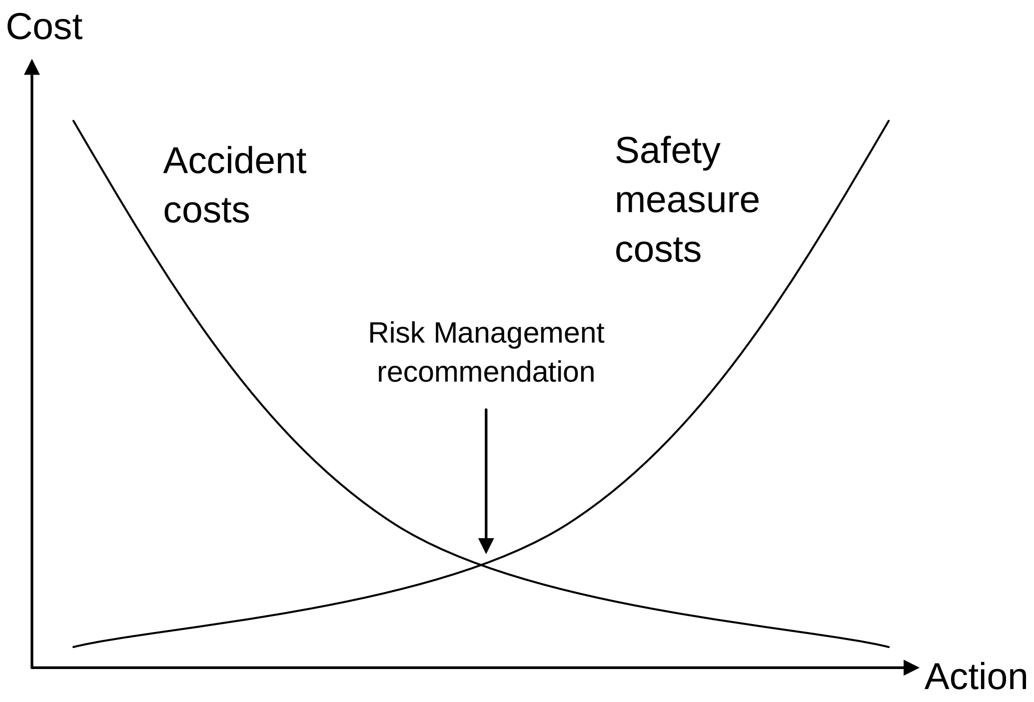


Figure 1 Simplified generalisation of the risk management procedure leading to recommendation on balancing costs for accidents and safety measures.

Different safety measures are aimed to reduce these risks but often come with a cost. In order to invest in safety in an appropriate and efficient way, safety and economical risks have to be balanced in a risk management context meaning that an optimization is aimed for; the sum of safety measure costs and accident costs are to be kept at a minimum as is given by the figure below.

Except the economic limitations for safety measures, political and technical constraints have to be kept in mind.

Accidental risks are evidently present in **the Baltic Sea**. With a strong increase in transported oil volumes and a vulnerable ecosystem it is easy to assume pronounced and increasing risks for and with accidental oil spills. Recent accidents in the Baltic Sea with oil spills, as the ones with Baltic Carrier and Fu Shan Hai, obviously show that there is risk.

The overall aim of activity 6.3 is hence to create an automatic tool identifying potential dangerous situations and facilitate the traffic control work. More specific the aim is to develop a collision and grounding warning as well as risk assessment tool for VTS-control.

2.2 Background

Real-time information on risks associated with both a single vessel and a specific sea area would be extremely useful for improving safety and decision making for facilitating the work of VTS operators. A tool that provides dynamic risk information which is continuously updated could improve awareness of developing situations during workload peaks at Vessel Traffic Service (VTS) centres. During very busy times, there is the potential that an operator’s attention may be focused on one risky situation while another develops elsewhere. There is also the potential that an operator is involved with other responsibilities during “slow” periods while traffic monitoring is ongoing. A dynamic risk analysis tool that can provide warnings of developing high-risk situations is needed.

VTS centres are established around ports and areas with high traffic density around the world. The operators use different sources of information to provide the vessels sailing in their area of accountability, among these radars, VHF radiotelephony, close-circuit television, and computer systems based on Automatic Identification System (AIS). The service is regulated and governed by International Maritime Organization’s (IMO) SOLAS Chapter V Regulation 12 together with the Guidelines for Vessel Traffic Services (IMO, 1997).

In these, the responsibilities and competency of the staff is described and their capability and training is furthermore suggested to be as in IALA Recommendation V-103 (IALA, 2009).

In the IMO resolution (IMO, 1997), "Vessel traffic service (VTS)" is defined as "a service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in the VTS area."It is further defined, that the "VTS should comprise at least an information service and may also include others, such as a navigational assistance service or a traffic organization service, or both, defined as follows:

An information service is a service to ensure that essential information becomes available in time for on-board navigational decision-making. [...] A navigational assistance service is a service to assist on-board navigational decision making and to monitor its effects. [...] A traffic organization service is a service to prevent the development of dangerous maritime traffic situations and to provide for the safe and efficient movement of vessel traffic within the VTS area."

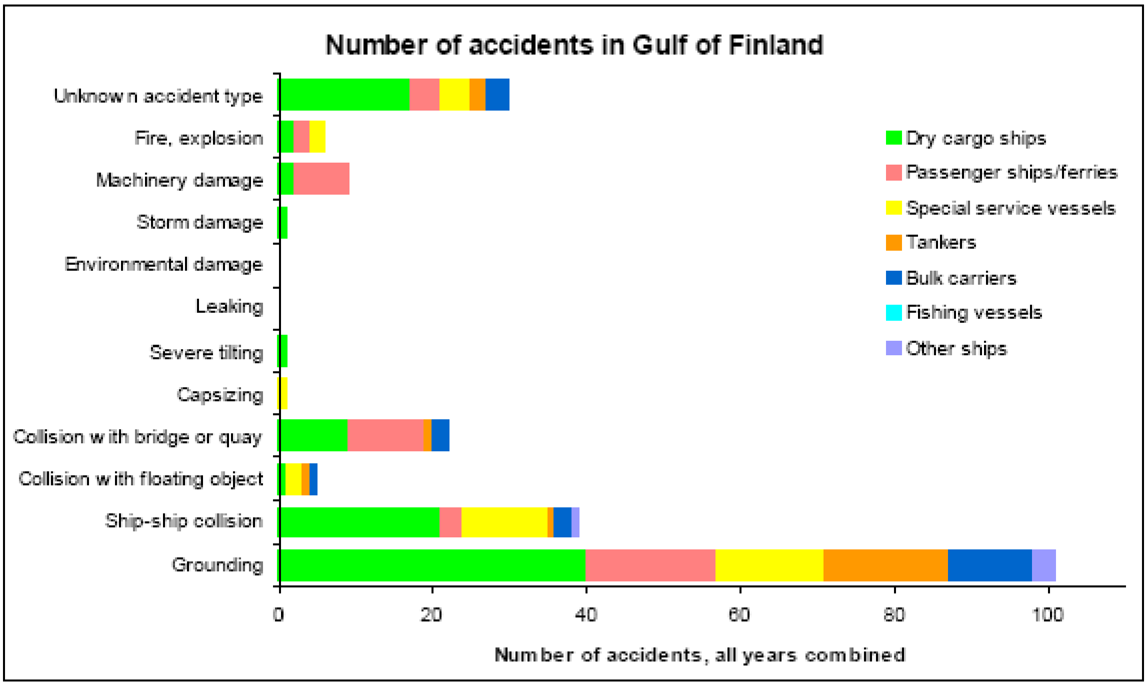


Figure 2 Number of accidents in the Gulf of Finland, years 1997-1999 and 2001-2005, Source: Hänninen, 2007.

There are no direct steering documents existing about decision support tools (DST) for VTS centres. The authorities have to "ensure that the VTS authority is provided with the equipment and facilities necessary to effectively accomplish the objectives of the VTS, ", which can be complemented by the DST.

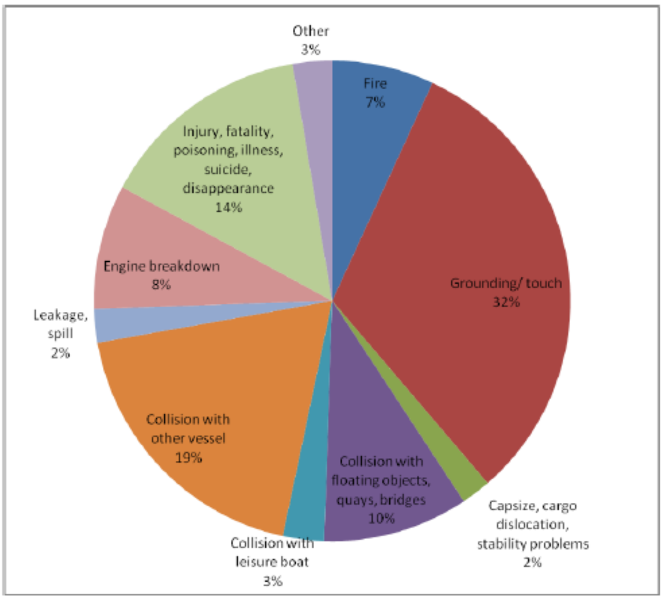


Figure 3 Göteborg harbour and archipelago, statistics for 1985-2008, Source: (Sjöfartsverket, 2008).

This is done today by mainly human manual information collection and spreading. Especially in dense traffic and complex fairways, the VTS operator is busy in fulfilling the duties and it can be difficult for the operators to identify critical manoeuvres leading to the most common accidents scenarios, collision and groundings. Groundings and collisions are statistically amongst the most common accidents in the shipping industry, as described in (Vanem & Skjong, 2004), or (Hänninen, 2007). Statistics about shipping accidents from the Danish waters and Danish registered vessels (Danish Maritime Authority, 2006) for the period 1997-2006 show that 31.6% of all accidents involving merchant vessels were grounding accidents, 15.1% contact accidents and 28.4% collision accidents.

The statistics for the Göteborg harbour and archipelago area show a similar trend, as shown in Figure 2. Collisions, groundings and contact are the typical event types in the statistics with a share of 63%.

The duties of VTS operators have been analysed by Westerlund (2010). In the study, statistics have been collected the purpose of interventions made by the VTS operators in three different VTS centres. The study shows, that almost half of the interventions were directly related to dangerous behaviour (categories 1,2,5,8,9 from Figure 4).

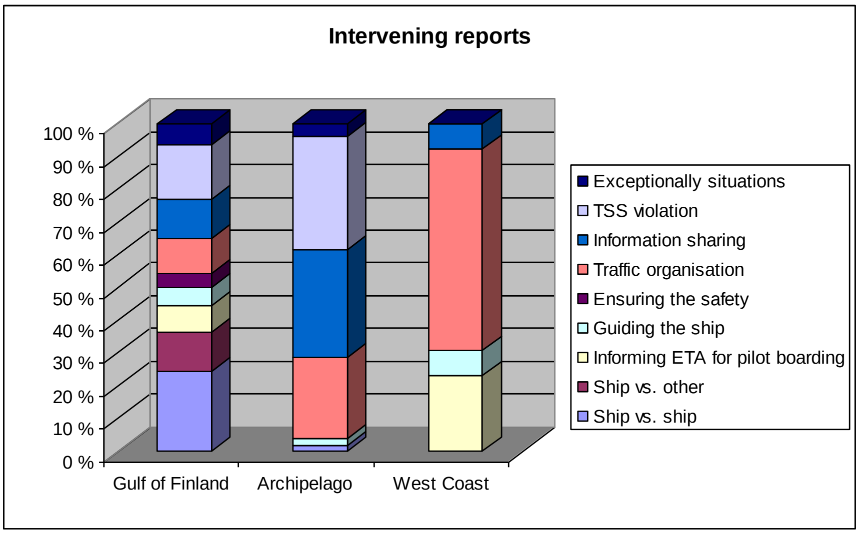


Figure 4: Intervening reports from 3 Finnish VTS centres (Westerlund, 2010)

2.2.1 Purpose

The overall aim of this Work Package is to **develop and demonstrate different approaches of dynamic risk management**[1] in order to optimise the investments for a safe and clean Baltic Sea. This means that the developed dynamic risk management in an efficient way shall reduce the number and the severity of foremost accidents leading to pollution of the marine environment, but also leading to losses of human lives and hampering of welfare development.

The problem to be solved is to reduce risk levels in spite of increased ship traffic in sensitive waterways. Due to new possibilities with the wide spread use of AIS the interesting coverage area increases and manual survey together with frequent analysis of big areas is not realistic.

This project aims to facilitate the identification of abnormal situations in VTS and Ship Reporting System (SRS) areas and to support the VTS operator in the decision-making process. By analysing processes involved in grounding and collision events as well as procedures and working methods of VTS centres, technical solutions are proposed based on identified information resources. A general raise of knowledge in this fairly new field of research, including collection of time before accidents and information acquirement with AIS data, is part of the purpose before building and programming these tools.

[1] Dynamic risk management is here defined as the continuous work on identification of among others, accident and economic risks, assessing risk levels, propose and perform risk treatment and communication of risks. Risks are here defined as the combination of probabilities and consequences of adverse effects as accidents and thereby indicating the expected accumulation of negative consequences with a given activity within predefined areas and periods.

The main objective of the activity is to develop a system which can provide real time prediction on risks (probability and consequence) for single vessels and for a defined sea area. The envisioned system will carry out the following:

- calculate and estimate dynamically the probability of collision, grounding, and contact situations for individual ships and developing ship traffic situations
- estimation of consequences (for humans, the environment, infrastructure, etc.) associated with possible incidents, based on ship characteristics and sea area characteristics
- provide automatic warnings and guidance to VTS operators

generate information on risks over time and over sea areas for input to decision making on implementation of maritime safety measures for risk reduction

2.2.2 Scope and delimitations

The problem of the grounding and collision in the context of VTS operators support, consists of three different phases, i.e.

- identification of an un-normal condition,
- contact and alert the ship,
- identification of the situation and avoidance manoeuvre by the ship.

This project focuses on the first of the three phases. Being aware of that the contacting of bridge personnel might be the most difficult task, a potential is still seen to provide the VTS operator with decision-making support tools and information to extend the time span for informing the crews and reducing the risk of collisions and groundings. At the same time, the decision support tool could be a complement to bridge systems, in which the step two is not required.

2.2.3 Structure of the report

The description of the mathematical models has been divided into SSPAs and VTTs part, as the approach is fundamentally different to simplfy understanding.

As parts of the tools have been based on rpior projects (BaSSy and IWRIS), the conclusions from these projects are presented to give an introduction to the reader.

The algorithms are described fairly detailed in this report as this is the aim of this report.

3 On-line offshore risk indication system based on probabilistic models – VTT's VTS tool

The idea behind the Intelligent Water-borne Risk Indication System (IWRIS), the on-line offshore risk indication system developed by VTT, is to predict the movement of the ships and see if there is a chance of collision. Using the actual AIS data normal movement of the ships can be modelled within a certain area and be used to predict coming close encounters. The same ship movement data is also used for anomaly detection, i.e. to identify ships that behave differently than expected.

3.1 Background and user needs

3.1.1 Background from earlier research at VTT

In 1997 the IMO drafted performance recommendations for a worldwide AIS. Before that, VTT took part in a project (POSEIDON) where a prototype system was tested in the Baltic in 1996. Nowadays most ships in international traffic are required to have the ship-borne AIS installed.

To study the possibilities to use AIS data for traffic analysis, VTT initiated a research project within the theme on Safety and reliability, one of the four strategic technology themes of VTT during 2001-2005. The projects of these programmes represented a high international standard and were also expected to raise the level of VTT's other projects, paving the way to technological breakthroughs and innovations. The name of the project was IWRIS® - Intelligent Water-borne Risk Indication System and was one project among some others developing frontier technologies and new operating principles for providing possibilities for new business concepts. The needs for real-time risk indication related to the traffic between Helsinki and Tallin had earlier been discussed between VTT's researchers in 2000.

The objective of the research project was to develop a technology, based on real-time position data of vessels (AIS-data), to support operative decision-making of VTS-operators. The core of the technology is a data model that takes as input AIS-data and provides in its output risk estimates that are used to alert VTS operators of possible hazards that are developing in the monitored traffic area (VTT, 2006).

The long-term objective of the R&D effort should be a product that possesses properties of an intelligent product (VTT, 2006):

- observation (understands and processes telematic information in realtime)

- adaptability (understanding structural changes in the environment)
- learning (giving better predictions as observations accumulate from repetition)
- communication (alerting operators in a meaningful way)
- feedback (operators can affect the functionality).

For IWRIS® to be a successfully implemented decision aid for VTS operators, three different methodological aspects have to be taken into consideration and integrated: user-centered design, bayesian statistics, and user interface technology. The overall methodological frame work of IWRIS® is depicted by Figure 5 (VTT, 2006):

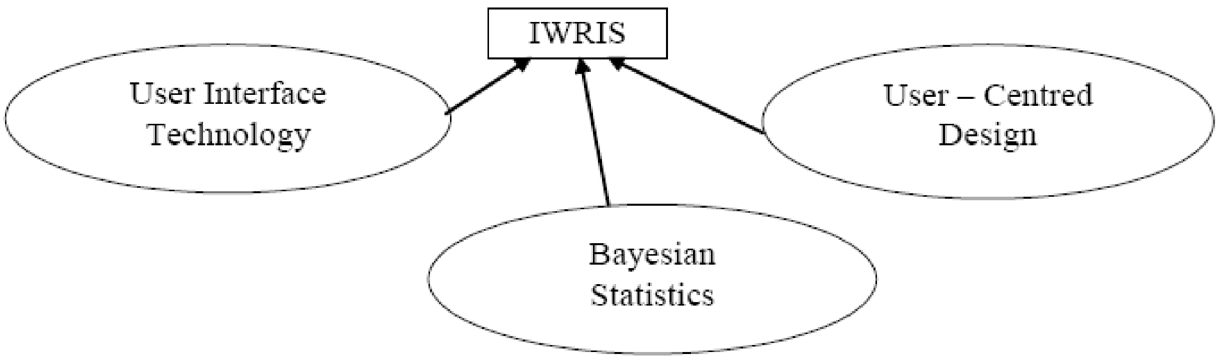


Figure 5 The methodological framework for IWRIS® (VTT, 2006).

In the IWRIS project focus was on developing the Bayesian mathematical formulation of the real-time risk-indication technology as well as on the development of the AIS analysis application. The latter was, however, beyond the resources allocated for the project and instead a simulation-based demonstration was developed to illustrate the concept in relation to applications for furher funding in the future. The demonstration was finally implemented as a power point show.

To summarize the output of the project the following results where obtained:

1. Trajectories of vessels over a two-dimensional grid are produced by computer simulation of Markov chains (special work by Lassi Similä, Helsinki University of Technology, supervised by Tony Rosqvist, VTT). The aim of this task was to produce stochastic position data of crossing trajectories that can be used as input data to the data model. Markov chains of the first and second order were used in the simulations.

2. A Bayesian updating algorithm, where transition probabilities are estimated dynamically, as observations on trajectories become available, was defined and implemented (special work by Sampo Etelävuori, Helsinki University, supervised by Tony Rosqvist, VTT). The Bayesian approach supports learning from observations, resolving initial (prior) uncertainties related to the transition of vessels through a grid, superpositioned on the monitored sea area.

3. A graphical display to show simulated traffic with risk indication based on a coloured probability scale was developed (see details in VTT, 2006)

Also a trademark for the approach was received: IWRIS®. Currently a patent is pending for the developed algorithm.

3.1.2 Conclusions from the expert panel workshop at Chalmers

An expert panel workshop was held at Chalmers (09.–10.12.2010) with the objective to find the user needs of VTS operators and try to understand the way they are working. VTS operators from Sound VTS, Malmö, Sweden, Archipelago VTS, Pärnäinen, Finland and Fedje VTS, Norway participated in the session concerning the risk indication tool under development by VTT.

3.1.2.1 Movement prediction and collision warning

The Movement prediction and collision warning system under development by VTT was presented. The system learns ship routes based on historical AIS data. Movement probabilities from one cell to another are estimated for different ship categories. Using this information, the movements of a ship can be predicted and situations where two or more ships will be near each other identified and displayed. See section 3.2 for details.

According to the experts, the Finnish VTS centres have already a simulation tool in use, with which they can simulate the movements of a ship. The tool assumes either that the ship will continue straight forward or that it will follow a route chosen by the user from a library of standard routes. The ship is assumed to maintain its current speed. There is also a possibility to define default speed alterations to specific parts of a route. The tool uses AIS targets, but new targets can also be generated to simulate ships without AIS or tests with alternative speed for a ship.

The Sound VTSOs did not find any need for a simulation tool, because there are only two main routes in their area.

A large part of a VTS operator’s work is to anticipate future situations. The operators work with a short strategic time window of about 10-30 min (e.g. monitoring meeting ships) and a longer strategic time window, 1 h – 3 h (e.g. anticipating when a tanker leaving port will join the open sea main route).

VHF was seen as the most important source of information, through which the operators get intended route, destination and other important data about the ship.

The experts did not prefer too much automation in VTS centres, but preferred a certain level of manual labour and voice communication. This was seen to activate the operator and help maintaining a good situational awareness better than a too automated system. They also saw a risk in relying too much on automation. However, in high traffic situations, an option of higher automation could be beneficial.

3.1.2.2 Anomaly detection

The main ideas of the Anomaly detection system under development by VTT were presented. The system is designed to alert the user about ships behaving in an unusual manner compared to earlier traffic.

Quite a large variety of warning criteria are already in use at least in some VTS centres. These include e.g.:

- exceeding limits (alarms when a ship crosses a predefined line)
- acceleration and deceleration
- dragging anchor
- stops
- drifting
- sudden turns
- AIS and radar target deviation: priority to the radar signal, gives warning if the AIS information deviates from the radar information
- ship leaving anchorage area

A comparison between a ship's draught and fairway depth was also seen beneficial. As stated by the experts, the Finnish centres have received a system update in early 2011, which will make it impossible to connect a ship to a route with too small depth. An alert based on air draught was desired by Sound VTS, because of the vicinity of the Copenhagen Kastrup airport. Air draught is currently lacking from the standard AIS data, but there is a field for it in the new AIS Application-Specific Messages. However, the new messages are not yet widely implemented.

The user interfaces of the alert systems vary from centre to centre depending on the manufacturer. A system similar to the one in use in Sound VTS was preferred. When the system detects a situation fulfilling an alert criterion, both the ship and a light in the upper corner of the screen start flashing. Additional information on the situation is received in a pop-up window by clicking the ship.

The general usability of a VTS system was also discussed. There was dissatisfaction with window-based systems that display irrelevant information and require too many clicks in order to display relevant information. According to the experts, the most relevant information about a ship is

- route,
- position,
- draught,
- name of ship,
- air draught (important because of Kastrup airport).

3.2 Dynamic algorithms for analyzing online-situations

The system learns ship routes based on historical AIS data. The area under observation is divided into cells of 0.25 X 0.25 nautical miles. Movement probabilities from one cell to another are estimated for different ship categories, see section 3.2.2.The learned probabilities are stored into transition matrices, where each entry position (*A,B*) gives the probability of moving from cell *A* to cell *B*. Using this information, the movements of a ship can be predicted and situations where two or more ships will be near each other identified and displayed. Figure 6 shows an example visualisation of ships' possible movement destinations depicted with white lines, and possible areas of close encounter as colour coded squares. Additional information, such as time of the encounter and ships that are involved, are received by pointing on the square.

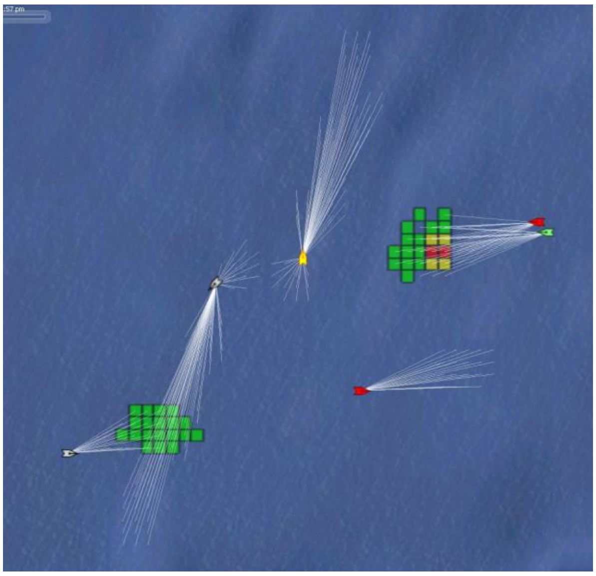


Figure 6 Visualisation of collision warnings.

The system is also designed to alert the user of ships behaving in an unusual manner compared to earlier traffic (see section 3.2.4). The anomalous ship is indicated on the chart, as shown in Figure 7. Additional information, e.g. anomaly criterion and ship name, are received by pointing on the ship.

Figure 7 Visualisation of an anomaly.

The system is taught with stored AIS data from the examined area. To show the results, the system produces kml-files, which can be displayed using e.g. Google Earth. Using a common platform such as Google Earth makes it easy to add e.g. electronic nautical charts (ENC) as a layer underneath the results.

The system has been implemented in Java.

3.2.1 Preprocessing of AIS data

The system accepts AIS data in a simple csv format. The csv form is used to extract the information required for training the transition matrices and for predicting the movement of the ships. The extracted relevant information includes the timestamp (when the message was received at recording server), MMSI, latitude, longitude, speed, course over groud, and UTCSEC (the exact GPS second when the message was produced in the ship's transponder).

The real time AIS data is read with a socket connection and the raw data messages are parsed using AIS+ software (http://aisplus.vtt.fi). The messages are then stored in the csv format.

3.2.2 Estimation of transition matrix from AIS data

The idea behind transition matrices is to model the movement of the ships in the sea area. The area under monitoring is divided into a set of cells, i.e., a grid. For each cell of the matrix there is a probability of moving from that cell to any other cell in the matrix. For example, moving from cell 1 to cell 4 may have a probability of 0.1. Using the probabilities found from the transition matrices the movement of the ships may be predicted.

The process of training the transition matrices is divided into 7 steps:

1. For each day in the AIS database, fetch the movement of all ships. Preprocess the data.
2. Cluster the ships into clusters that hold similar movement (speed and destination).
3. For each cluster, fetch the movement for each ship.
4. Interpolate the movement with the given parameters.
5. For all the locations in the ship’s route:
    - Map the location to the grid.
    - Update the count of moving from the previous cell to this cell.
6. After all the ships for the given cluster are processed, calculate the probabilities for each cell in the grid.

7. Store the resulting matrix as the transition matrix of the given cluster.

The first step of the process is simple; simply fetch and parse the information, and store it in a data structure. This step also involves some preprocessing. Only the ships that are moving in a specific area in the Gulf of Finland are fetched. The area in question begins from the coordinates (59.65 N; 24.1 E) and ends at (59.96 N; 26.0 E). The area and the grid are shown in Figure 8.

There are some ships that have several passages within the time period of one day. For example, fast ships that travel between Helsinki and Tallinn do so several times a day. The routes of the same ship are separated using the following approach: If a ship goes outside the grid or if there is more than 10 minutes between two AIS transmissions (received while within the grid), the ship is considered to be on a different passage.

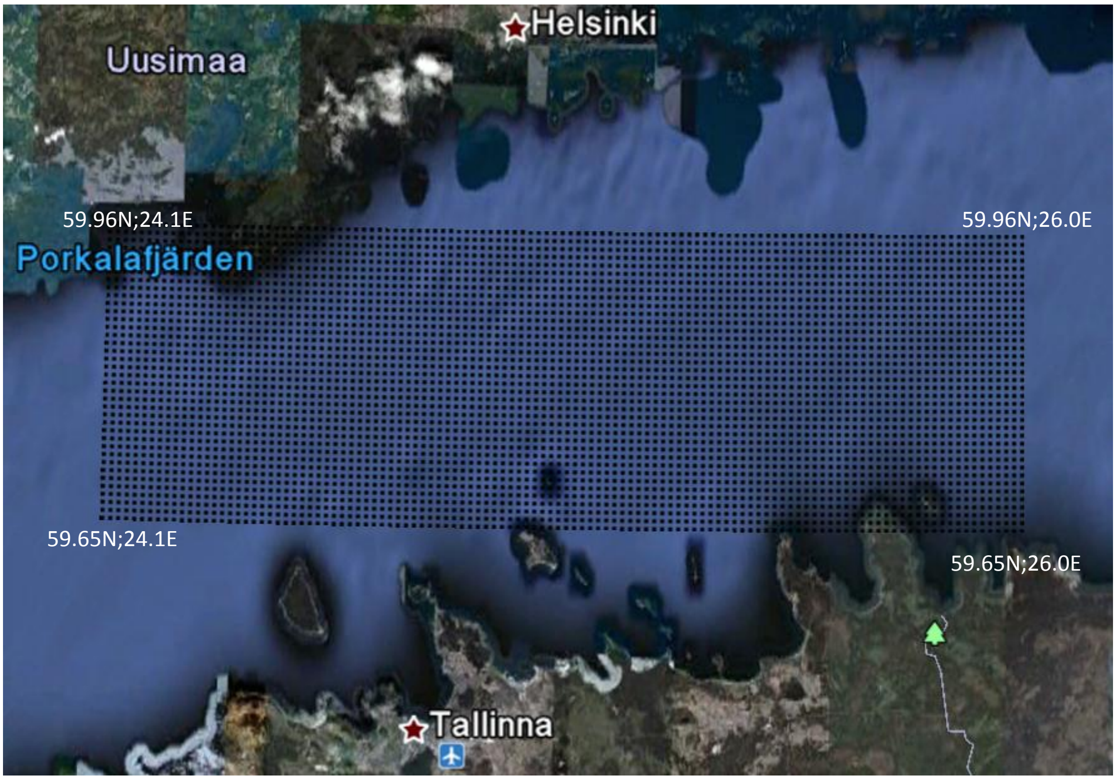


Figure 8: The area used for monitoring. The grid consists of cells with size of 0.25 x 0.25 nautical miles.

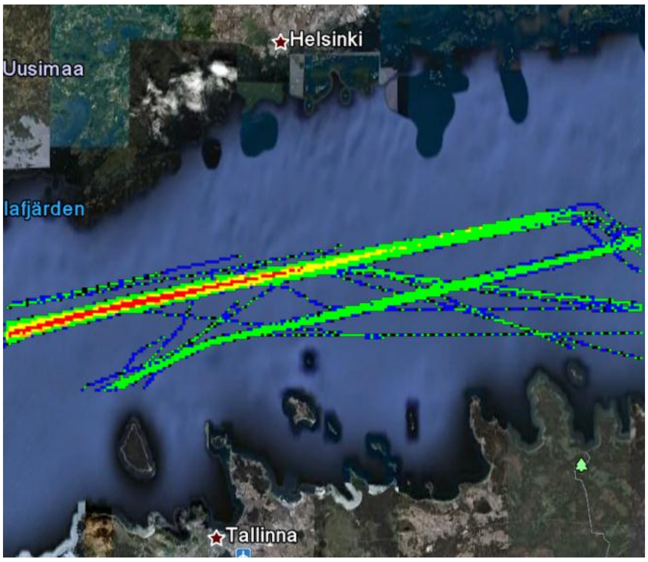


Figure 9: Traffic in the cluster east to west at normal speed

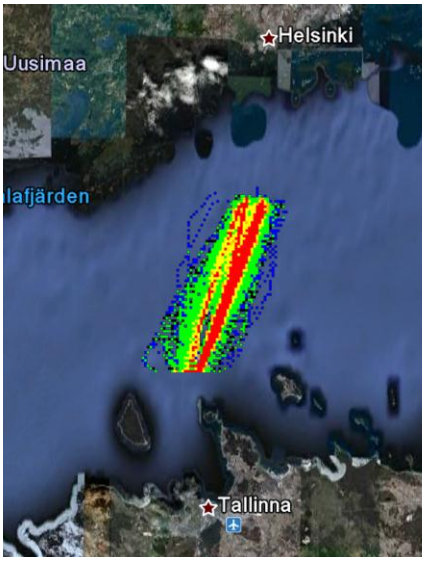


Figure 10: Traffic in the cluster south to north at very fast speed

In the second step, shown in Algorithm 1, the destination and the average speed of the ship are evaluated. Destination is evaluated by assessing the entry point to the grid and exit point from the grid; for example if the ship moves from cell 1 to cell 220, its cluster will be *west_to_east*. There are 12 routes used for clustering: east to west, east to south, east to north, west to east, west to north, west to south, south to west, south to east, south to north, north to west, north to east, and north to south. That is, all the cardinal directions are used. The ship's route is assessed by taking the first and last appearence of the ship within the area. The coordinates are mapped to the label: e.g. a ship at the south edge of the grid, say (59.70 N; 25.0 E), maps to south. If the label cannot be deduced, the course over ground of the ship is used instead. The following thresholds were used for each of the labels: If there is an overlap (e.g., ship is at the south west corner 59.65 N; 24.1 E), the direction that comes earlier in the list will be used. The mappings are the following: north: 59.8825 N – 59.96 N; south: 59.65 N – 59.7275 N; west: 24.1 E – 24.575 E; east: 25.525 E – 26.0 E. For example, if a ship is at (59.50 N; 25.60 E) its label is east. If the ship is at (59.90 N; 25.60 E) its label is north.

Using the average speed, the original cluster will be further split into subclusters. Figure 9 and Figure 10 show traffic of two subclusters. The possible subclusters are *very_slow*, *slow, normal, fast* and *very_fast*. The thresholds for each cluster are crisp: *very_slow*: <5 knots, *slow*: 5-11 knots, *normal*: 11-16 knots, *fast*: 16-25 knots, *very_fast*: >25 knots. These thresholds were decided after reviewing the distribution of average speeds. The distribution of average ship speeds within the grid during May and June 2010 is shown in Figure 11.

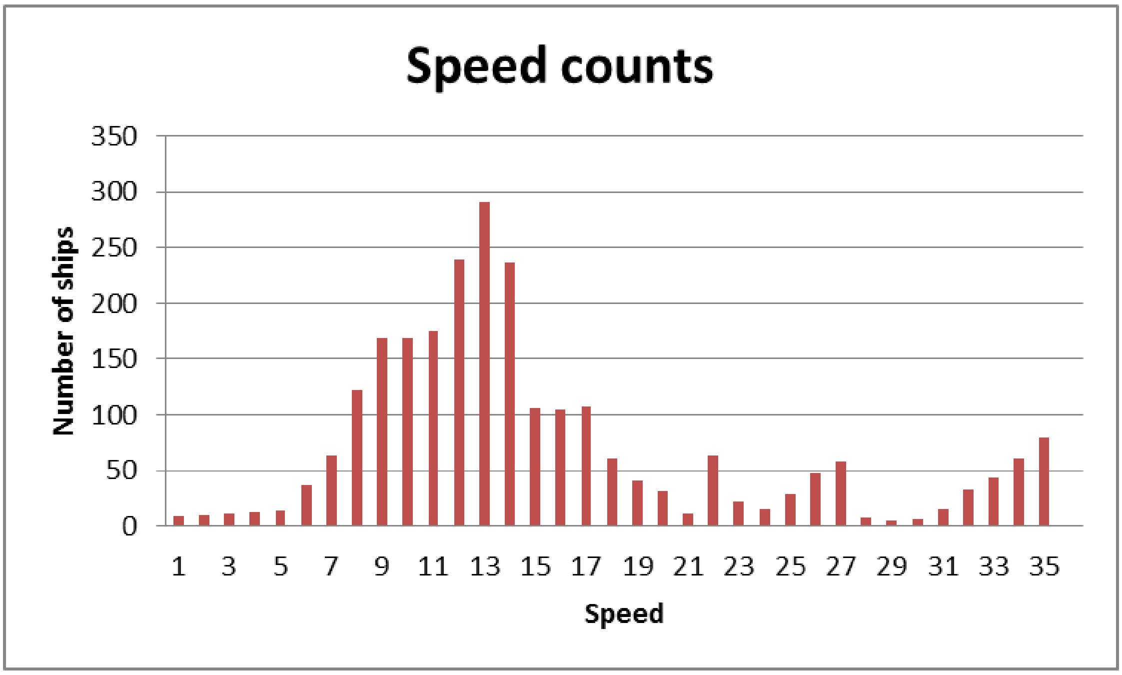


Figure 11: Distribution of average ship speeds within the grid in May and June 2010.

Algorithm 1. Cluster routes based on their average speed and movement.

```
cluster_routes(routes)
1. initialize all clusters
2. for all route in routes
2.     cardinal_from = route's first coordinates
3.     cardinal_to = route's last coordinates
4.     get cardinal_label using cardinal_from,cardinal_to
5.     get speed_label using route's average speed
6.     store route to cluster speed_label+cardinal_label
7. end for
```

Next, each cluster is looped and the transition matrix is trained. For each ship in the cluster, the movement is interpolated. This means that using the actual AIS entries for the ship, the additional entries are added to match the wanted time interval of the entries. In other words, if a ship has entries for times 0, 30, 70 and 130 seconds, and entries exactly on each minute (i.e., every 60 seconds) are desired, the actual entries have to be interpolated to have entries on 0, 60 and 120 seconds. The interpolation is done by taking the two closest entries of the given timepoint and using them to calculate the speed, heading and coordinates of the ship. In the example above, for the timepoint 60 seconds the entries for 30 and 70 seconds would be chosen to calculate the speed between the two points. The location of the ship at 60 seconds would be calculated by taking the weighted average of the two original locations. Interpolation is shown in Algorithm 2.

Algorithm 2. Interpolation of the AIS transmissions.

```
interpolate(route)
Initialize previous timestamp p = -1
for each location loc on ships route
   get timestamp t from loc
   if t - p > 1min
      initialize interpolated location iloc
      calculate interpolated coordinates (ix,iy)
      set coordinates (ix,iy) for iloc
      store iloc
   end if
end for
```

After the interpolation, each interpolated entry is looped (i.e., each 60 second movement is used). First, the ship's location is mapped to the grid. That is, the coordinates of the ship are transformed into a cell identifier; for example, if the coordinates are (59.65 N; 24.42167 E), the location of the ship in the grid is cell 1. Second, the count of the previous location is increased byone. Third, the transition count of the previous location to the current location is increased by one. If the previous location was cell 123 and current is cell 220, the count of cell 123 is increased by one (this indicates how many times a ship has visited cell 123) and the count of cell 123 → cell 220 is increased by one (this indicates how many times a ship has moved from cell 123 to cell 220). Algorithm 3 shows the process in more detail.

Algorithm 3. Estimation of a transition matrix for a cluster.

```
estimate_transition_matrix(cluster)
Initialize previous location l = -1
for each route in cluster
   for each location loc in ships route
      get coordinates (x,y) of the ship's location loc.
      get grid id n for the (x,y).
```

```
            add one to count matrix for grid n.
            if l >= 0: add one to transition matrix for index l,n
            l = n
        end for
    end for
    for each transitition i -> j
        s = transitioncount[i][j] / count[i]
        store s to transitionmatrix[i][j]
    end for
    write results to file
```

The whole process of transition matrix estimation is shown in Algorithm 4.

Algorithm 4. The process of transition matrix estimation for a file.

```
estimate_all_transition_matrices(file)
    read data from file
    routes = separate routes
    cluster_routes(routes)
    for each cluster
        initialize trans_matrix_for_cluster
        for each route in cluster
            iroute = interpolate(route)
            t_m_for_cluster = calculate_transition_matrix(iroute)
            update trans_matrix_for_cluster with t_m
        end for
    end for
```

For training the matrix, the user can decide on how many time steps is to be used for the movement. For example, if 2 is selected, the transition of a ship is calculated after 120 seconds. The possible time steps that can be used here fall between 1 – 10 (i.e., between 60 seconds and 600 seconds).

The counting is done for each day that is used for training. The time period can be given as a parameter. During the development experiments, data from June 2007 to July 2007 was used.

After the counts for the movements are fetched and the wanted time period is looped, the actual transition matrix is calculated. This is a simple process: for each cell A in the grid, get the count (count(A)) of the visited ships. For each transition (A → B) of the ships in the given cell, get the count of transitions in the cell (count(A → B)) and calculate the probability:

P(A → B) = count(A → B) / count(A).

This process is done for each cluster separately, i.e., there is a transition matrix for each cluster. After the process the matrices are stored. As most of the transition probabilities are nil, there is a need for a more efficient data structure. Therefore the resulting matrix is stored using a sparse matrix.

3.2.3 Estimation of close encounters

The transition matrices are used to predict the movement of the ships. Given a matrix *M* that holds the probabilities $P(A \rightarrow B)$, which indicate the probability of moving from each cell *A* to each cell *B* within a time period *t*, the probability distribution for different locations for the ship after a time period *n* x *t*, where $0 < n < 10$ can be calculated.

Before calculating the movement probabilities the transition matrix to be used for each ship has to be determined. The speed and destination clusters are approximated using similar algorithm as described in section 3.2.2. It should be noted that the cluster selection is an approximation, as the last known location of the ship may be in the middle part of the grid instead of exiting the grid. Because of this, the destination part of the cluster id is determined using the last known course over ground (COG). The course over ground thresholds for destination cluster are as follows: *west*: 225≤*COG*<315, *north*: 315≤*COG* or *COG*<45, *east*: 45≤*COG*<135, *south*: 135≤*COG*<225. The origin of a ship is determined by its location history. However, if the system has just been started, also the origin may be unknown, because there is no location history available. The approximation process is depicted in Algorithm 5.

Algorithm 5. The process of transition matrix selection.

```
select_transition_matrix(route)
    cardinal_from = route's first coordinates
    cardinal_to = route's last course over ground
    if (cardinal_from == null || cardinal_to == cardinal_from)
        if (cardinal_to == west) cardinal_from = east
        if (cardinal_to == east) cardinal_from = west
        if (cardinal_to == north) cardinal_from = south
        if (cardinal_to == south) cardinal_from = north
    end if
    get cardinal_label using cardinal_from,cardinal_to
    get speed_label using route's average speed
```

The idea is to calculate the joint probability of the movement chain within the time steps. The movement probabilities to each cell from current cell *A* after one time step can be read straight from the transition matrix from row *A*, where *A* is the current grid id. For each consecutive time step, the probability distribution is calculated by multiplying the distribution from previous step by the transition matrix, i.e., to get a movement probability for each of the destination grid cells *B,* the dot product of the current distribution and the column *B*, where *B* is the grid cell id of any destination cell, is calculated. The process is shown in Algorithm 6.

Algorithm 6. The process of movement probability calculation.

```
calculate_movement_probability(ship, number_of_time_steps)
    distribution_vector = transition_matrix.row(current_cell_id)
    for each time step
        distribution_vector = distribution_vector · transition_matrix
    end for
```

The risk of collision is the joint movement probability of two or more ships; if at least two ships have a high probability of being in the same cell in the same time step, there is a risk for collision. The risk probability can be calculated as

P(*Collision_risk*) = 1 – (P(*no_ships*)+P(*one_ship*))

for each cell, where *P*(*no_ships*) is the probability of an empty cell, and *P*(*one_ship*) is the probability of only one ship in the cell. Collision risk probability calculation is described in Algorithm 7.

Algorithm 7. The process of collision risk calculation.

```
calculate_collision_probability(cell, distribution_vectors)
    P(no_ships) = 1
    P(one_ship) = 0
    for each distribution_vector v
        P(this_ship) = v(cell);
        no_ships *= 1 – P(this_ship)
        if (P(this_ship) > 0)
            for each distribution_vector w
                if (v == w) continue for
                P(this_ship) *= (1 – w(cell))
                if (P(this_ship) == 0) break for
            end for
        end if
        P(one_ship) += P(this_ship)
    end for
    P(collision) = 1 – (P(no_ships) + P(one_ship))
```

The length of the time step to use, as well as how many time steps ahead the prediction will range, are given as parameters for the prediction component. The component returns a vector of predicted snapshots of the observation area. There is one prediction snapshot per time step. A prediction snapshot includes ships' movement probability distributions, close encounter area probability distributions, and location anomalies (a ship is in a grid cell that has a probability below a given threshold). Anomalies and their thresholds are covered in more detail in the next section.

Configurable parameters used in the prediction component:

- Close encounters:
  - Low probability, indicated with green cell, default value=0.009
  - Medium probability, indicated with yellow cell, default value=0.005
  - High probability, indicated with red cell, default value=0.02
- Movement probability to be shown:
  - Low probability, indicated with line width 0.1, default value=0.015
  - Medium probability, indicated with line width 0.9, default value=0.25
  - High probability, indicated with line width 1.7, default value=0.6

The whole prediction process is given in Algorithm 8.

Algorithm 8. The prediction process.

```
predict_ship_movement_and_collision_risk(file, time_step_length,
number_of_steps)
   1. snapshot=read data from file
   2. for each time step
   3.     for each ship in snapshot
   4.         select_transition_matrix
   5.         distribution_vectors = calculate_movement_probability
   6.     end for
   7.     for each cell in grid
   8.         calculate_collision_probability(distribution_vectors)
   9.     end for
   10. end for
```

3.2.4 Anomaly detection

Anomaly detection is a process of identifying abnormal events and movement of ships in the given sea area. First, the transition matrices may be used in the process: when comparing the assessed probability of the ship's movement to the actual movement, if the probability is low, there may be an anomaly. Second, by modelling the normal attributes of the movement such as ship's speed and heading, anomalies may be identified by comparing the ships movement to the model of normal movement. If the ship is e.g. heading 90 degrees off the normal heading, there may be an anomaly.

Modelling the normal attributes is similar with the process of training the transition matrices. For each cluster the movement of each ship is used and the average speed and heading is calculated and stored.

The anomaly detection may also be used to prune the training set of the transition matrices. If the training set holds anomalies, the probabilities hold a little bit of noise. By identifying and removing the noise from the training set the transition probabilities will be more accurate and model the normal transitions.

The only anomaly detection method implemented in this work is for location anomalies. A location is considered anomalous, if there are no transitions from the cell to any other cell in the transition matrix, and if the ship is not expected to leave the area during the next time step. The absence of transitions from a cell means that no ships have visited the cell during the training period, unless the cell is so close to area boundaries that the next transition would be outside the monitored area. To check if the ship is about to leave the area, we make a simple transition estimate based on the current speed and course over ground. The process is given in Algorithm 9.

Algorithm 9. The location anomaly detection process.

```
detect_location_anomaly(ship)
   distribution_vector = transition_matrix.row(current_cell_id)
   if (max(distribution_vector) == 0)
       if (estimated_next_location in area)
           report anomaly
       end if
   end if
```

3.3 Tests with different parameter values

There are a few parameters that can be tuned in the model. For training the transition matrices, the interpolation interval (the time interval of each AIS entry to be used) can be chosen as well as the length of the time steps to be used in training.

Tests have shown that most useful length of a time step falls between 180 and 300 seconds with the chosen grid size. With shorter time steps the probability of staying in the same grid is too large, whereas with longer time steps the movement probability distribution scatters. The same scattering applies also to using many time steps regardless of the length of the time step. The method seems to be most suited for quite short term predictions, ranging from 1 to ~5 time steps, i.e., from 3 minutes to 25 minutes depending on the length of the time step.

3.4 Tests with real time AIS data

AIS data from June 2007 to July 2007 was used for training of the model. AIS data from May 2007 was used for testing the results. The purpose of the tests was two-fold: 1) to test the prediction accuracy, and 2) to test the performance of the method when simulating a real time situation. 1) is covered in section 3.5.

To simulate a real time usage, a testing component that reads a snapshot of the recorded AIS data from csv file at given time intervals, does the necessary interpolations, and makes the movement and encounter predictions, as well as detects anomalous movement was implemented. The component produces a kml-file showing the current situation in the observation area, and a view per time step showing the predicted situation after each time step. The views can be changed in Google Earth by using the time slider. The possible destinations after a time step for each ship are shown as white lines. In addition, a movement prediction using current speed and course over ground is shown as a black line. Grids with an encounter probability over a set threshold are visualised using a colour code, where green is a small probability, yellow a medium probability, and red a large probability. An example of the visualisation is depicted in Figure 6.

According to the tests, the computation time of the system is reasonable. A snapshot with a five-step prediction is produced in less than 5 seconds. This enables having a nearly up-to-date picture of the situation.

The same simulation component is used also for real time prediction. For user tests of real time traffic surveillance AIS data from summer 2010 and spring 2011 was used for training the models to get more up-to-date traffic patterns.

3.5 Validation

To validate the approach the predicted movement probablility distributions and encounter area probabilities were compared with real recorded situations. This is essentially the same method that can also be used for detecting anomalous movement. When the testing component takes a new snapshot, it is compared to a prediction of the same moment, if such a prediction is available. The idea is to validate how accurately the system predicts normal ship movements. A list of close encounter situations from May 2007 was used in selecting the test times. The list was compiled from the near miss analysis results (Berglund & Pesonen, 2010). A day when no close encounters were detected was selected, because it can be assumed that a close encounter situation may result in avoidance manouvers that are not in the scope of normal ship movement. A test on real-time AIS data in a dense traffic situation was also performed. Another method of validating the approach is through user tests. All model validation methods and results are reported in Deliverable D_WP6_3_02 Final test report including uncertainty analysis.

4 On-line risk indication system for restricted waters – VTS tool

The decision-making support tool is thought to be for avoiding accidents and incidents while they start to occur and not in a preventative stage, as the VTS centres in Sweden are of information-giving character and not giving navigational assistance service or organise the traffic. At the same time the information provided can be given in an early stage and influence the actions taken by the ship crews.

4.1 Methodology

To be able to program the decision support tools, several steps had to be worked through, building the method used in this study.

Conclusions from the BaSSy research and implementation of ideas based on user needs: In the BaSSy ("Baltic Sea Safety") research project, several ideas where developed and preliminary tested. The results from the user need study in WP6.1 were analysed and applied.

AIS data conversion and analysis of traffic data: AIS as a source was identified as a useful tool to detect abnormal functions, the accessible data needed to be found and processed. In order to find limitations and restrictions of AIS data, before processing, the available raw data were converted into ASCII format and steadiness and reliability were analysed.

Development of the dynamic algorithm for analyzing online-situations: Using the program language MATLAB, the decision tools were developed and tested based on the idea that there exists a common normal behavior – a regular traffic pattern. The ships deverting can then be identified based on their irregularity/ abnormality that is in more detail described below.

Building a Matlab stand-alone application for testing: To visualize and to be able to test the decision support tool with users, a Matlab stand-alone application has been developed. More details on the results of the tests can be found in the report Final test report including uncertainty analysis, Deliverable No. D_ WP6_3_02

4.2 Conclusions from the BaSSy research and implementation of ideas based on user needs

In the BaSSy research project, SSPA developed several ideas theat were preliminary tested. Now the results from the user need study in WP6.1 were analysed and applied. A short decription of the research results is given below, based on (Hüffmeier, Wilske, & Grundevik, 2009).

The special task for the SSPA tool is according to the proposal:

Within the BaSSy project SSPA has developed a computer based decision support system concept for VTS operators, including detection of un-normal ship situations that may lead to collisions, groundings or passing certain limitations.

The system uses real-time AIS data and the approach is from a geometrical perspective and not statistical.

The following work has been accomplished within the task:

- A deeper study and further development of warning criteria's. The objective is to give alarm only for critical situations.
- The algorithm for grounding and collision warning has been developed further.
- Extensive tests using AIS data input has been performed.
- The possibility of receiving information and using intended routes from the ships has been analyzed. This means that an earlier detection of un-normal conditions can be accomplished.
- Inclusion of the end-user requirements from task 6.1 into the design
- Design of the system so to release the VTS operator from manually entering a lot of data to the system.

4.2.1 Conclusions from the BaSSy project

Interviews with VTS operators
There is the possibility seen by VTS operators to get support through decision support tools to help identifying collision and grounding "candidates" as early as possible.

Accident/ incident report study
The analysis of collision scenarios reveals that there is not a lot of time to warn the vessels prior to a collision, but the VTS operator and the crews should be informed as early as possible about possible meeting spots to avoid the meeting or overtaking in difficult parts of the

fairway. Only the vessels involved need to be informed and the number of warnings appearing for the VTS operator should be limited.
The grounding scenario solution should facilitate early detection. The system can be based on AIS data of historical traffic and statistics when the ship exceeds typical course over grounds/ headings, typical speed ranges or common fairway areas. Typical time span for this phase is on the average about 12 minutes. I will be easier to detect early un-normal situations in wider fairways.

AIS analysis
AIS data are a good base for VTS decision support tools. The quality is still imperfect to a certain extent. Especially the data which have to be updated manually need to be handled with care and AIS signals of a vessel can be interrupted. However, the historical AIS data can be used to identify un-normal conditions.
Draught information from the AIS cannot be used as an indicator for grounding accidents due to insufficient quality, but other applications like the load calculator or GNSS heights could in the future help to set this parameter automatically.

Decision Support Tool development
The study has shown, that it is possible to support the VTS operator during the decision making process with useful information. For the three different scenarios (collision, grounding, drifting), three different solutions have been studied.
The collision decision support system has been implemented as a simple visualization tool. The VTS operator gets the meeting location visualised in the VTS system and inappropriate passages can be pinpointed via an alarm which alerts the VTS operator. The role of the VTS operator to inform, advice or steer the involved vessels is an interesting question. Today the intention is to inform only in most of the VTS centres.
The grounding DST uses historical ship track patterns based on AIS data. Different parameters can be used to give information and alarm about ships which do not follow the common patterns.
At last a simple algorithm has been implemented and tested to identify drifting vessels which can be a hinder for other vessels. This information tool might be of great importance for the VTS centre and all ships in the surrounding.
The system can have the potential to be used even on vessels. While downloading the newest sea chart to the ECDIS system, the common routes for the area can be downloaded as well as typical traffic distributions and densities. This can give efficient dynamic information about the fairway, possible dangerous parts of the planned route, possible alternatives and typical appropriate speeds.

4.2.2 Implementation of ideas based on user needs

Based on the questionnaire used in EfficienSea WP6.1, the following conclusions were made (Grundevik & Hüffmeier, 2011):

- There is a stronger belief in the possibilities to build a reliable automatic grounding warning system than a collision warning system.

- There is a clear scepticism regarding AIS data quality.
- There is also to a lesser degree scepticism regarding RADAR data quality. In the comparison between RADAR and AIS, the RADAR got a 13% better result (on a 100% scale). These results show not that big difference in attitude between the two techniques regarding data quality. In discussions with bridge operators the RADAR is often put forward as the "truth". In this study there is a weak tendency that RADAR position data can be misleading. The big difference between the RADAR and the AIS is that he RADAR has been used for a very long time and the limitations are known, whereas AIS is proportionately new and there is uncertainty in its reliability.
- Communication is essential and the VHF radio was ranked as the most important tool in the daily work for VTS operators. The second most important tool was the RADAR and the third was AIS. The high scoring for VHF and RADAR are in line with earlier studies, whereas AIS got maybe a higher mark than expected.
- There are relatively few grounding and collision accidents per year in the represented VTS areas. The rough average figure is 1½ groundings and ½ collision, whereas there are more than 5 times more near-miss grounding and collision incidents a year.
- There were big spreads in the opinion about the ratio of ships that operate dangerously and have unacceptable behavior in the traffic area. Four respondents experience 1 ship out of 50 or 1 ship out of 25 as being dangerous. We interpret this as a serious message, pointing towards the need for further investigations and probably actions to cope with this issue.
- Communication problems were put forward as the biggest problem in the respondents' work. Vague instructions and routines for the work were stated. This is probably connected to the sometimes unclear role of the VTS service. This issue is also serious and has to be taken care of and further investigated.
- Correct information given at the right time was the concluding answer to what activities are included in "good VTS-service". It comprises the main functionality of the VTS service which is communication of information. The amendment, "given at the right time", is of outmost importance to avoid overload and the provision of possibly not relevant information being given too early and of course it should not be given too late. It should be given with the aim to be pro-active.
- Communication problems were also put forward as the key issues to "what characterizes a near-miss situation". Shortcomings in communication may

lead to a near-miss or an accident, and good communication may prevent an accident that is close to occurring.

4.2.3 Conclusions from the expert panel workshop at Chalmers

At an expert panel workshop at Chalmers (09.–10.12.2010) with various VTS operators from various countries were used to find the user needs and try to understand the way VTS operators are working. The following conclusions were drawn:

- The detection of abnormal situation has to be more "intelligent" in order to avoid input of data (like draught, intended route)
- Transmission of intended route is an important base for ability of early warning of route diverge
- Reliable and continuous data of the ships is a requirement for the system
- ARPA are in many cases too slow to detect route divergence
- discussion about the reliability of AIS information – different opinions about the quality
- small CPA is often accepted by the mariners
- the information about the ship's route (sent from the ship to VTS) would help the operator
- combination of information (wind + current & in which side of the fairway the ship is) would be helpful
- the more automation there is, the less overall view the operator has about the situation
- indications of near miss situations
  - should be divided in controlled and uncontrolled near miss situations
  - controlled: e.g. two big ships meeting in a narrow fairway
  - uncontrolled: e.g. shouting in the VHF, abnormal manoeuvring
- route exchange: how to use the information
  - e.g. the traffic situation has an effect on that, when ships reach their waypoints
  - a wish to get accurate route plans from small ships without pilot onboard

4.2.4 Description of the different components

There are four different suggestions to VTS decision support tools. Two intends to avoid ship collisions, one to avoid groundings and one to give more general navigational information. More details can be seen in chapter 4.3 "Dynamic algorithms for analyzing online-situations".

4.2.4.1 Grounding avoidance based on historical traffic pattern

Similarly to the case described just above, the AIS pattern is analysed to derive the normal traffic behavior, i.e. where do the ships of a certain size in a certain position usualy sail? A cell pattern is applied to the VTS area. Historical data are analysed and for each cell the typical ship parameters are saved including ship size, SOG, COG, heading, draught. When a vessel with size A, speed B and COG C enters the cell , the grounding avoidance will check, if there were ships of the size A with speed B and COG C prior in this cell giving relevant information about the typical traffic behavior. If a ship is on grounding course, the analysis will detect the deviation from the normal behavior much earlier than other geographic tools, such as "non-passing lines" in the common systems.

4.2.4.2 Visual collision avoidance information

Based on the very short time frames prior to collisions, a visual addition information is proposed.

Assuming two vessels approaching a certain fairway, the visual collision avoidance helps the VTS user to see into the future, i.e. see, wehere the two vessels will pass each other based on their current speed and heading. This information is updated via AIS or possibly radar. The calculated meeting point is visualized on the map. The warning level can be changed based on:

- Areas where ships passing should be avoided, such as bends, narrow and confined waters, areas with high density of leisure boats, etc.
- Areas, where three or more ships meet each other

Critical situations can be defined by forehand. If one of the vessels is leaving the fairway, the meeting point is disabled. There should be a filter deployed to avoid fast motion of the meeting point due to faulty AIS messages.

4.2.4.3 Collision avoidance based on historical traffic pattern

Based on historical traffic pattern, the component derives appropriate passing distances. The VTS area is divided into small cells describing the traffic pattern in the area. For each cell, the

AIS historical data are analysed in terms of ships meeting each other, their minimal and actual passing distances. Historical AIS tracks are taken, the position messages interpolated and the geometrical distances derived.When ships now approach a certain position, it can be calculated, if the other vessels are in an appropriate position compared to each other.

By combining the two different information sources for historical and real time ship collisions, conclusions can be derived regarding the risk for collision. The vessels will meet in a certain cell if they succeed with the same speed and course on the fairway. Based on the data it can then be concluded, if a meeting there is appropriate or not.

4.2.4.4 Consequence route planning

This tool visualizes risky areas for a certain ship to pass. When holding the mouse above a certain ship, layers show on the screen of the VTS centre identifying dangerous areas, the ship should pass safely with special care or possibly not at all. These areas should be communicated to the officer on watch (OOW). Examples for this could be:

- HSC passing at high speed areas with diving activities, exposed leisure boat harbours, beaches (wash waves)
- Pressurised gas tankers entering areas with risk for contact with ignition sources or explosion risks
- Tankers entering areas with high sensible environmental features.
- Passages of gas tankers with passenger ships.

4.3 Dynamic algorithms for analyzing online-situations

Using the program language MATLAB, the decision tools were developed and tested based on the idea that there exists a common normal behavior – a regular traffic pattern. The ships deverting can then be identified based on their irregularity/ abnormality that is described in more detail below.

4.3.1.1 Grounding avoidance based on historical traffic pattern

Todays systems are based on simple geographic reference lines, that vessels are not allowed to pass. As there is little time in limited firways prior to groundings, the alarms based on these simpler algorithms might come possibly to late to avoid the accidents. Taking into account historical traffic pattern, one should be able to detect vessels behaving in an untypical way and give warnings, if these ships exceed certain limits. These ideas are based on the following assumptions:

- Ship traffic follows certain structures and a traffic pattern can be detected,
- for a successful alarm as early as possible, the ships, that are on grounding course deviate early from the common traffic behavior, and
- AIS data in the main are a sufficient and reliable source of information

A "real-time" ship with a certain position, a certain COG, a certain draft and a certain speed will then follow either a typical traffic pattern or not. A typical traffic pattern is decribed by the distribution of parameters decribed above and shown in Figure 12. The figure exemplifies that ships with different sizes follow distributions of COG in a certain fairway. For example it can be noted that smaller ships have a wider spread of COG as they have easier to manoeuver in absolute terms (stopping, turning).

The SSPA algorithm analyses the fairway based on a mesh that is put on the area of interest (Figure 13).

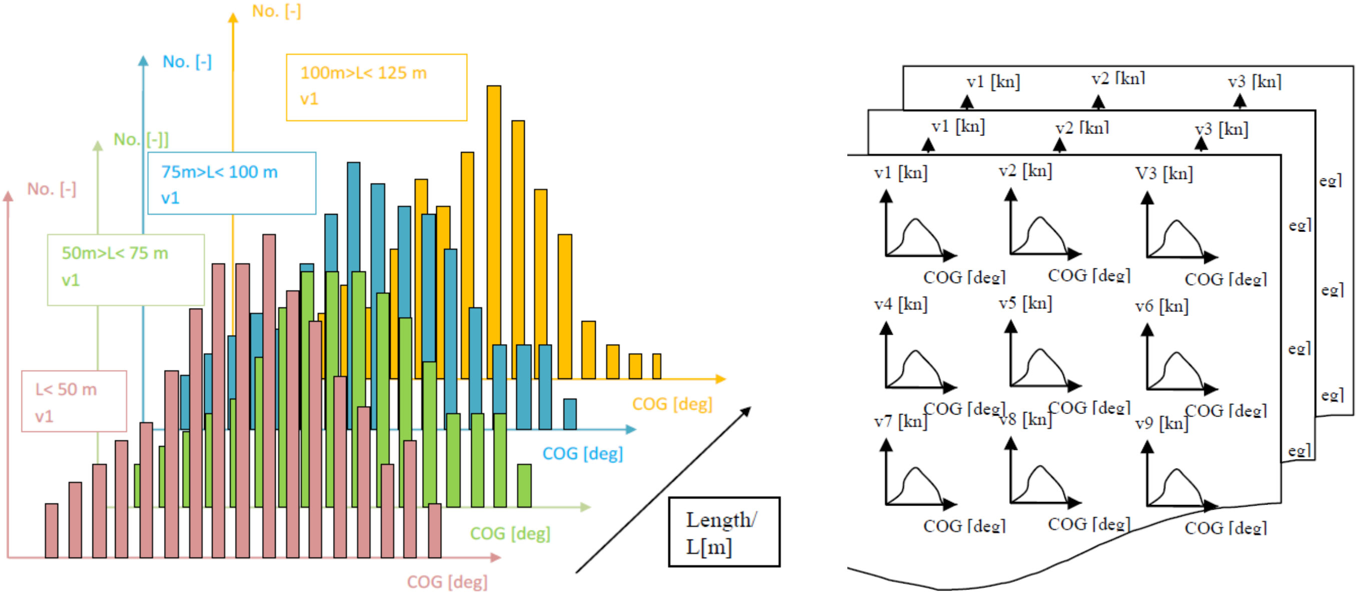


Figure 12: Distribution of parameters on a fairway, Storage of relevant data in matrices

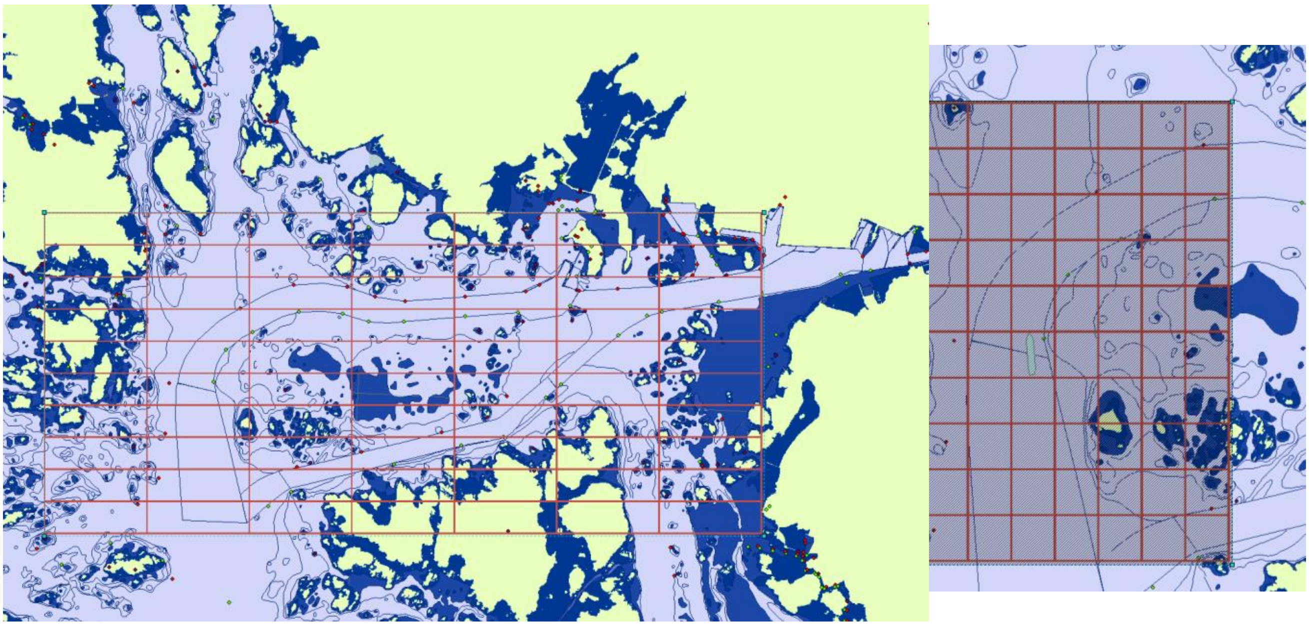


Figure 13: Schematics of the grounding avoidance tool for the Gothenburg Archipelago, cell size in reality about 25x25m, in the figure much bigger to visualise schematics

In each of the cells, the relevant traffic is analysed based on historical AIS traffic pattern. The AIS data have been saved for several months, the geographic position is determing in which place in the matrix the information is stored, than all the main parameters are stored in the matrix:

- Ship speed
- Ship size (length)
- Ship draught
- Course over Ground
- Wind speed and direction while passing the cell
- Ship type (from AIS)
- Ships MMSI number

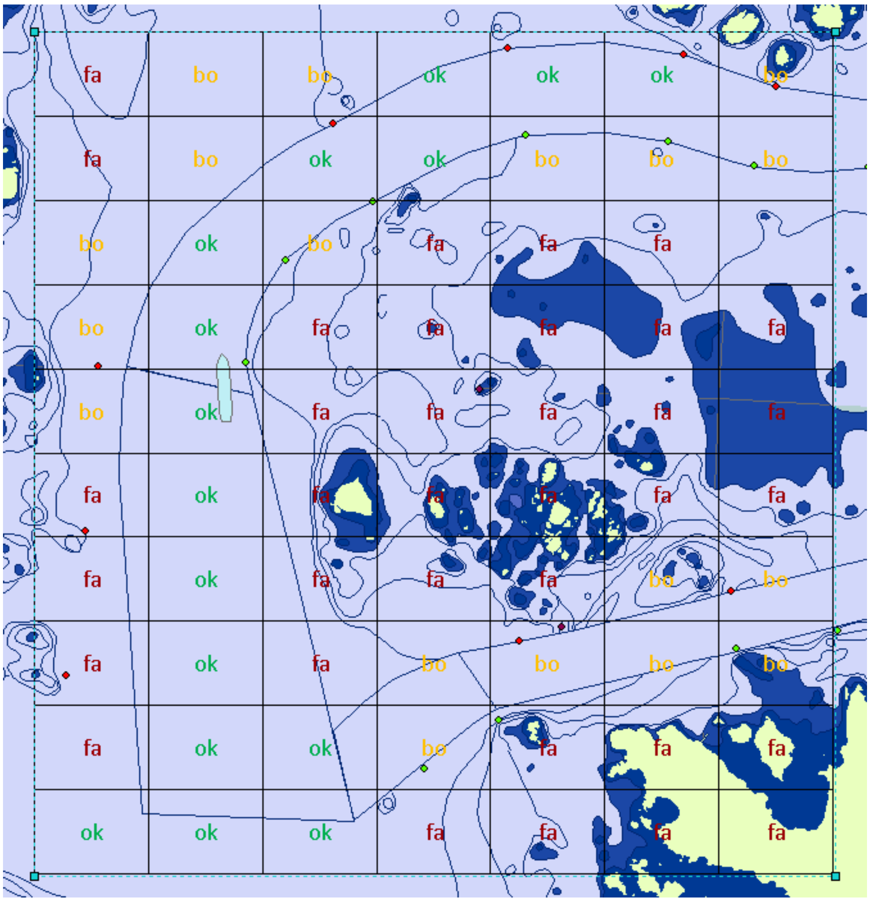


Figure 14: Position check output based on AIS data, schematic presentation

Looking at the cyan colored ship in the figure above, this ship has all these parameters in the AIS message. The algorithm searches the distributions with the stored data in the matrix. The following parameters are checked against:

- Has there been a ship of this size before, or has there been a bigger one before (both in terms of length and draught,
- The ships that have been there before, did they have such a speed as the actual ship?
- Is the course over ground fitting the distribution of the other ships?

Optionally, the following checks could be performed as well:

- Based on the ship type, e.g. has there been a tanker of this size sailing at this position before?

- Based on the MMSi number, did this ship sail in that manner before (mainly valid for ships with regular visits to the area, such as ferries (e.g. Helsingör-Helsinborg, Gothenburg-Fredrikshavn, etc.)
- Based on the weather, e.g. did ships of this size sail so close to the fairway borders in strong sidewinds?
- If current data are available, did ships sail in that way when there were strong currents? Is it appropriate to sail in this way when ships are experiencing currents?

In Figure 14, the cells that ships of this size have visited earlier are presented with "ok". Ships that have passed cells with a size class below are marked with "bo" (border case) and cells that have never been visited of this ship size class are marked with "fa" (failure). The picture shows that it is important to have the right grid size and arrangement to reflect the traffic pattern. This is done by using small cell sizes.

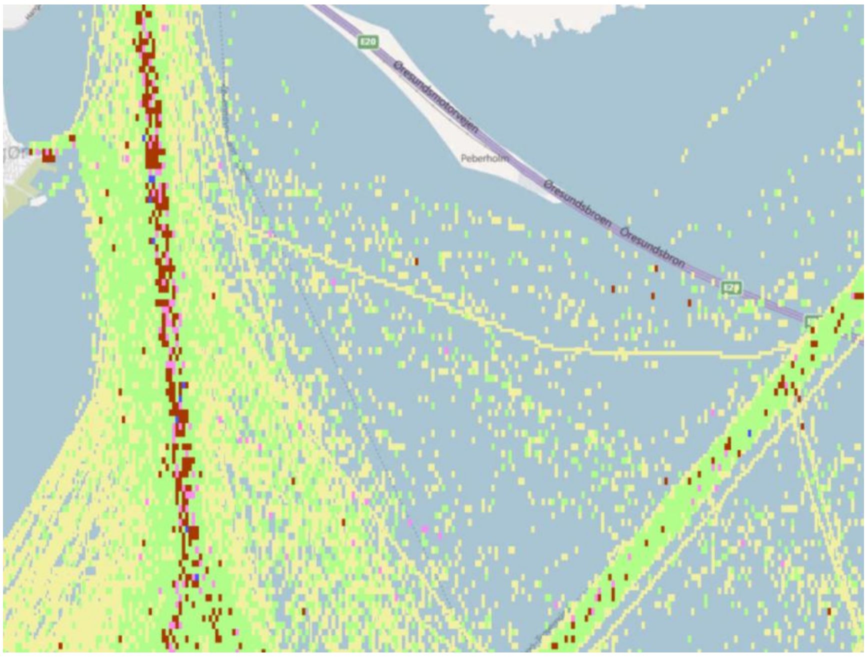


Figure 15: Ship length distribution in the Sound: Drogden Channel and Flintrännan

The tool is sensitive to the historical AIS data as an input. There is the question of AIS data quality. There is furthermore the question of new ship sizes sailing in an area as shown below for the Sound (Figure 15). The different colors in the plot show the maximum size of the ships that have passed the cell (Blue: L >300m, brown: L>250m, pink: L>200m, green: L>150m, yellow: L<=150m). Ships bigger than 300m are rare. If a new "real-time" ship is approaching bigger than 300m, there is little foundation for the warning system and data must be based on smaller vessels. Is the AIS history still a good source to validate against?

Another example visualises the speed distribution at the same spot, classing vessels with higher speeds (red: v>20kn, orange: v>15kn, light green: v>10kn, dark green: v>5kn).

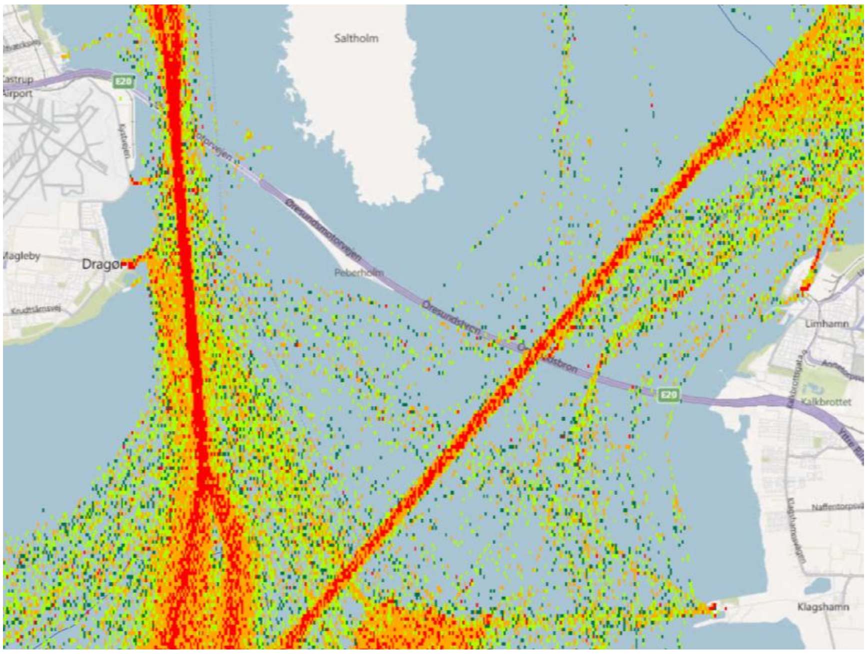


Figure 16: Speed distribution in the Sound: Drogden Channel and Flintrännan

All the small marks beside the bigger fairways in Figure 16 represent often only one single vessel. A vessel of a type and size that is new in the area might be sailing in an appropriate manner, but there is too little data to check against. Is it then appropriate to use the cells around for validation?

Tests with different grid sizes

There were tests made with different grid sizes to capture the traffic pattern. Using too small cell sizes, the calculation might possibly slow and the cells contain an insufficient amount of data. There willalso be a need for an accurateness, that is technically not feasible due to GPS transponder qualities.

Using too big cells it will not represent the traffic pattern in narrow fairways as shown for example in the schematic sketch in Figure 14. Fairway parts as well as grounds are situated in the same cell if the cell size is too big and a big share of traffic movement will be accepted and too little alarms will be given.

Probably the best grid would be adjusted to the fairway with a mesh generator. This would allow a very god representation of the fairway, but the creation of the mesh requires a certain amount of man-power. Critical parts of the fairway have to be modeled more precisely.

4.3.1.2 Algorithm description "Grounding avoidance"

Algorithm 1. Cell initialisation and sorting of historical ship data into it.

```
Define grid for the area
Define Length classes, Draught classes, Speed classes and COG classes
Possibly define wind and current classes
Read in historical AIS data
   For all data
     Quality check AIS data
     Sort data into grid
   End
   For all grid cells
      For each ship size class
         For each ship speed class
            If wind and current classes defined
               For each wind and current class
                  Find distribution of ships in cell
               End
            Else
               Find distribution of ships in cell
            End
         End
      End
   End
```

Algorithm 2. Detection of normal behaviour/ anomalie compared to information of traffic saved in the current cell the ship is in.

```
For all ships in the area
  Get current position from ship's AIS
  Get information from grid net to connect vessel geographically to
  relevant cell information
  Receive information from current cell on ship behaviour
   If ship size is within limits (length/ draught)
      If ship speed is within limits
         If ship COG is within limits
           ➔ Ship has normal behaviour
         Else
           Check all adjacent cells
             If ship size is within limits (length/ draught)
               If ship speed is within limits
                  If ship COG is within limits
```

```
                    → Ship has normal behaviour
                    Else
                    → Alarm
                    End
                 Else
                 → Alarm
                 End
               Else
               → Alarm
               End
           End
        Else
         → Alarm
        End
     Else
       →Alarm
     End
```

If wind and current classes are defined, some additional checks have to be performed in order to validate for the present weather situation.

4.3.1.3 Visual collision avoidance information

The ship collision avoidance information is based on an algorithm with the following input parameters:

- Fairway layout
- Ship sizes
- Actual ship speed of the ships in the area
- Actual ship positions in the fairway including direction
- Typical traffic behavior
- Manual input of areas with inappropriate passages

By taking the example figure below from the Gothenburg archipelago, the tool can be described as follows:

There are two lines in the figure representing the middle of the fairway (red for the northern, green for the southern . Ships approaching the fairway are allocated to the fairway they have chosen. The green areas represent parts of the fairway were vessels should not meet. For each time step, possibly even interpolated inbetween AIS messages, the ships positions are updated, then using the tool the following steps are conducted in the algorithm:

- the ships are allocated to the actual fairway,
- the meeting points to other ships in the fairway are calculated, based on the current speeds and directions,
- the calculated meetings points are checked if they fall within one of the green polygons. If that is the case, an alarm is sent to the VTS operator,
- If there are more than two ships meeting within a certain area, an alarm is sent to the VTS operator.

In Figure 17, the purple vessel sails faster than the turquoise vessel and will overtaking it soon. The meeting will take place at the white marked dot. As the meeting place falls outside a critical area, no alarm is given.

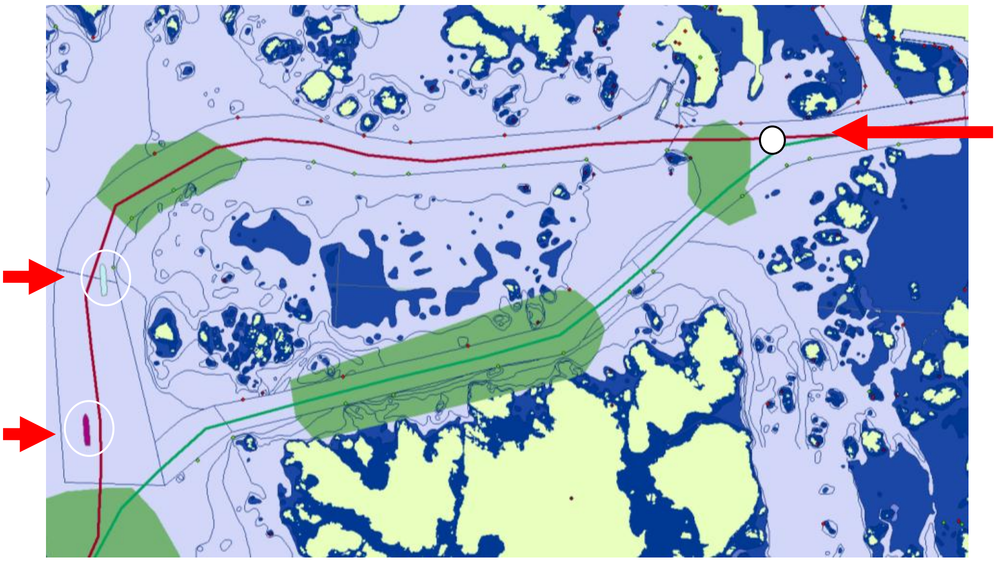


Figure 17: Example for tool application, Gothenburg archipelago – no alarm

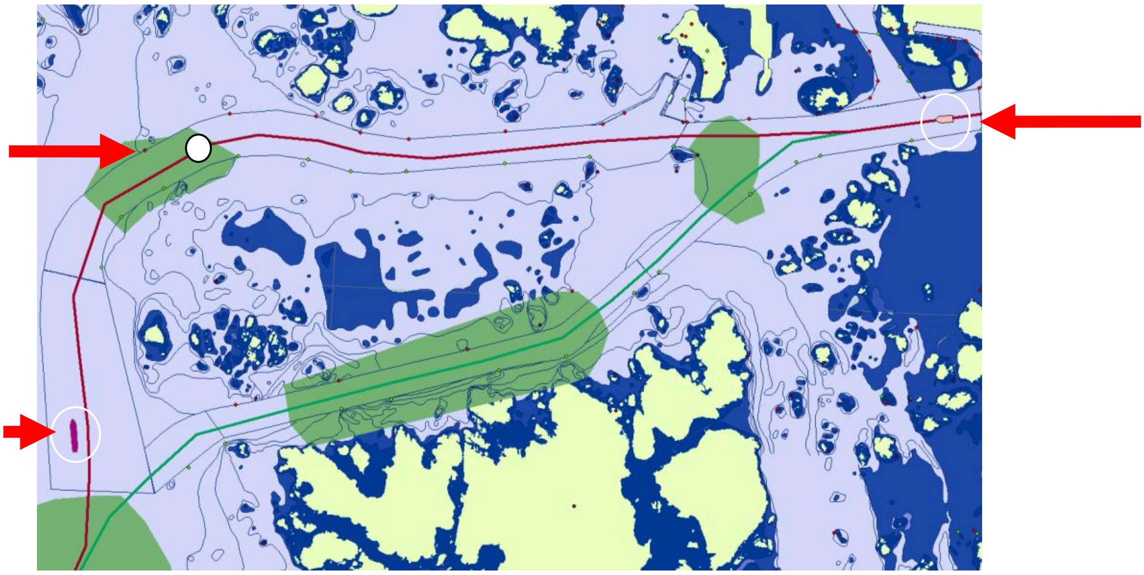


Figure 18: Example for tool application, Gothenburg archipelago – alarm

In Figure 18, the purple vessel is sailing slower than the orange vessel. The calculated meeting point falls within one of the "no-passing" areas and an alarm will be given to the VTS operator.

By taking more complex traffic scenarios with three vessels, an alarm is given, as the meeting points of the three ships fall within the same area, as shown in Figure 19.

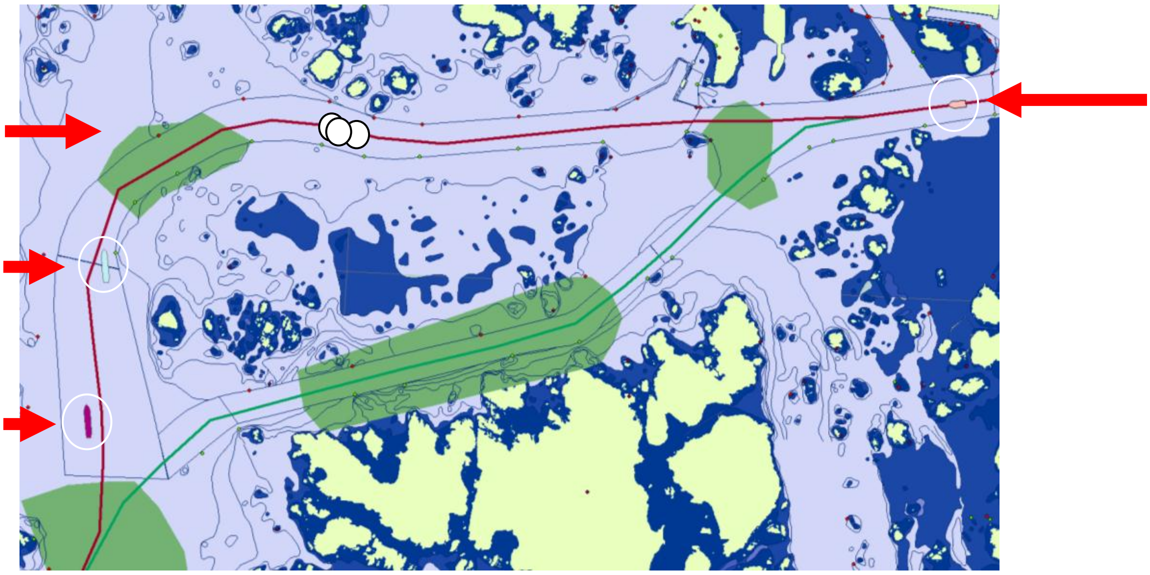


Figure 19: Example for tool application, Gothenburg archipelago – alarm

The relevant ship sizes that are taken into account for the calculations depend on the fairway. In the following an example from the fairway into Gothenburg is taken. Here ships with a length above 75m are taken into account for the northern fairway, while ships above 50m are taken into account in the southern fairway, as the fairway is rather narrow. That implies, that if one of the vessels fulfills the length criteria, it will be included in the analysis. There has to be a border in time, were the meeting point is not calculated, i.e. if the meeting will take place in more than one hour, the information is non-reliable. Optionally there is the possibility to include speed limitations in an area to adjust the meeting point. Additional filters are required to cover for bad AIS messages, which make the meeting point uncertain. Other traffic situations to be kept in mind, are ships manoeuvring to or from quays, giving uncertain information, or ships having the choice of several fairways as exemplified in the figure below. The orange and the pink vessel could choose either of the fairways, so they could meet in the northern fairway, the southern or not at all depending on their choice of fairway.

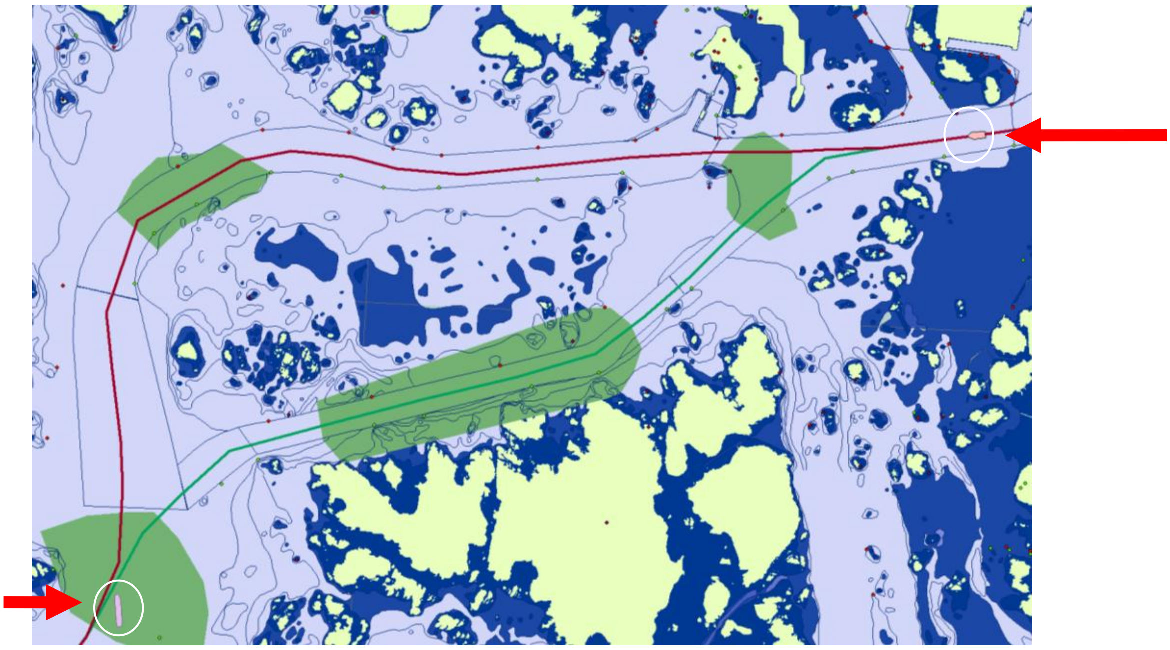


Figure 20: Scenario where vessel could possibly meet

The green areas for "no passing" are based on accident statistics, where each turquoise mark represents a ship collision based on data from the Swedish Transport Agency (Transportstyrelsen, 2010), AIS traffic data on risk analysis performed for the Gothenburg archipelago and based on information by pilots and VTS operators. In this study a general approach is taken. It is possible to think of adjustments of the green polygons for different ship sizes, viz. small ships might be allowed to pass each other even within the green areas and no alarm wil be given for them.

The fairways are represented as lines, since it is uncertain in which distance ships will pass each other widthways. Additional information regarding where the ships are sideways will only give uncertain information, especially if the ships are far away from each other.

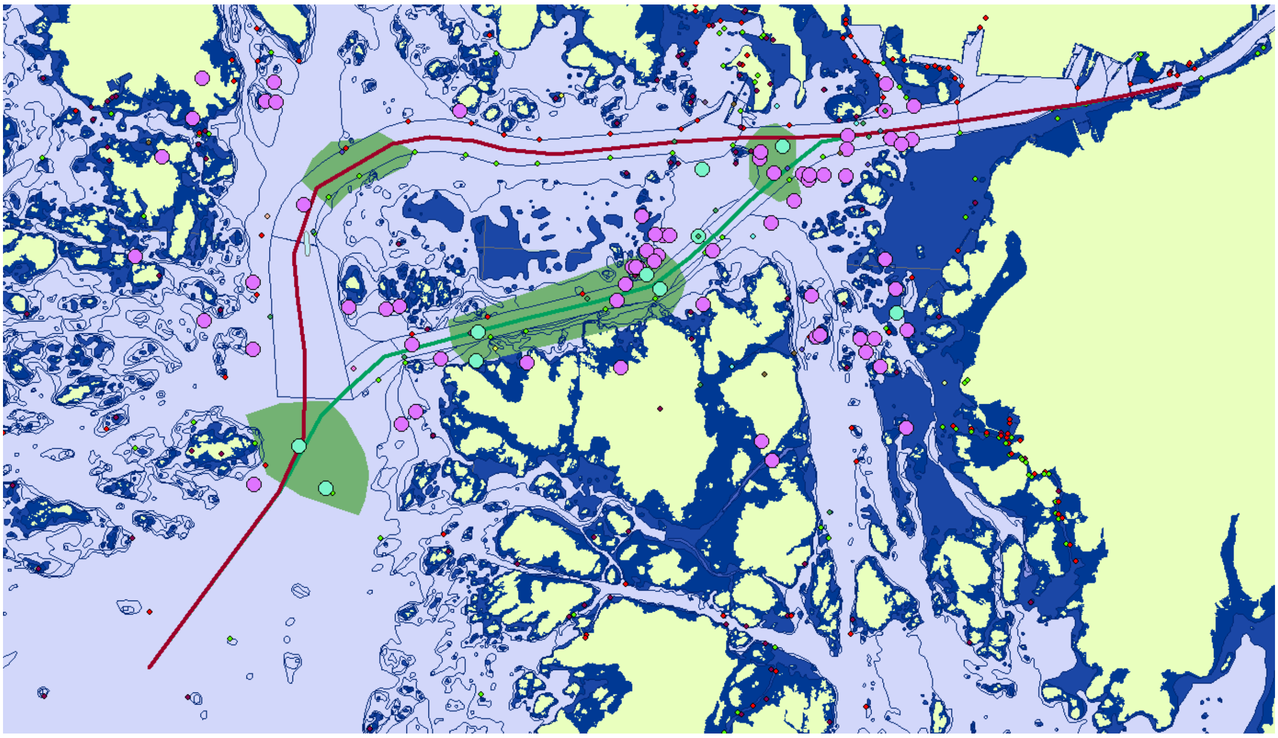


Figure 21: Accidents in the Gothenburg Archipelago based on data from the Swedish Transport Agency (Transportstyrelsen, 2010), cyan: ship-ship collision, purple: grounding accidents

4.3.1.4 Algorithm description "Collision avoidance"

Algorithm 3. Find meeting points and collision candidates

```
Read the predefined fairway definitions from file
Read the predefined "no-passing" area definitions from file
Receive all current AIS data from the area and the current time step
For all fairways
   Find number of ships connected to current fairway
     If number of ships bigger 1
       For number of ships-1
         Calculate meeting point based on speed, COG and heading
         If ships have meeting point
             If ships meeting point within "no-pass" area
               ➔ Alarm, Visualise meeting point
             End
```

```
                If ships meeting point close to another meeting point
                  ➔ Alarm, Visualise meeting point
                End
            End
          End
        End
   End
```

4.3.1.5 Collision avoidance based on historical traffic pattern

The collision avoidance based on historical traffic pattern follows a similar approach as the grounding avoidance tool. The whole fairway is modeled based on a mesh. The mesh information for each cell includes the typical passing distances of ships in the cell. If two vessels approach a cell, an alarm will be given if the ships typically do not meet close to each other in the area. Important in the calculations here is to keep the information on ship sizes, as ships such as tug boats and pilot boats come very close even to very big ships. These ships will have to be filtered out in the algorithms.

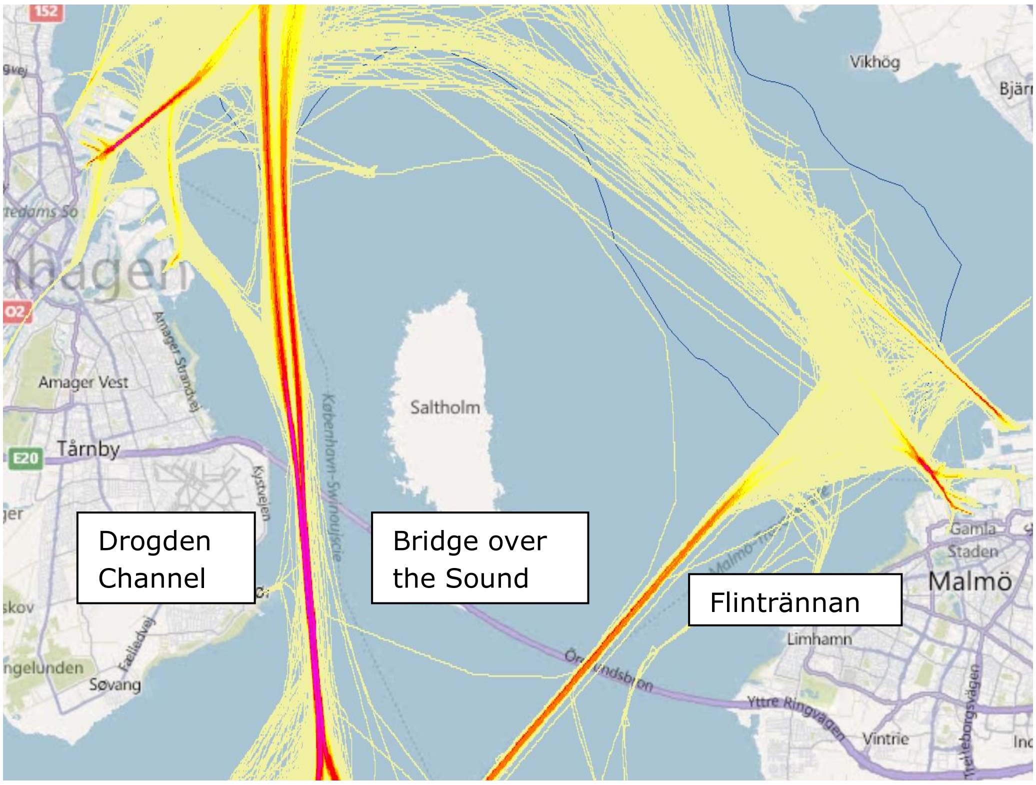


Figure 22: Density plot from the Sound, on the east side Flintrännan on the western side Drogden Channel

It is possible to use the information even as a complement to the visual collision avoidance information. Ships are there predicted to meet at a certain position. If ships at that position usually do not meet close to each other, viz. the fairway is wide and not restricted, an alarm would be given. If the fairway is very narrow and the ships pass each other with a short minimum distance, no alarm would be given to the VTS operator. An example of this is given in the figure above from the Drogden Channel in the Sound. In the channel, close passing distances are commonly use, while a bit north and a bit south of the channel, passing distances are bigger.

The Ship domain model based on Fujii (Fujii, 1974) expresses an safety ellipse around ships. It is understood as the safety zone with which a navigator intuitively operates when his vessel passes other ships, banks, shallow water, lighthouses or other obstacles. It is important to state that it is not only used for distances to other vessels.

There are several values for the size of the ellipse, most commonly used is L_e=4xL_{ship} for the ship length direction and B_e=1.6xL_{ship} for the transverse direction (semimajor and semiminor axes). The size depends clearly on the size of the vessel, vessel speed, navigational area, but even on the type of passed objects and weather influence such visibility, current and wind. These influences will be exemplified with some pictures.

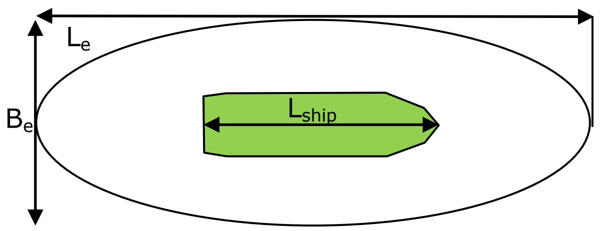


Figure 23: Safety ellipse as suggested by Fujii (Fujii, 1974)

The results of the analysis for the Sound are shown as series of pictures representing a passage from north to south through the Sound, using the Drogden channel and the way back through the Flintrännan. The tracks and positions visualized in the picture series are geographically allocated as in the figure below.

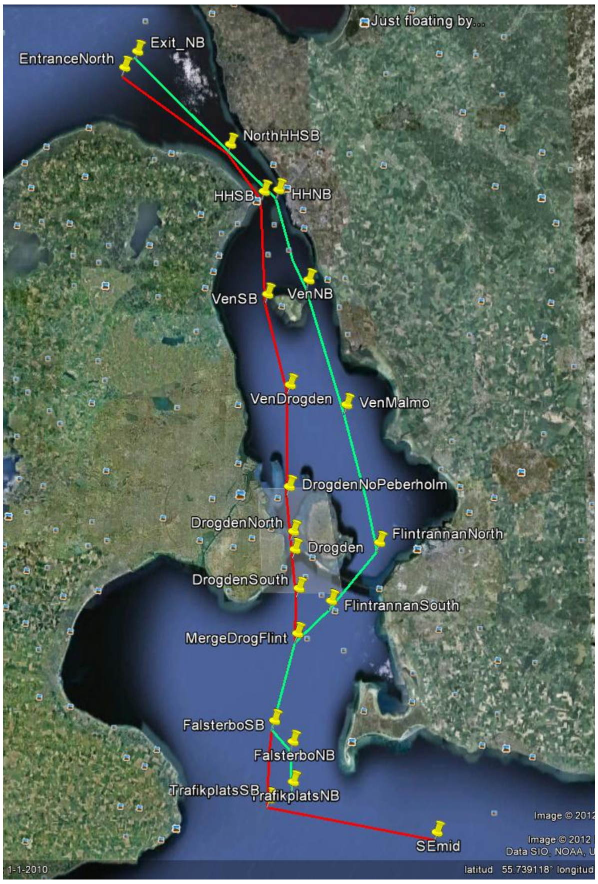


Figure 24: Tracks visualised in the picture series below. Red is the southbound track, green is for the northbound track, visulaised in Google Earth

Each picture shows the passing distances of vesssels as the position compared to other ships. The pictures are based on historical AIS of a bit more than one year. Each picture represents the distance data from historical AIS in a cell of about 0.04 degree latitudal and 0.05 degree longitudinal direction. Each point represents the distance between two vessels at the time stamp of the AIS message. Limits set are:

- ships over 50m (smaller vessels such as pilot boats and tugs excluded)
- ships sailing faster 3 knots (to avoid including similar meetings as above)

black color indicates no passing ships at this distance under the evaluated period, red an increased amount of passing ships up to yellow. The ellipses follow Fujii, with the semimajor axis, 1Lx0.4L, 4Lx1.6L, 8Lx3.2L and 12Lx4.8L. SB and NB are southbound respective northbound traffic.

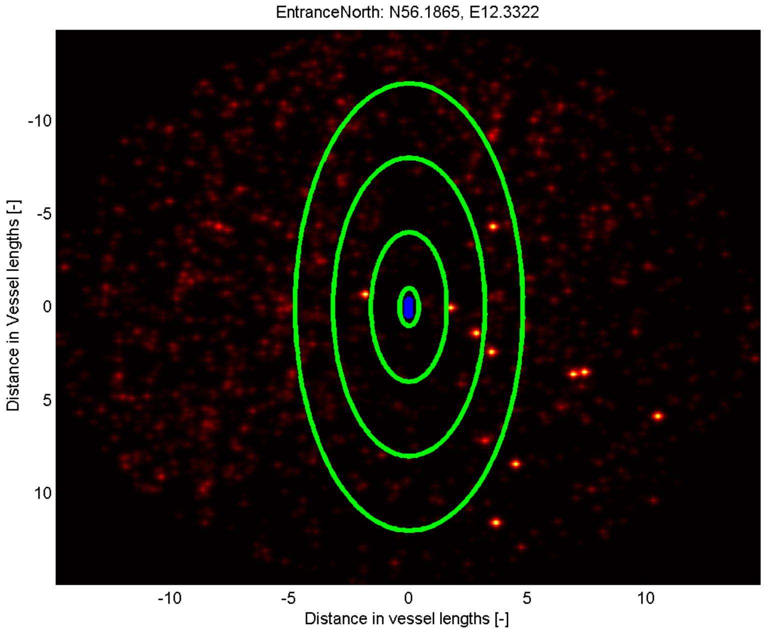


Figure 25: Entrance from north to the Sound, little traffic, wide distances to other vessels

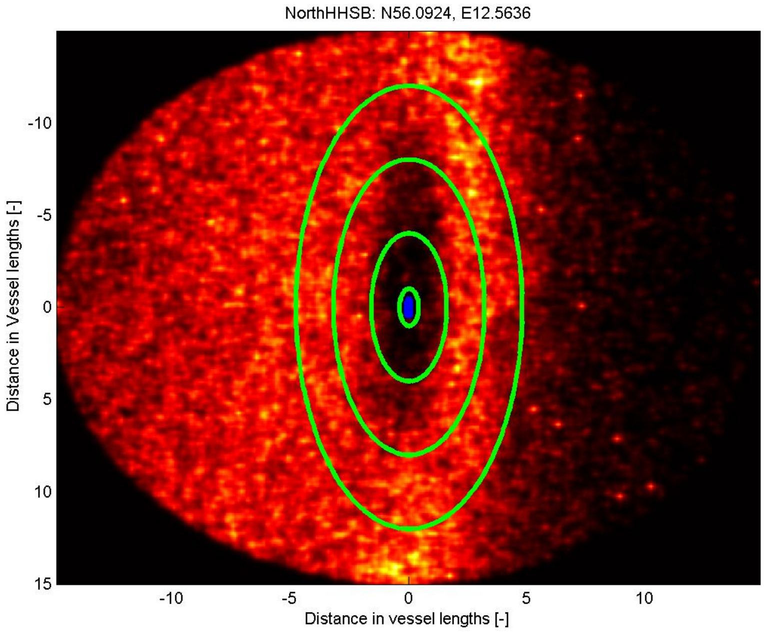


Figure 26: North of Helsingör-Helsingborg, traffic restricted and safety zones are visible, more space in front of the ship than behind

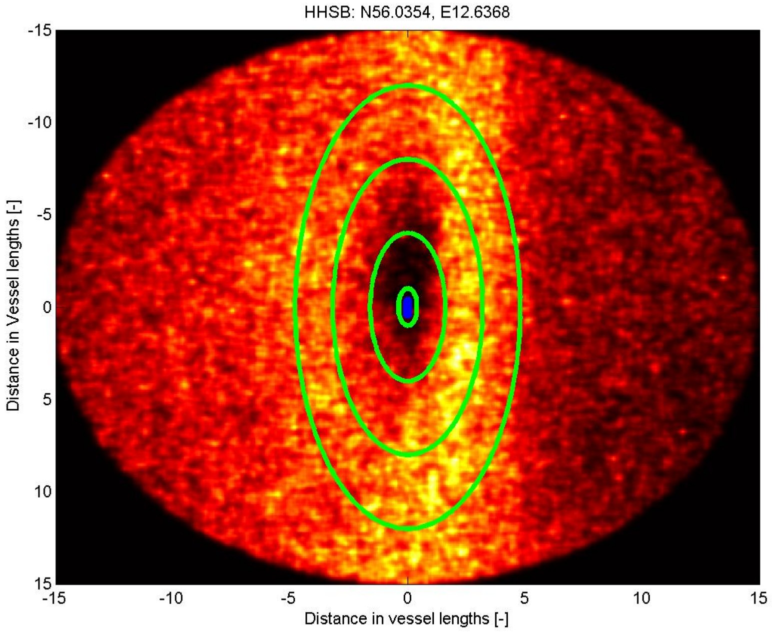


Figure 27: North-south going traffic meets the ferries trafficking Helsingör-Helsingborg, more traffic on the starbord side due to givnig ways of the ferries and south going traffic and ferries in port.

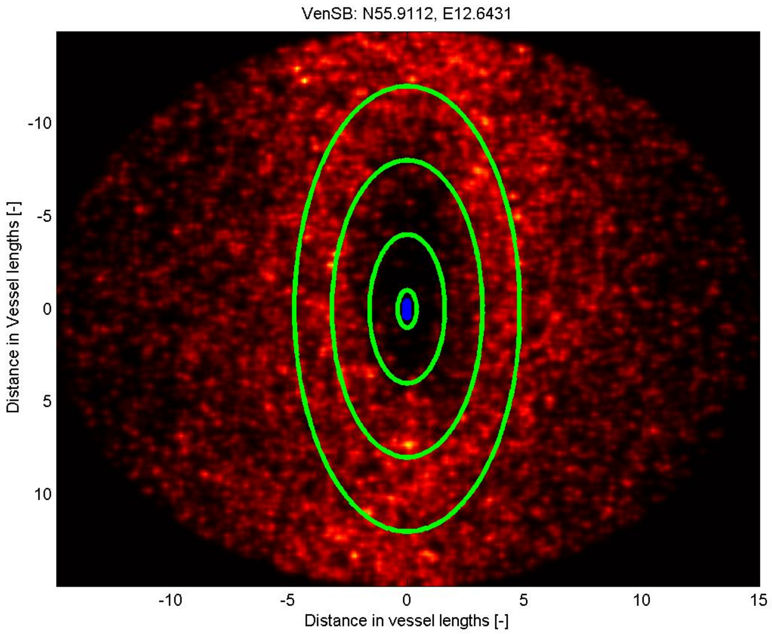


Figure 28: In height with the Island Läsö, traffic not as dense and less restricted, bigger safety ellipse

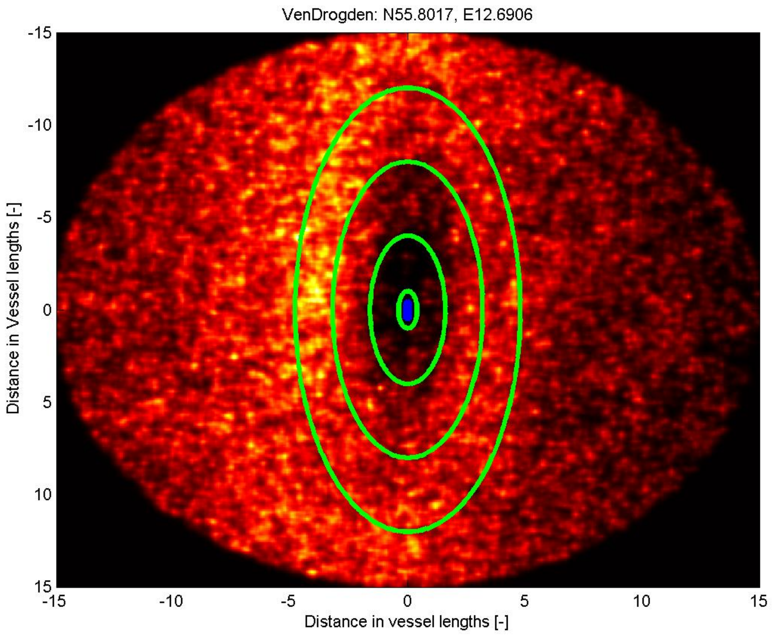


Figure 29: Between the island Ven and Drogden, traffic in both directions, but somehow restricted, space for overtaking

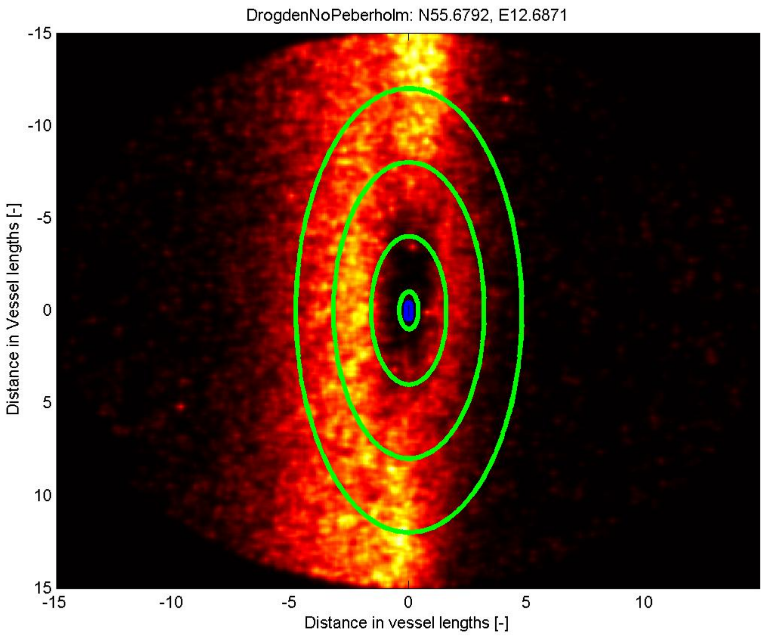


Figure 30: Close to the entrance of the Drogden Channel, Fairway is more and more restricted, almost no overtakings possible and narrower passages of meeting ships

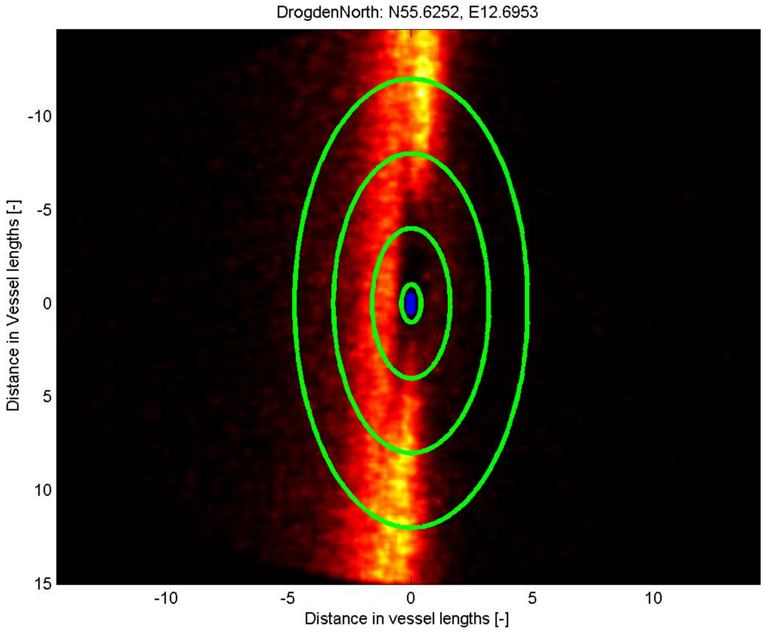


Figure 31: In the beginning of the channel, keeping distance to vessels in front, meetings can be very narrow

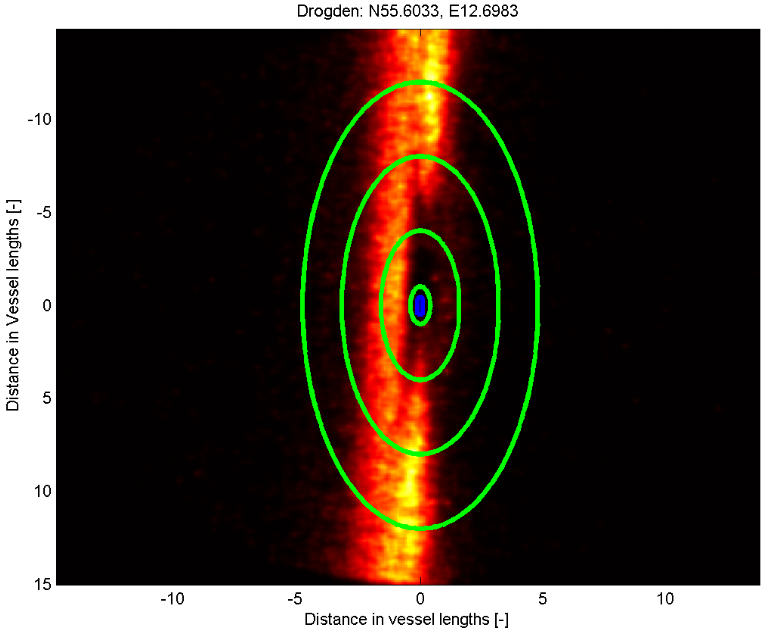


Figure 32: In the middle of the Drogden Channel, similar picture compared to the previous figure

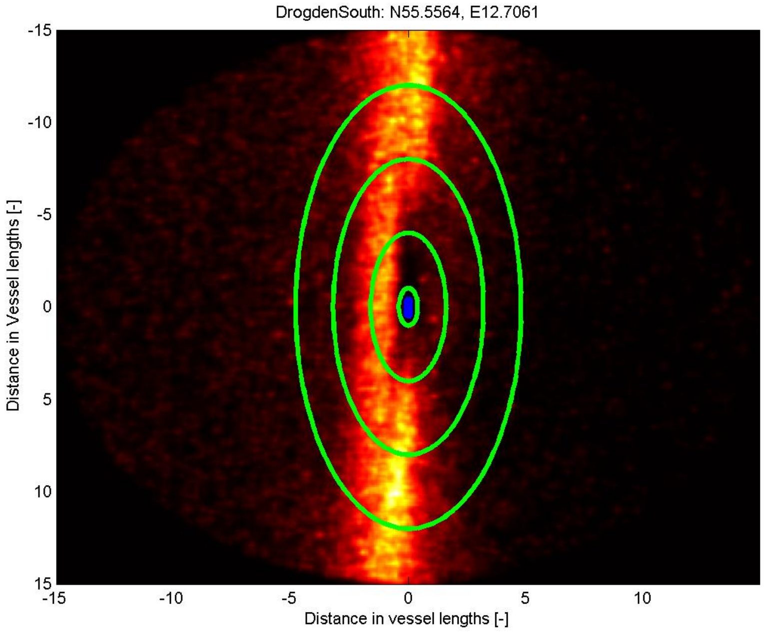


Figure 33: At the southern end of the Drogden Channel, fairway opens up slowly again and vessel tracks are a bit more split

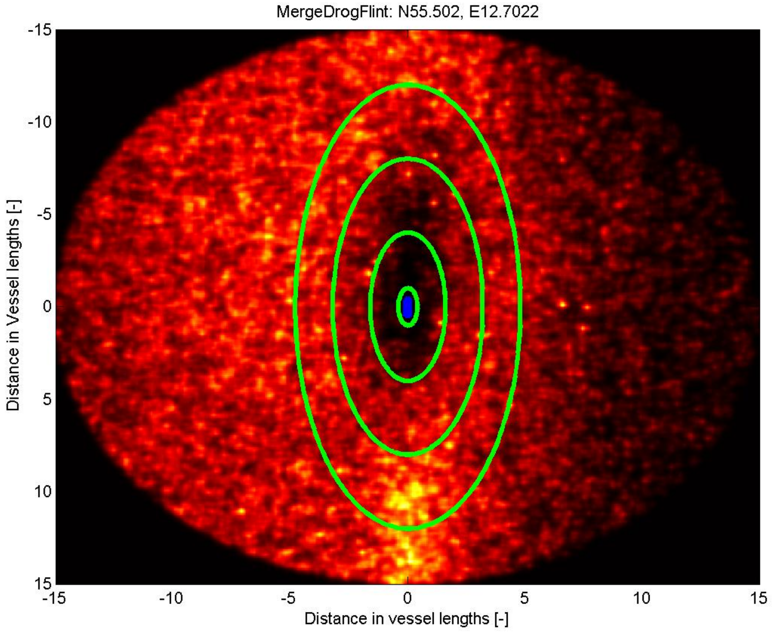


Figure 34: Merging of the Drogden Channel and Flintrännan

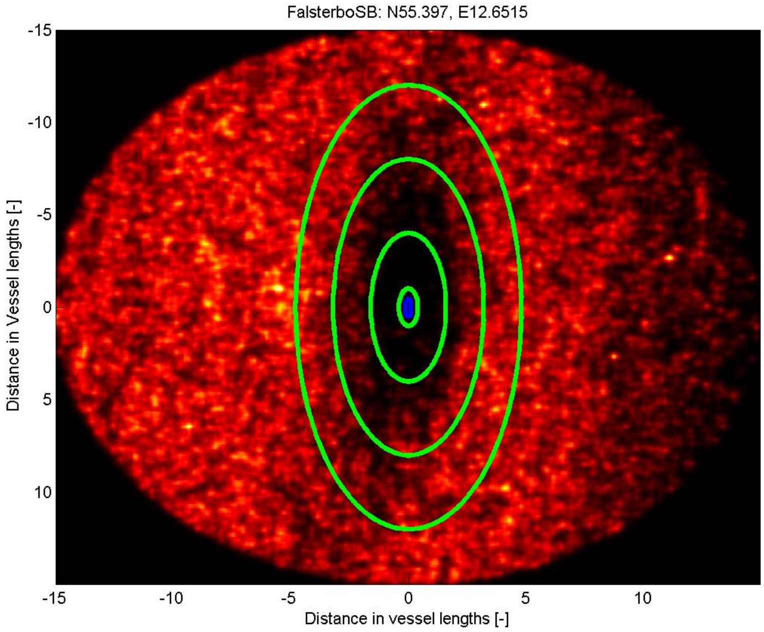


Figure 35: Traffic more widely spread, bigger safety zone outside Falsterbo for the southbound traffic

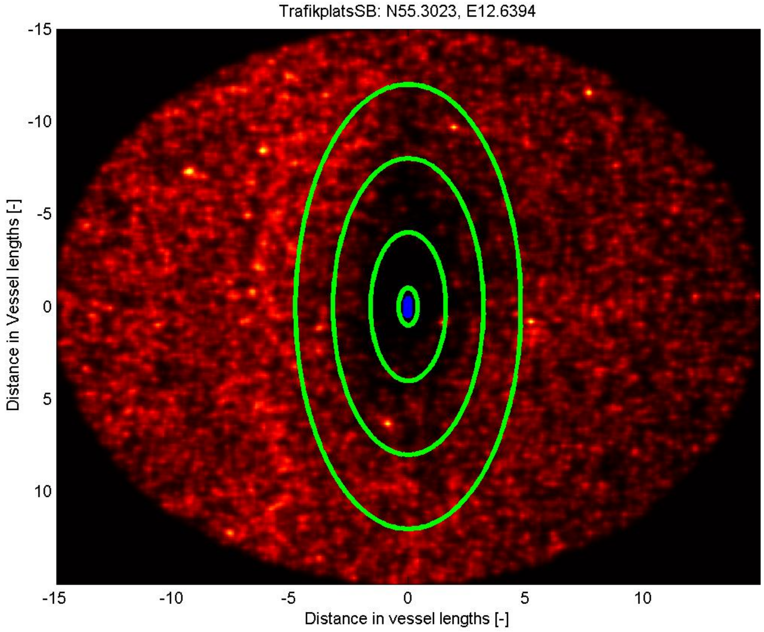


Figure 36: At the traffic place south of the Drogden the vessels are less restricted

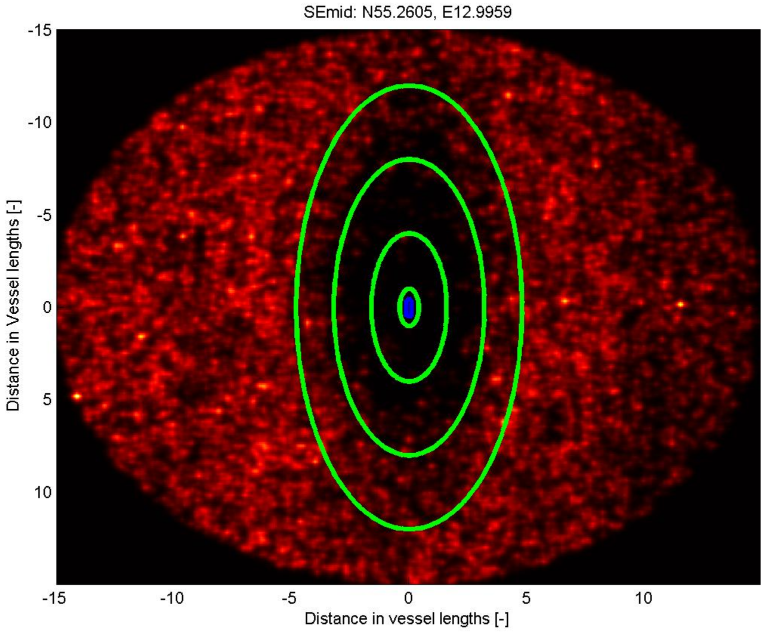


Figure 37: Traffic seperation south of Trelleborg, much space and big safety ellipse

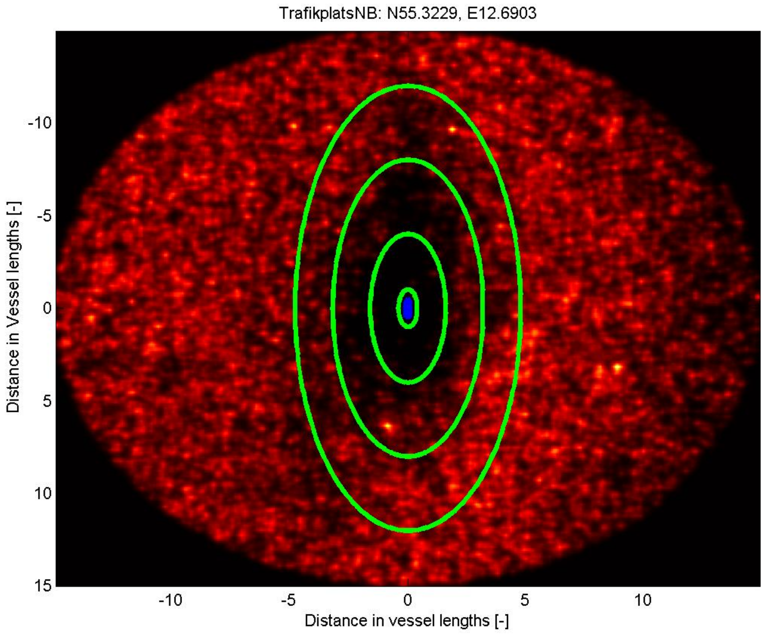


Figure 38: Now going back trough the Flintrännan, north bound traffic at the traffic place, still much space to meet and pass each other

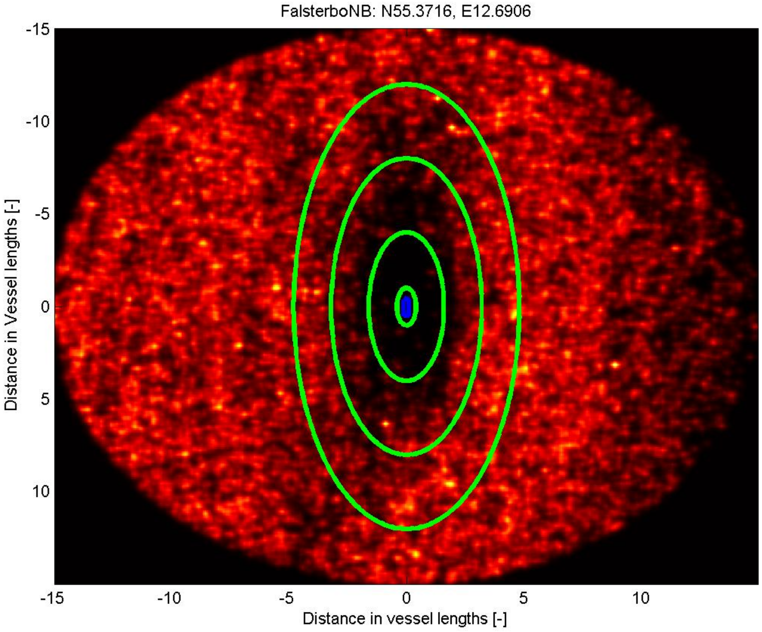


Figure 39: At Falsterbo, the traffic is more restricted again

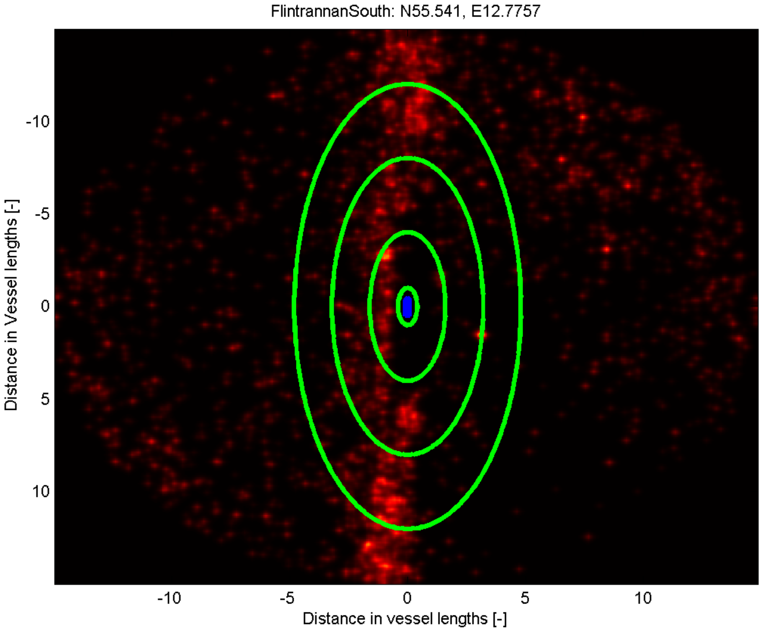


Figure 40: In the Flintrännan the traffic the pattern is similar to the Drogden but with less traffic and less chances to meet

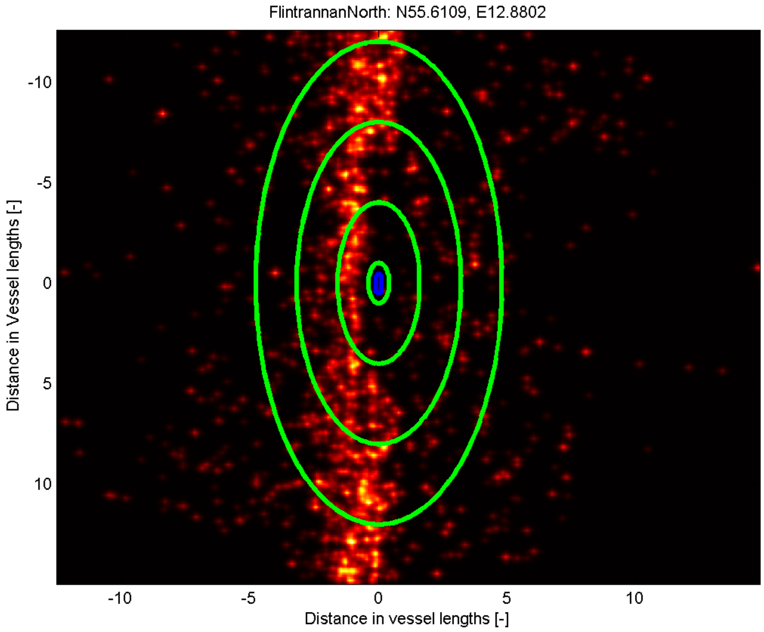


Figure 41: Northen part of the Flintrännan, even a bit more restricted than in the southern part of the Flintrännan

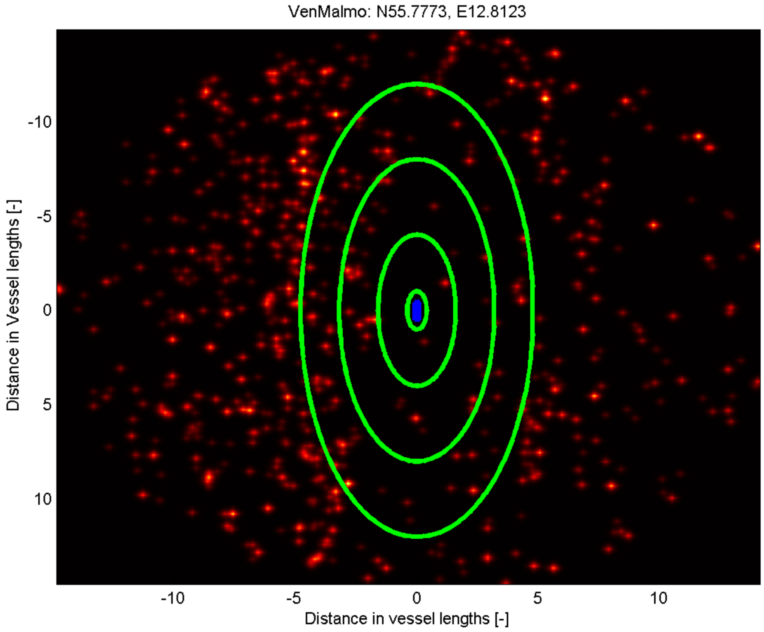


Figure 42: Little traffic and wider spread between Malmö and Ven on the eastern side and enough space

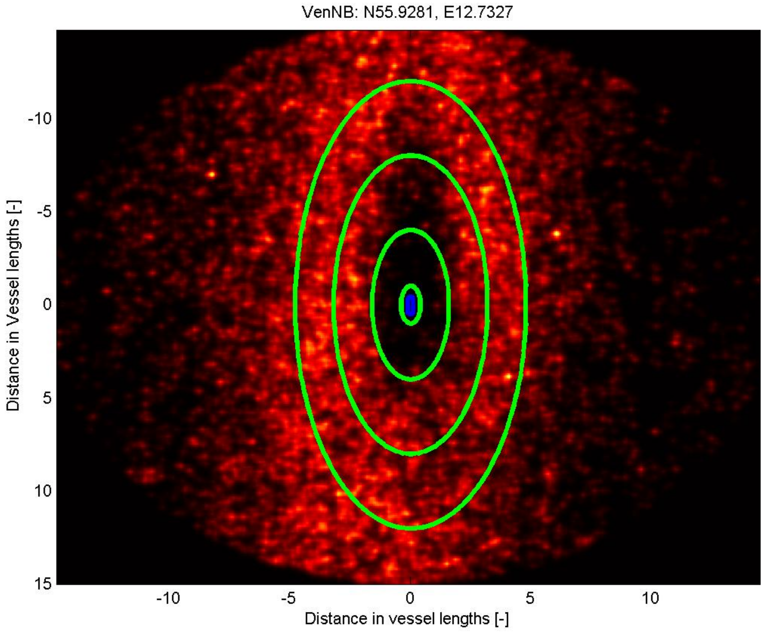


Figure 43: Close to the Island Ven the waters are more resticted and the safety ellipse is smaller

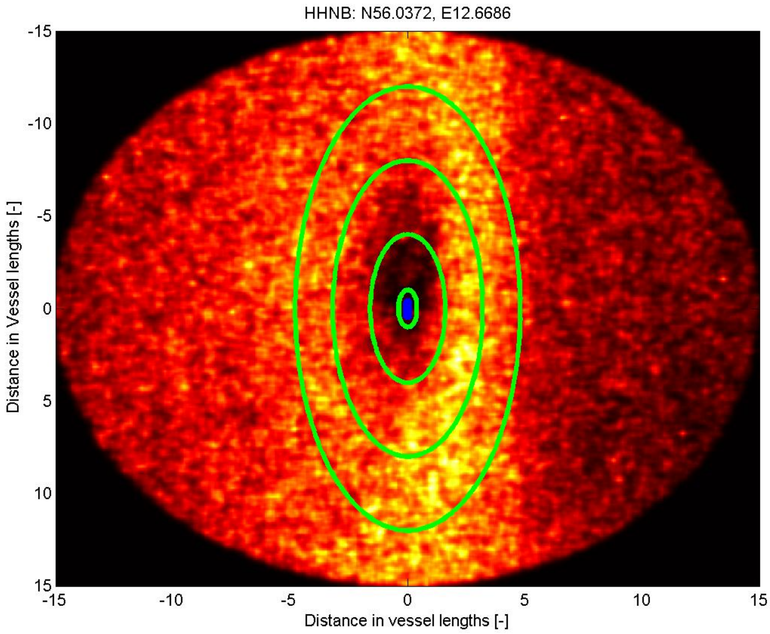


Figure 44: At Helsingör-Helsingborgs eastern side, alot of crossing traffic, many meetings

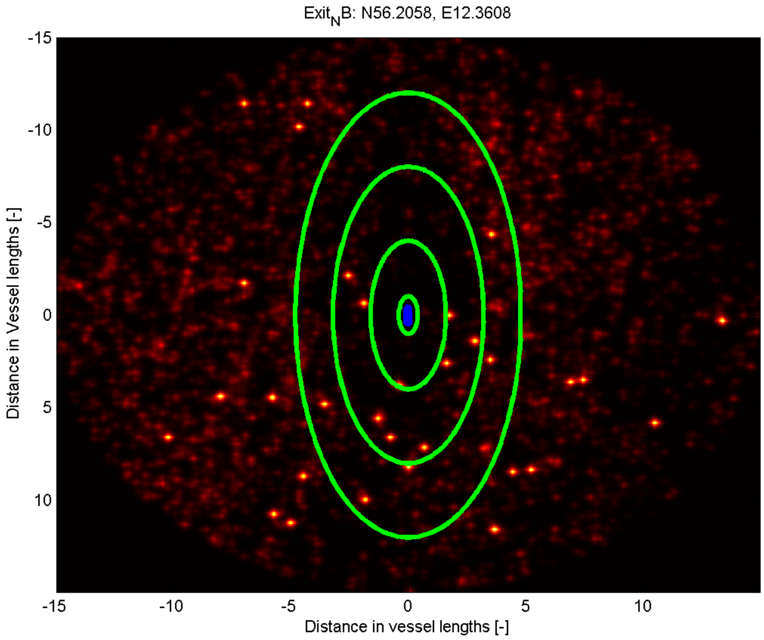


Figure 45: North of the Sound, wide fairway and enough space, less dense traffic

Based on the limits set and the calculation made, statistics can be collected on close encounters in the area of interest.

It can be seen, that the restriction and traffic intensity has an enourmus impact on the ship behavior and the accepted behviour in terms of passing distances and directions. It can be concluded, that the safety ellipse is kept throughout the Sound of four vessel length forward and aftward. In denser traffic situations as between Helsingör and Helsingborg, mainly the ellipse is affected behind the vessel. In restricted channels passing distances are much smaller sideways and margins are small. Due to the variation in the sea area, the information can be used for the warning tool. Fairly long time series are needed to get relevant and significant data for the tool.

The distributions depend on the ship size and even the ship speed. The figures above would for instance change significantly if it is looked at fasdter ships or bigger ships only.

4.3.1.6 Algorithm description "Collision avoidance based on historical traffic pattern"

Algorithm 4. Cell initialisation and sorting of historical ship data into it.

`Define grid for the area`
`Read in historical AIS data`
`Quality check AIS data`

```
      For all timesteps in AIS data
         Calculate passing distances and bearings
         Sort data distribution into grid, saving headings, COGs,
         bearings, distances, locations
      End
```

Algorithm 5. Detection of normal behaviour/ anomalie compared to information of traffic saved in the current cell the ship is in.

```
   For all ships in the area
     Get current position from ship's AIS
     Get information from grid net to connect vessel geographically to
     relevant cell information
     Receive information from current cell on ship meeting behaviour
       Perform Algorithm 3
       Get projection distances of the meeting ships compared to the
       fairway
       If ship distances at the meeting location is within limits
         ➔Ships have normal behaviour
       Else
         ➔Alarm
       End
```

4.3.1.7 Consequence route planning - Dynamic consequence management

As part of the dynamic risk managment, the involved VTS operator and even the mariners have to be aware of the consequence side in case of evolving accidents. It can be a part of the decision making for choosing a certain route, making short term changes in the planned route, etc.

Today, there are some implementations in the common systems, giving the VTS operator relevant information or just visualizing the information from other sources, such as construction works, diver work, anchoring areas with ships laying at anchor, etc.

Possible improvements could include the visualization of sensible areas for certain types of ships. An example could be the arrival of a tanker in a VTS area, where especialy sensible beaches, riffs are marked to give an indication of where a passage is more critical.

This tool visualizes risky areas for a certain ship to pass. When holding the mouse above a certain ship, layers show on the screen of the VTS centre identifying dangerous areas, the ship should pass safely with special care or possibly not at all. These areas should be communicated to the officer on watch (OOW). Examples for this could be:

- HSC passing at high speed areas with diving activities, exposed leisure boat harbours, beaches (wash waves)
- Pressurised gas tankers entering areas with risk for contact with ignition sources or explosion risks
- Tankers entering areas with high sensible environmental features.
- Passages of gas tankers and passenger ships.

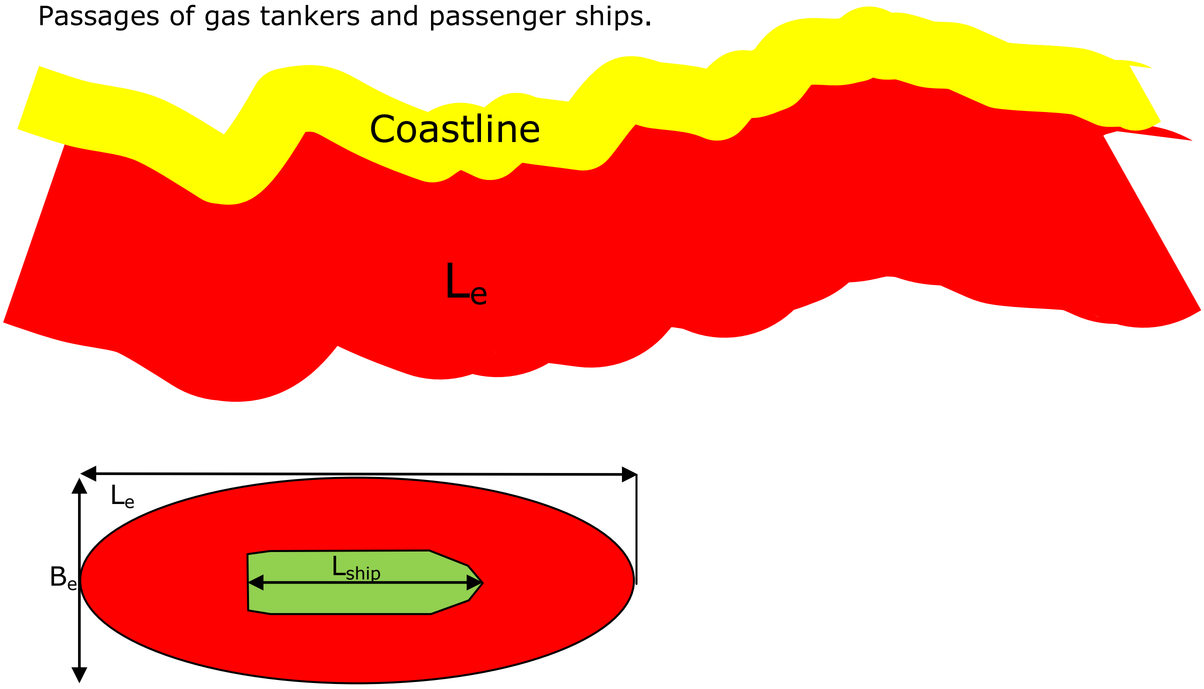


Figure 46: Safety ellipse as suggested by Fujii projected on the coastline, the vessel is passing, based on its ship length Le

This tool could visualize as well the fairway limitations that exist for the specific vessel based on Fujiis approach.

Based on Fujiis approach for passing distances the vessel that is observed can be calculated back to a minimum passing distance to objects based on the ship's length. This distance can be visualized in a layer, showing the parts of the fairway, where a vessel with a certain draught have to stay. This is viualised in the picture below.

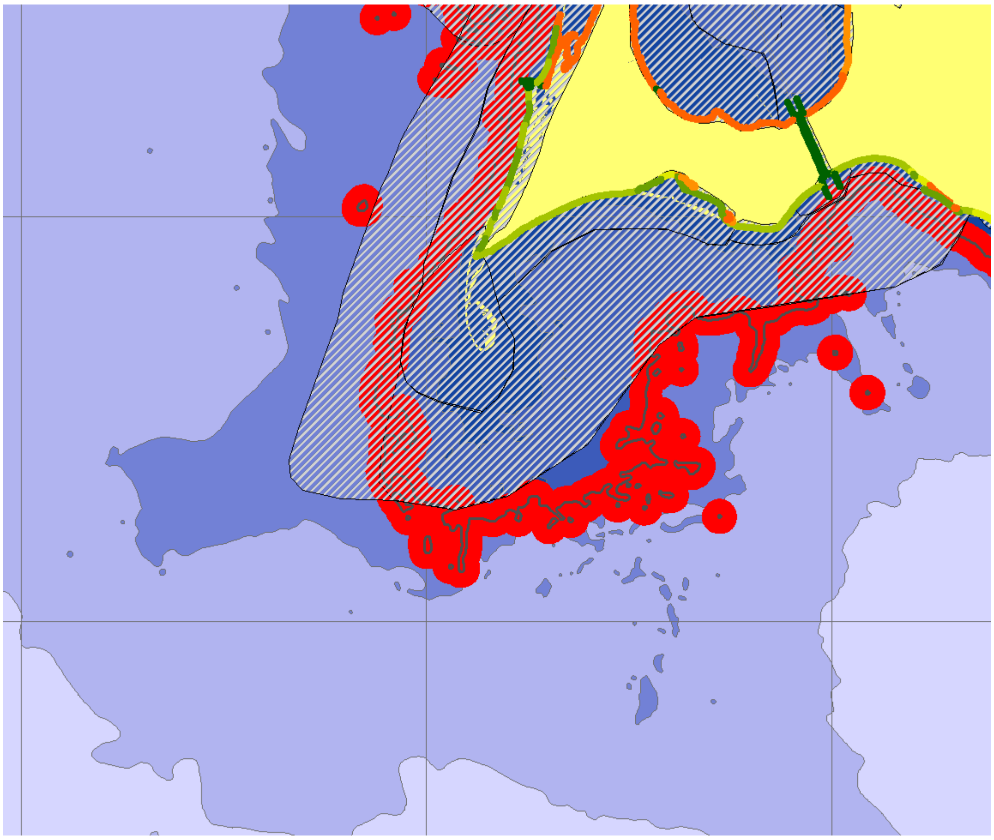


Figure 47: Falsterbo, minimum passing area for a vessel with 6.1m draught and a length of 290m. Thick red line visualises the border of the minimum passing distance. Along the coast visualises the environmental sensitivity mapping of the Swedish Coast line with rainbow colours (ESI code - Environmental Sensitivity. Index) and special sensitive areas based on the Environmental Sensitivity Atlas (Source Länsstyrelsen Sweden, (*www.gis.lst.se*)

4.3.1.8 Algorithm description "Collision avoidance based on historical traffic pattern"

Algorithm 6. Get information on ship type and consequences.

```
Get information on ship types, ship speed, length and position from
current AIS data
If mouse-on ship contour
   Read from database information on ship type consequences
   Visualise critical parts in the area connected to the current ship
   Calculate fairway that is available
End
```

4.3.2 Comparison of processed AIS data with accident statistics

Data have been compared of the AIS data analysis with accident statistics from the Swedish Transport Agency, Swedish Maritime Administration (Sound VTS area) and from HELCOM. The following conclusions can be drawn:

- Risky areas can be identified in both areas studied
- The critical spots in terms of groundings are situated in areas were there is a high standard deviation of the main parameters researched in this study
- Another critical parameter is narrowing parts of the fairway, transition from unrestricted waters to restricted waters and crossings/ joints of fairways.
- Vessels do not follow the typical traffic pattern prior to accidents.

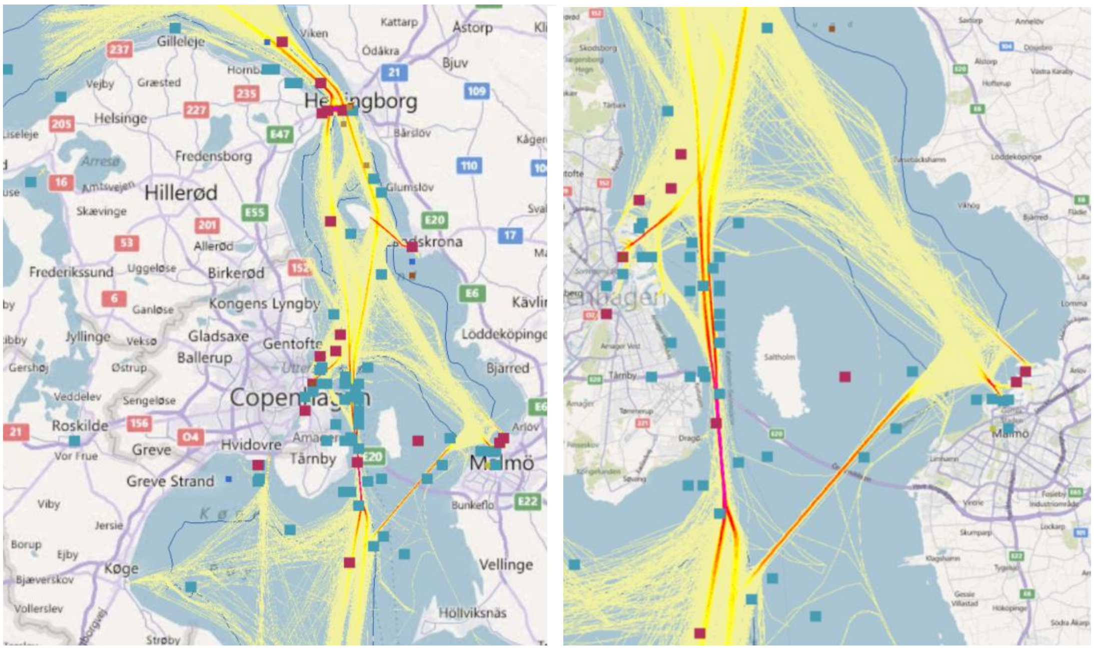


Figure 48: Collision and grounding accidents in the Sound, based on HELCOM data, green: groundings, red: ship collisions

Especially the minimum distance in a cell and the standard deviation of the distance to other vessels fit the collision statistics from HELCOM for the Sound area.

4.3.3 Tests with real AIS data

There is the assumption behind the grounding tool, that there is a kind of normal traffic behavior. Some indications can be found in the AIS data statistics as described below:

Taking all the AIS data for the Sound, the following statements can be made:

- The main routes follow a average speed in the center of the fairway with a constant value and a constant standard distribution. At the outer sides, the speed has a more varying average value and varying standard distributions, as shown in the map below:

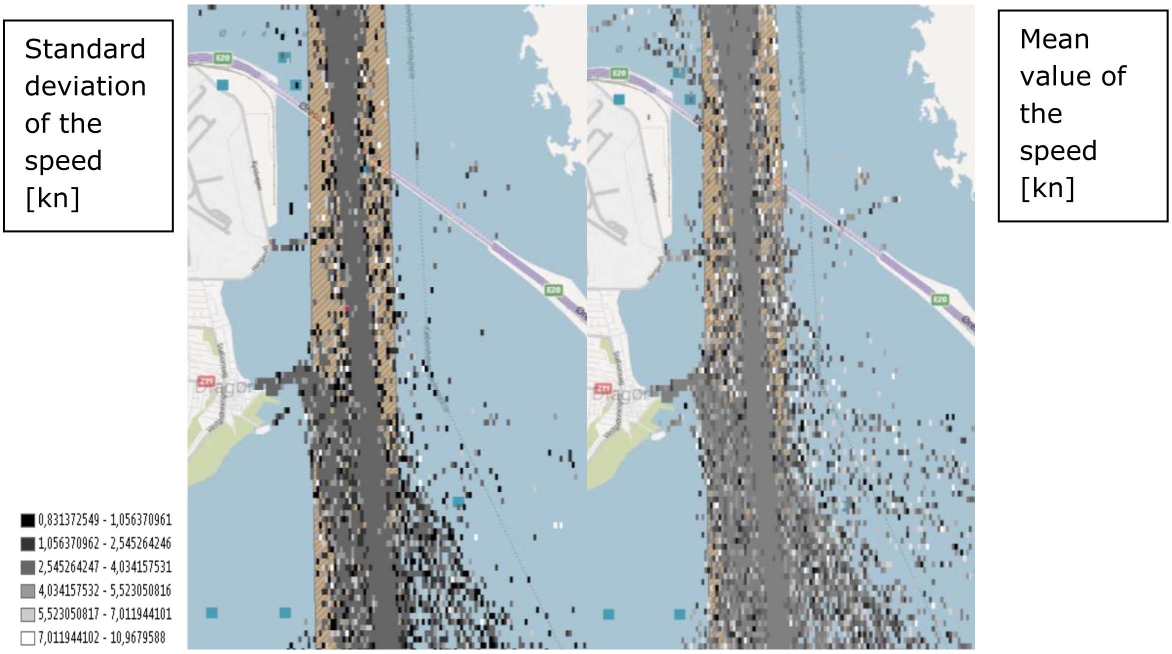
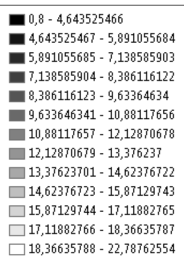


Figure 49: Speed distribution in the Drogden channel



- Si can be produced for the ship length, ship draught, etc.
- Th ribution of the vessels passing the Sound are distributed following a lo ibution for the whole area, as shown in the probability density function be

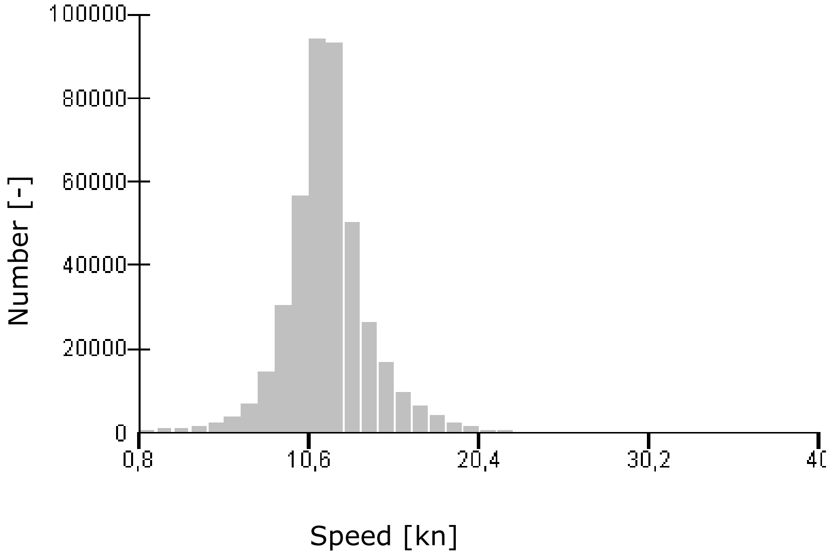


Figure 50: Speed distribution of the traffic in the Sound

- Different ship categories follow different traffic pattern. One restriction for instance is the ship draught. The figure below shows the ship drafts from the southern end of the Drogden channel. Yellow coloured cells correspond to vessels with maximum draft of 6 meters, blue 6-7 meters, turkos 7-8 meters and pink >8 meters. Due to draught restrictions, the vessels with bigger drafts have to keep more to the middle of the fairway.

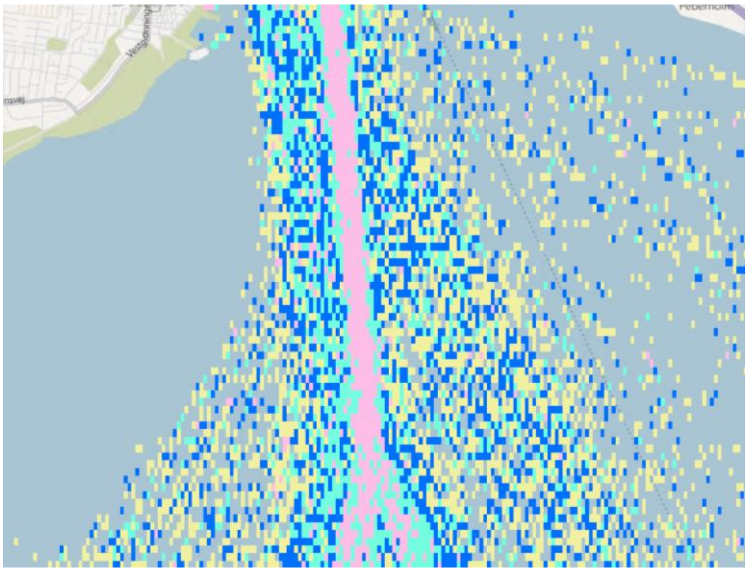


Figure 51: Ship draught distribution in the Drogden channel

4.4 Stand-alone application for testing

To visualize and to be able to test the decision support tool predicts ships' movement, and basedwith users, a Matlab stand-alone application has been developed. More details on the prediction, gives warnings of possible close encounter situationsresults of the tests can be found in the report Final test report including uncertainty analysis, Deliverable No. D_ WP6_3_02.

5 Conclusions

5.1 VTT’s VTS decision support tool

The VTT decision support tool predicts ships’ movement, and based on the prediction, gives warnings of possible close encounter situations.

The major outputs from the activity are:

VTT has developed a prediction tool prototype for collision warning. The software program has been developed and tested with collected and real-time AIS data from the Gulf of Finland in the area between Helsinki and Tallinn. The concept has been tested with experienced VTS operators.

The prediction tool enables the user to monitor the traffic situation in a specific area. The tool divides the area of interest indicated by the AIS position data into a certain number of rectangular cells. Ship movement is predicted based on collected AIS data, and warnings are given if two or more ships have a risk of collision, i.e, that there is a high enough probability for more than one ship being in the same cell at the same time.

The VTS operators may use the tool as a help in supervision of the chosen area.

5.2 SSPA’s VTS decision support tool

The SSPA decision support tool is able to identify abnormal traffic behavior on an eraly stage.

The major outputs from the activity are:

- SSPA has developed an analysis tool concept for collisions and grounding warning. Critical parts of the fairway have been identified. The software program has been developed and tested with collected AIS data from the entrance of Göteborg and the Sound region. The concept has been communicated with experienced VTS operators and user aspects have been gathered and included in the development.

- SSPA has developed an analysis tool to enable the user to analyse AIS data for a specific area. The tool divides the area of interest indicated by the AIS position data into a certain number of rectangular cells. Ship movement is predicted based on collected AIS data, and warnings are given if two or more ships have a risk of collision, i.e, that there is a high enough probability for more than one ship being in the same cell at the same time.For each cell the following information is registered:

- Maximum draught of vessels which have passed the cells
- Average course over ground
- Standard deviation of the course of the vessels
- Number of vessels that have passed the cells
- Average speed
- Weather impact on route planning

- Another tool calculates for each vessel in each cell the distance to other vessels within the area. Different passing distances can be identified for different restrictions of the fairway.

- The information extracted by the tool is then used to identify near misses and dangerous behavior of vessels passing the analysed area. By identifying the normal and accepted traffic behavior, unacceptable behavior can be identified in terms of low passing distances of vessels or deviating courses, speeds and on the long run positions. The VTS operators may then use the concept as a help in supervision of the chosen area and get automated warniongs for the ubnormal behavior.

Definitions and Abbreviations

AIS	Automatic Identification System, a system that transmits certain information about the ship (name, position, speed etc.) and receives the same information from other AIS-equipped vessels in the vicinity.
BaSSy	Baltic Sea Safety, research project 2006-2008
COG	Course over Ground
DRM	Dynamic Risk Management.
DST	Decision Support Tool
ECDIS	Electronic Chart Display System, a navigation information system for vector-based digital charts.
ESI	Environmental Sensitivity. Index
Fairway	Fairway in the widest sense of the term refers to the water areas used for shipping. It is however normally used in the sense of a cleared channel intended for navigation.
GIS	A Geographic Information System (GIS), or Geographical Information System, is any system that captures, stores, analyzes, manages, and presents data that are linked to location.
GOFREP	Gulf of Finland Reporting System, a mandatory ship reporting system in the Gulf of Finland.
GPS	Global Positioning System, a system for satellite navigation.
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	International Maritime Organization
IWRIS	Intelligent Water-borne Risk Indication System
MMSI	Maritime Mobile Service Identity
NAS	Navigational Assistance Service, advice given by the VTS
OOW	Officer On Watch

RADAR	Radio detection and ranging, an object detection system.
SOG	Speed over Ground
SOLAS	International Convention for the Safety of Life at Sea (SOLAS) is an international maritime safety treaty
SRS	Ship Reporting System, a voluntary or mandatory reporting system for vessels in a specified area. It collects and distributes information of importance for the vessel traffic safety.
SSPA	SSPA Sweden AB, Task leader
VHF	Very high frequency, a band of radio frequencies used for among other things maritime communication.
VTS	Vessel Traffic Service, a shore-side service for vessel monitoring, navigational assistance and information service.
VTT	Technical Research Centre of Finland contracted by the Finnish Maritime Agency

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Appendix

Appendix 1: AIS Data Conversion and Analysis of Traffic Data

AIS as a source was identified as a useful tool to identify normal traffic pattern and to detect abnormal functions, the accessible data needed to be found and processed. In order to find limitations and restrictions of AIS data, before processing, the available raw data were converted into ASCII format and steadiness and reliability were analysed. The AIS data mapping and analysis is described below.

Programs for calculating statistics from AIS-data

The purpose of the program is to use AIS-data to get statistical average behavior of ships in an arbitrary area. By comparing the behavior of a ship to this statistic it will be possible to identify unusual behavior and get a warning before an accident.

The program calculates the statistical mean value and the standard deviation of chosen AIS-data parameters. The parameters are calculated for each cell of a mesh that covers the area that is chosen and where AIS-data is available.
The program has two parts; the first part is the statistical calculation described above. In the second part the average distance to the closest ship is calculated for each ship in each cell. This second part is calculation vise the heaviest part in terms of required calculation time and is therefore separated.

Both programs are described in more detail below.

Program for calculating general statistical data from AIS

This program goes through the route for each ship in the data and each time a ship crosses a cell it saves the maximum, minimum, mean and standard deviation of the following data:

- Date and time*
- MMSI-number*
- Speed over ground*

- Position longitude*
- Position latitude*
- Corse over ground*
- Heading*

More detailed description is given below.

Mesh

The mesh is used to the previously mentioned continuous properties in discreet positions. The geographical area that is used in the calculation is a given by the bordering latitudes and longitudes, resulting in a more or less rectangular area defined. The mesh consists of MxN simple rectangular cells. Since all cells are rectangular and equal size they are defined only by their centre point.

Reading and preparing AIS-data

The AIS-data is converted using in-house developed software in C++. This software produces two files; one dynamic file and one static file. The static file contains the following ship data:

- Date and time
- MMSI number
- IMO-number
- Ship name
- Ship type
- Length
- Beam
- Longitudinal position of GPS-receiver
- Transversal position of GPS-receiver
- Draught at current loading condition

The dynamic file contains the following data:

- Date and time*
- MMSI-number*
- Navigational status
- Turn rate
- Speed over ground*
- Position longitude*
- Position latitude*

- Corse over ground*
- Heading*

The dynamic file is first sorted by MMSI-number (ship by ship) and time in the order of lower to higher. The AIS data often contains errors and some missing data and the above conversion does not handle all of these. After this conversion missing numbers have been replaced by a dummy and doublets still exist. Since the program interpolates the different dynamic properties to get results at arbitrary times it needs a value at each time step. This is handled in a simple manner:

- For speed the program simply uses the previous value unless the missing value is the first value, then the next value is used.
- For course the next or previous value is used as done for speed. If the next value is missing at the first time step the value for heading is used.

After this all the longitude and latitude are converted to meters and the lowest and the highest value for each time step are found.

Main loop

The main loop steps through all the data that was prepared by beginning at the lowest time indication in the data. Then it steps forward at predetermined time step finding the positions and other properties of the ship by interpolating between the AIS-messages that are closest in time to the current time step. When the AIS-file is finished all the data is saved and the next file, if there is one, is loaded.

Program for calculating minimum passing distance from AIS-data

This part of the program is used for calculating the distance to other ships in the area. The distance to the closest ship, the average distance to all ships and the standard deviation of the distance is saved for the different cells in the area.

Preparation loop

Each file typically contains AIS-information for one day of the desired area. Each day a large number of ships pass through the area but there are a lot fewer at a given time. The preparation loop goes through the file one time step at a time to find out which ships are active at each time step. By only selecting these ships the calculation of separation between the ships will be much faster. Since ships sometimes only transmit an AIS-message every few minutes the program checks the AIS-file for ships that are active between five minutes before and five minutes after each time step.

Mesh

The geographical area that is used in the calculation is a given by the bordering latitudes and longitudes, resulting in a more or less rectangular area defined. The mesh consists of MxN simple rectangular cells. Since all cells are rectangular and equal size they are defined only by their centre point.

Main loop

The main loop goes through the matrix that was prepared in the preparation loop one time step at a time. At each time step another loop goes through the ships that are active at that time step and measures the distance to each of the other ships that are active at that time step. This distance is added to the mean distance, minimum distance and standard deviation of the distance for the actual cell the current ship is in. There is a maximum distance, i.e. ships at a longer distance then 2 nm are not considered.